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Intention to Respond in a Special Way Protects Against Forgetting Associations: A Test of Three Hypotheses of Working Memory, Transfer, and Desirable Difficulty

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Abstract

In an attempt to examine the protective function of prospective memory as outlined by Bourne, Healy, Bonk, and Buck-Gengler (2011), a follow-up study was designed to introduce a more critical examination of the phonological loop and its effects on this process. Primary study procedure consisted of a memory task involving remembering the color of a name and a location as a means of determining where to click on a screen subsequently. Experimental design included a day of training in which participants were exposed to a secondary task, consisting of either of one of two articulatory suppression strategies, either counting backwards by threes or constant repetition of the word “the,” or silence for the duration of the current block of trials. Participants were asked to return on a second day 48 hours later at which point their retention and transfer of ability to the other secondary conditions was tested. The same protective function demonstrated by Bourne et al. (2011) was found for prospective memory, as well as transfer between the experimental conditions, indicating that the location of this protective function may exist outside of the phonological loop. An additional desirable difficulty hypothesis was explored using the gradient of difficulties created by the different secondary task conditions, but no significant results were found within these data.

Keywords: Transfer, Retention, Working Memory, Desirable Difficulty, Prospective Memory

Intent to Respond in a Special Way Protects Against Forgetting Associations:

A Test of Three Hypotheses of Working Memory, Transfer, and Desirable Difficulty

Running parallel to the flow of time there are only two directions that a memory can be found. A memory can be pulled from the ether of the past, the sweet smell of a baked good triggering the memory of sitting in the kitchen of a grandmother or the sight of a name triggering the memory of an individual which a person had a long-forgotten spat back in their elementary days. In this aspect memory is traditionally thought to be brought up from the framework of long-term memory and by nature, largely works in retrograde. Moving in the opposite direction, a memory can be carried with individuals as they move forward in time, a silent rehearsal reminding of the doctor's appointment that they might need to make later that day or the people that they might need to send correspondence to at work. This form of memory is believed to be part of the structure known as short-term or working memory. Working memory, unlike long-term memory, has the additional distinction of being able to be used both in the temporally forwards and backwards directions depending on the nature of the stimulus encountered. Each of these forms of memory guide a person to create a unique response to a stimulus that would generally be entirely banal in an otherwise day-to-day circumstance, but it is important to note that only the forwards direction creates the anticipation of that special response. Because only the forward direction of memory processes requires a person to create a special response, the question then becomes whether the prospective, or forward-thinking memory, can out-perform the retrospective, or backwards-thinking memory, in a cognitive trial and whether working memory and if so, what portion mediates that ability.

Current Theory on Working Memory

The process of working memory is most typically described within an academic setting using the framework and theory outlined by Alan Baddeley and Graham Hitch in 1974, with subsequent revisions by Baddeley in 2000. In the original theory, working memory is a system made up of three major components: Central executive function, the phonological loop, and the visuospatial sketchpad (Baddeley & Hitch, 1974). Beginning from the first encounter with information that is cognitively processed as being valid for entry into the system of working memory (with current research debating whether all sensory information enters this system when encountered or whether only that to which attentional processes are devoted), the central executive process begins by "targeting" the information and creating a link between short-term and long-term memory as necessary. This process directs attention to the relevant stimuli such that a person is believed to have conscious awareness of the stimulus that is being coded and that an attempt is made to inhibit distractions. As a supervisory system, the central executive function will then recruit various so called "slave systems" to assist in the process of maintaining the information that is currently being cognitively held. These slave systems are the phonological loop and the visuospatial sketchpad.

The phonological loop, or articulatory loop as it is referred in some parts of the literature, is concerned with the maintenance of information that has a verbal component. When an individual either hears a sound or reads a word that can be articulated, it is assumed that this information enters a phonological storage which is then supported by rehearsal. In practice this can be represented in such ways as people repeating the numeric combination to a lock in their minds over and over again until they believe that they could otherwise remember that information when it is needed. This rehearsal can be either be done by engaging motor systems involved in speaking to physically rehearse the information or silently, such that the only observational report given that an individual has been rehearsing the information is the individual's word of affirmation. This process has been noted to have a neuropsychological component in silent rehearsal as patients with apraxia of speech, or a disturbance in speech planning due to damage of neural tissue, experience difficulties in short-term recall of information that would be believed to be held within the phonological loop (Gloria, Rochon, & Caplan, 1992).

Additional evidence to support the existence of the phonological loop exists in the form of techniques that would otherwise suppress the articulatory rehearsal component of the process. As phonological data are believed to be subject to rapid decay, the articulatory rehearsal step is necessary for the information to continue the process of being held within working memory. As such, the phonological loop overall can be inhibited using any technique that would recruit the power of the articulatory rehearsal step and thus prevent its use for the information being processed, otherwise known as articulatory suppression. Two techniques of articulatory suppression with direct relevance to the study performed here would be the oral repetition of a distractor word, such as "the," or a cognitively difficult and repetitive arithmetic task performed orally, such as counting down from one hundred in increments of three. Both practices have been proven to be efficacious in the eradication of memory effects associated with the phonological loop in multiple research studies (Baddeley, Lewis, & Vallar, 1984; Miles & Borthwick, 1996; Murray, 1968). Anecdotal evidence segregates the difficulty of the two conditions based on the experiences and performance of participants. Generally, people who have been tested on both of these techniques report that the counting backwards by three condition is considered to be more difficult than the repeating the same word condition.

The second “slave function” noted within Baddeley and Hitch’s (1974) original model of working memory is called the visuo-spatial sketch pad. In this function both the “where” and the “what” of visual information are maintained through a mental reconstruction of what has been observed that is revisited in the instances in which an individual needs to remember something. This function of short-term memory is also what is primarily used when individuals encounter the need to mentally manipulate the orientation of an object space as this reconstruction is considered to be fairly complex in detail. The neuroscientific basis of this working memory process has also been fairly well documented in the segregation of a dorsal and ventral stream of cognition associated with each process (Turnbull, Denis, Mellet, Ghaëm, & Carey, 2001). The dorsal stream is associated with the “where” portion of the function and projects visual information into the parietal lobe, whereas the ventral stream on the other hand works on the “what” processes and receives primary input from the thalamus to project to the inferior temporal lobe. These streams work concurrently to create the experience of working memory in visual systems.

As a more recent addition to the hypothesis, Baddeley also specified an additional function in the model of working memory that he described as the episodic buffer (Baddeley, 2000). This function operates as a linking factor between the visual, spatial, and verbal systems along with specifying the episodic order in which something occurred, such as the chronological points in a story, so as to act as a “buffer store” between the functions previously described. Additionally this function is noted to link working memory to the processes of perception and long-term memory, although more research still needs to be conducted on whether conscious recall of working memory information occurs from this point or from one of the other components of the model.

Prospective and Retrospective Memory

When looking at the process of working memory in practice, researchers have also noted two separate directions in which working memory can operate (see e.g. Einstein & McDaniel, 2008). The forward direction, known as prospective memory, is concerned with information that individuals have already noted to be important and that will require a special response at a later point. The backwards direction, known as retrospective memory, is largely the domain of information that has been recently encountered but has not been explicitly noted to require a distinct response. In a study conducted by Bourne, Healy, Bonk, & Buck-Gengler in 2011, a certain unique attribute was found to be associated with the process of prospective memory. In this experiment, subjects were exposed to common English names that were then associated with a color. After trials to ensure the subject correctly knew the names in use and the colors associated, the primary memory task began. On the display, subjects were presented with an inner square that contained response buttons in the cardinal directions, each corresponding color, and an outer square encompassing the inner square with response buttons of the same color in the same place on its cardinal direction. Subjects were first shown in study trials the names in the center with either the first letter in uppercase, known as the default location items, or names that were presented all in uppercase letters, known as the special location items. In either case in the study trials, subjects were asked to respond in the inner square, defining this as the default response area. In either 2-back or 8-back testing increments, subjects then had to remember the way that the name was presented on the previous instance, along with the color previously associated with that name using an input display. In the test trials, subjects were asked to respond to the default location items in the same places that they had in the study trials while the special location items now had to be responded to in their correct location on the outer square.

When examining the results of the test trials, the researchers found that interestingly, memory for the special location, or prospective trials, had a greater accuracy for the color associations than memory for the default location items, or the retrospective trials. More importantly, the special location items experienced a less pronounced decay in accuracy over a longer retention interval than did the default location items, suggesting that the usage of prospective memory, or the knowledge that a certain stimulus will require a special response, actually managed to protect the information (association) held within it better than the information that had been retained retrospectively (Bourne et al., 2011). This study forms an important part of the basis for the research that was conducted for the purposes of this thesis, as one of the limitations that Bourne et al. describe in their paper is that, although this finding seems to suggest support for the theory of working memory as outlined by Baddeley (1980), the exact role and components of working memory that are associated with this "protective function" of prospective memory still require a greater degree of research. One such component of working memory that the design of this study will choose to focus on is the aforementioned phonological loop and how potential perturbations in this memory strategy may affect this protective function.

Retention and Transfer

As the experimental question turns to focus on memory accuracy within various conditions, an important memory and training process that must be examined is that of transfer and retention. As indicated by Healy and Wohldmann in 2012, retention is typically described as differences in performance between the learning of an ability and the testing of that ability that may occur after a certain delay. A high retention would describe an individual who experienced similar results on the day that they were tested on the information they had learned as on the day that they had originally learned that information. Transfer on the other hand, describes cases in which an individual may be trained on one task and then evaluated on a task that shares a degree of similarity. For example, if an individual who was taught to be able to recite the alphabet backwards without pausing was then asked to recite the alphabet backwards while skipping every other letter, their performance on this task would indicate the degree of transfer that the ability they developed had (Healy & Wohldmann, 2012). For the purposes of studying the mechanism of memory, each of these processes has become of particular interest to researchers in the field of learning as they can describe the extent to which a memory task has created a new skill in the participant being studied.

As will later be described in greater detail, to examine a potential mediator for the protective function of prospective memory a set of strategies known to cause the eradication of the effects of the phonological loop will be employed within this study, creating the importance of determining whether there is a transfer of ability to be noted when participants are exposed to the conditions in which they had not otherwise been trained. In a study by Healy, Wohldmann, Parker, and Bourne in 2005 subjects were tested on a primary task involving time estimation while in some cases a secondary task was performed that otherwise had nothing to do with the task. The secondary task was either the aloud repetition of a letter given at the beginning of the task or a reverse alphabet recitation skipping by every third letter. When the subjects in this case were tested in the same conditions in which they were trained they were found to perform optimally, but when the secondary task was changed between training and testing a lack of transfer was noted, indicating that the manipulation of the secondary task actually caused participants to develop a way of approaching the primary task that was incompatible with an alternative version despite the overarching presence of the primary task (Healy et al., 2005).

Due to the potential that the secondary task created a mechanism by which individuals could more easily estimate time and thus perform better if trained and tested in its presence, in a 2015 follow-up by Healy, Tack, Schneider, and Barshi an additional manipulation was introduced of distance estimation. This study also examined the differences in transfer that might occur through a change in the primary task and a change in the secondary task. In this study the original hypothesis of specificity of training to the secondary condition performed was reproduced. It was also noted that task relevant external cues can help bridge the gap created by being trained and tested on a separate primary condition while a task external or inhibiting process did not (Healy et al., 2015). This finding also was shown in studies by Wohldmann, Healy, and Bourne (2010, 2012) as in these cases, participants were able to find mechanisms within which their secondary task could be made task relevant although it did not initially seem to be.

Desirable Difficulties

In a more directionally specified version of the theories of transfer, some evidence has come to suggest that it may be possible that the training of a skill in a setting of greater difficulty can result in an improvement in the overall performance of lower-level versions of that task. This process of learning is known as “desirable” difficulty as there may be an optimum difficulty for a certain type of task that can otherwise bolster people’s overall retention of learning over a period of delay and their transfer to tasks of a similar nature, an end that would be found to be desirable. As described by Bjork and Kroll (2015) this concept has largely been the domain of studies in the realm of language learning and has led to an increased focus on the idea of testing as a device to be employed for the benefit of learning rather than simply an assessment and as such, a test can help a student and an instructor gauge the effectiveness of their training. Studies have supported the idea that even though a person's rate of apparent learning may be lower, he or she might still exhibit higher rates of retention, in particular for foreign language learning, if they have been exposed to a certain level of difficulty in training (Schneider, Healy, & Bourne, 2002). An important point to recognize within this literature is that it does not indicate that there is a linear relationship between the difficulty of a training task and the tested performance. Certain kinds and levels of difficulty can still be considered "undesirable" and are not effective for the overall process of learning. This was encountered by Schneider, Healy, and Bourne (2015) in a study examining navigation ability in a task that involved the manipulation of memory demands that found that participants who had been trained in a hard condition had no advantage over participants who had been trained in an easy condition.

The Current Study

Based on the considerations of memory outlined by all prior work that have been detailed thus far, a few new dimensions are worth exploring. As described by Bourne et al. (2011), despite the theory of working memory being fairly well outlined within the current literature, some aspects, such as the protective function of prospective memory, are still not entirely understood in how they operate cognitively and what processes support them. Following the framework outlined by Bourne et al. (2011), this study will attempt to advance those findings by applying a few additional parameters. This study will employ a similar methodology but will use a set of articulatory suppression strategies to eradicate the process of the phonological loop, thus examining the effect this has on the protective function of prospective memory. As well, because this study will be examining a set of conditions that can be ascribed discrete difficulty levels, the processes of retention and transfer will be explored as a means of determining whether the protective function is a product of a certain type of learning or whether it may exist within other training conditions. Finally, the differential difficulties of the suppression strategies will be used to examine whether articulatory suppression can be used as means of creating desirable difficulty within a semantic memory task.

Methods

Subjects

Forty-one subjects (15 male and 26 female) were used in total over the course of this experiment but only 36 were retained for the purposes of data analysis. Reasons for discarding data included glitches within the experimental software and a subject who only attended one of the two required sessions. Complete counterbalancing was still achieved using the retained data of subjects. All retained subjects (13 male and 23 female) were young adults currently enrolled in an undergraduate general psychology course. For this class subjects were enrolled in an online system consisting of all psychology experiments at the institution searching for research subjects and were given the opportunity to either participate in research or complete an essay for the course. No additional incentive was offered for completing this experiment. All subjects confirmed that English was their first language and that they were right-handed.

Materials and Procedure

On first entry to the lab, all subjects completed a University of Colorado consent form for the current experiment, a NASA consent form, and a demographics sheet assessing basic information such as handedness and first language. Once this stage was complete, subjects were given some background on the research purpose of the experiment in which they would participate. Subjects were told that the experiment would be part of a collaborative study with NASA as a means of assessing potential cognitive changes due to zero gravity and that their data would assist in the creation of baseline research by which to compare data from astronauts in space. At this point, subjects were moved into a room with a computer and began reading a set of on-screen instructions.

Two programs for MAC computers previously designed by Carolyn Buck-Gengler and James Kole for the purposes of studying cognitive retention and transfer in astronauts were used for this experiment. Each program corresponded to either the first session or the second session of the experiment, with the only difference being the number of trial blocks in each program and the nature of the oral testing conditions. Instructions given on screen specified that subjects would be engaging in a memory task in which they would be exposed to eight different names in combination with a cardinal direction, with each name-direction combination occurring in one of three different colors. Each name was a member of the phonetic alphabet such that subjects would see such combinations as “alpha north” or “charlie west.” On screen, two response areas arranged side by side with boxes corresponding to north, south, east, and west were shown (Figure 1). Underneath the response area on the left were the words “Mission Control” and underneath the response area on the right was the word “Spacecraft.” When name-direction combinations appeared at the top of the screen in the color black, subjects were asked to click the corresponding box on the spacecraft side. When name-direction combinations appeared at the top of the screen in the color green, subjects were asked to click the corresponding box on the spacecraft side as well but were told that this information was special. When name-direction combinations appeared at the top of the screen in the color blue, the direction portion was omitted, and subjects were asked to remember both the most recent direction they had seen that name associated with as well as the previous color the combination had appeared in. When a name-direction combination was shown in blue after having previously appeared in black, subjects were asked to click the corresponding box on the spacecraft side again. When a name-direction combination was shown in blue after having previously appeared in green, subjects were asked to click the corresponding box on the mission control side of the screen instead. On-screen, when subjects clicked on the correct box for the cue, a small asterisk would appear within the box they had clicked. When subjects clicked on the incorrect box, a larger asterisk would appear in the correct location. Subjects were instructed to respond as quickly as possible but were asked to not click on the screen when there was no cue to respond to. Between trials the cursor snapped to the middle of the screen to avoid subjects using their cursor location as a hint when completing the task. After having read all of these instructions, subjects were then asked to orally describe the procedure of the experiment in their own words. The test administrator then once again described the procedure of the experiment a final time.

Alongside completing the name-direction-color memory task, subjects were also instructed to complete one of three oral testing conditions, designated as standard, articulatory suppression, or counting. In the standard condition subjects were asked to complete the task without speaking. In the articulatory suppression condition subjects were asked to complete the task while repeating the word “the” out loud as fast as they comfortably could. In the counting task, subjects were asked to count out loud from 100 down to one in intervals of three, repeating the sequence once they reached the bottom. Subjects were not stopped if they incorrectly counted down occasionally but were asked to restart from 100 if their counting seemed to demonstrate a lack of effort. For all conditions the instructor sat within the test administration space to confirm that the task was completed as assigned. Once all instructions were given, subjects were allowed to begin the experiment.

In the first session of testing, subjects completed the task in three blocks each consisting of 124 depictions of name-direction combinations. In each block of these combinations 32 were a test of retrospective memory or black combinations and 16 were a test of prospective memory or green combinations. At the end of each block subjects were allowed to momentarily rest and stop whatever oral task they were assigned but were asked to proceed into the next block as soon as they were ready. At this point subjects reengaged in their oral task and restarted the name-direction task. In the first session, subjects remained with the same oral condition through all blocks and were assigned that oral condition using a fixed rotation of standard, articulatory suppression, then count (e.g., every third subject trained on the count condition in Session 1). After these three blocks were complete subjects were asked to return in 48 hours to complete the second session of the experiment. In the second session, subjects were shown the same on-screen instructions but were now asked to complete all three oral tasks in an order determined by the counterbalancing condition assigned to each subject. The second session was arranged in 4 blocks each consisting of 124 depictions of the name-direction combination with the same number of prospective and retrospective memory tests per block as in the first session. The first block of this second session always consisted of the same oral task that the subject engaged in during their first session, but the subsequent three blocks consisted of a counterbalanced order of the three oral tasks. Between each block subjects were asked to orally confirm the directions of the block that they were proceeding into. After completing the second session, subjects were asked to answer a brief questionnaire to qualitatively assess their understanding of the experiment, their difficulty with each of the tasks, and any strategies they may have employed. Having completed this survey subjects were given a debriefing sheet and given time to ask any questions about the experiment.

Results

Analysis of the data collected consisted of five separate analyses of variance (ANOVA), three for the first session in which subjects participated and two for the second. Additional analyses were conducted but are not reported here because they were either redundant with the reported analyses or did not yield results of theoretical interest. In addition, not all significant results are given for the reported analyses, again to avoid redundancy and to emphasize the findings of interest. In Session 1 the independent variables of interest were part of a 3 x 3 x 2 x 2 (Training [Articulatory Suppression (AS), Count, Standard] X Block [1, 2, 3] X Trial Type [Prospective, Retrospective] X Retention Interval [2-back, 8-back]) ANOVA. Additional calculations were done to split cases into correctness based on side and correctness based on location. Based on the variables previously stated ANOVAs were calculated for cases in which participants answered on the correct side irrelevant of the correct location, cases in which participants answered the correct location irrelevant of the correct side, and cases in which participants had accuracy in answering the correct location given the correct side. Thus, there were three dependent variables examined: proportion correct side, proportion correct location, and conditional proportion correct side given correct location. Note that the analysis involving conditional proportions often employs fewer subjects than the analyses involving absolute proportions because subjects were eliminated from the conditional proportion analyses whenever they yielded no correct responses for a given cell of the design (to avoid dividing by zero). The independent variables of interest for the ANOVAs used for the Session 2 data were slightly more complicated as an additional distinction had to be made to test the transfer versus retention portions of the research hypothesis. Retention was analyzed as a 3 x 2 x 2 (Training [Articulatory Suppression (AS), Count, Standard], Trial Type [Prospective, Retrospective], and Retention

Interval [2-back, 8-back]) ANOVA, whereas transfer was analyzed as a 3 x 3 x 2 x 2 (Training [Articulatory Suppression (AS), Count, Standard] X Transfer Block [AS Transfer, Count Transfer, Standard Transfer] X Trial Type [Prospective, Retrospective] X Retention Interval [2-back, 8-back]) ANOVA. Each of these ANOVAs was calculated on accuracy of correct location with a disregard for correct side. All ANOVAs were calculated with the assistance of Professor Alice Healy and Senior Research Associate Vicki Schneider of the University of Colorado Boulder and Assistant Professor James Kole of the University of Northern Colorado.

Training and Retention

For Session 1 (training), when examining the accuracy of correct side disregarding the correct location a main effect approaching significance was found for trial type, $F(1,33) = 3.277$, $MSE = 0.508$, $p = .0794$, showing that participants had marginally less accuracy on prospective trials (.530) than retrospective (.654) trails. A significant interaction was found for Trial Type X Retention Interval, $F(1,33) = 30.023$, $MSE = 0.028$, $p < .0001$, demonstrating that in the case of the proportion correct by side, there was larger decline in accuracy for prospective trials than retrospective trials (see Figure 2). This result has been noted as typical for this type of test due to "default" processing and thus when the accuracy of correct location disregarding side is examined, the effect reverses. In the analysis for Session 1 of accuracy of correct location disregarding correct side, there was a main effect noted for trial type in Session 1, $F(1,33) = 24.805$, $MSE = 0.091$, $p < .0001$, in which prospective trials (.487) were found to have significantly higher accuracy than retrospective trials (.343). A main effect was found for retention interval, $F(1,33) = 85.593$, $MSE = 0.035$, $p < .0001$, which exemplified that subjects remembered better information that was only two instances previous (.498) as opposed to eight instances previous (.332) as an overall decrease in accuracy with a delay. More interesting was the Trial Type X Retention Interval interaction, $F(1,33) = 5.999$, $MSE = 0.013$, p = .0198, which demonstrates a protective function in the prospective trials such that there is a steeper decline in memory due to delay in retrospective versus prospective trials (see Figure 3). Even when conditional accuracy is considered for Session 1, such that subjects had to be correct on the location given being correct on the side, the same effect is noted when examining the Trial Type X Retention Interval interaction, $F(1,25) = 6.085$, $MSE = 0.034$, p = .0208, and prospective memory trials experienced less decreased accuracy over time than retrospective memory trials.

Moving on to the Session 2 data, in the retention trial a similar finding is shown as the main effects of trial type, $F(1,33) = 18.197$, $MSE = 0.034$, p = .0002, and retention interval, $F(1,33) = 40.173$, $MSE = 0.024$, $p < .0001$, are significant in the same pattern as noted in the Session 1 data. Additionally for this retention block a significant interaction was found for Trial Type X Retention Interval, $F(1,33) = 4.394$, $MSE = 0.016$, $p = .0438$, demonstrating again that the drop-off in accuracy with delay is far more pronounced for retrospective than prospective trials. For the transfer blocks of the Session 2 data the same pattern is shown as there is a main effect for trial type, $F(1,33) = 39.890$, $MSE = 0.042$, $p < .0001$, retention interval, $F(1,33) = 32.141$, $MSE = 0.041$, $p < .0001$, and a significant interaction of Trial Type X Retention Interval, $F(1,33) = 12.892$, $MSE = 0.021$, $p = .00011$, all of which display the same results as previously noted.

Role of Working Memory in the Protective Function of Prospective Memory

To examine whether this protective function of prospective trials is a function of working memory, additional interactions must be examined to determine whether working memory eradication strategies significantly affected subjects' accuracy. In Session 1 using the proportion correct by location, when crossing the interaction of Trial Type X Retention Interval X Training, (*F*(2,33) = 7.521, *MSE* = 0.013, *p* = .0020) the protective function of prospective memory was noted to span training conditions, although the most dramatic difference occurred for those who were trained in the standard condition (see Figure 4). Within the Session 2 data, for the retention block no significant interaction was noted when crossing Trial Type X Retention Interval X Training (*F*(2,33) = 1.465, *MSE* = 0.016, *p* = .2458) (see Figure 5). This same pattern of results is found within the transfer block data as the results when crossing the interaction of Trial Type X Retention Interval X Training (*F*(2,33) = 0.127, *MSE* = 0.021, *p* = .8814). These data indicate some support for the transfer hypothesis in this case.

Desirable Difficulty

To establish the basis of the desirable difficulty hypothesis it is important to ascertain whether subjects truly experienced any one condition as more difficult than another. Using the survey sheet given at the end of the experiment, a majority of subjects noted the counting condition to be the most difficult while the standard condition was the least difficult. When examining the Session 1 data involving the participant answering the location correct irrespective of side, there was a main effect of training (*F*(2,33) = 12.283, *MSE* = 0.087, *p* = .0001) and subjects were found to be most accurate in the standard condition (.504), or the condition in which there was no additional task or working memory interruption, and least accurate in the counting condition (.332), in which subjects needed to speak during the task as well as perform mental arithmetic, with the articulatory suppression task in between (.408) (see Figure 6). Moving on to the Session 2 trials there was no main effect for training in the retention block, *F*(2,33) = 0.860, *MSE* = 0.053, *p* =.4325, indicating that this difficulty in training had no effect on the subject's accuracy by comparison to easier or harder tasks when tested in the same condition 48 hours later.

Examining the Session 2 transfer blocks, a couple of interesting findings arise. It is important to note that there was no main effect for training ($F(2,33) = 1.126$, $MSE = 0.102$, $p = .3363$), indicating that, although individuals who were trained in the counting condition outperformed their peers numerically, this effect could not be attributed to more than chance currently. Similarly for the interaction of Transfer Block X Training, $F(4,66) = 0.752$, $MSE = 0.037$, $p = .5602$, individuals who were trained in the counting condition were at least numerically more accurate than their peers in all three transfer conditions, especially that of counting, but again, this interaction is not significant (see Figure 7). This is an important possibility though as when the transfer block main effect is examined, $F(2,66) = 34.496$, $MSE = .037$, $p < .0001$, subjects still perform worst on the counting block (.313) than the articulatory suppression (.399) or standard (.501) blocks, indicating that any possible outpacing of peers in this domain may be helpful.

Discussion

When an individual is told that something is going to be important, it can be expected to an extent that they will hold that information within their memories to a greater extent than information that one is otherwise passed by innocuously due to the preparation of a special response. What is interesting within this research is, although the only difference in presentational styles is a mere color, people still demonstrated a pattern of remembering that was unique to the prospective trials and not found in the retrospective trials. In test after test, the protective function of prospective memory demonstrated itself quite clearly and this study does not seem to indicate any information to the contrary. Although participants in Session 1 (training) did perform marginally worse on prospective trials than retrospective trials in accuracy based on answering the correct side disregarding location, this was an expected result due to the nature of the study and retrospective item answers representing the default side of the screen. The protective function begins to appear more clearly once correct location becomes the measure of accuracy and all subsequent results that take this measure into account demonstrate that prospective trials consistently show less forgetting overall and even over a delay than retrospective trials. This result is entirely consistent with what has currently been shown within studies such as Bourne et al. (2011) and thus this study can be taken as a successful replication of the results found therein.

Within the research done by Bourne et al. (2011), one of the limitations that this study attempted to resolve was that, due to the inlaid nature of the screens used to collect responses, both prospective and retrospective memory items when tested were responded to in the same area, invoking the use of the visuospatial sketchpad as a means of memorizing the location regardless of whether the item was default or special. In the results shown within the present study, the use of two separate response areas assisted in the assurance that a major portion of the memorization of the location of an item had to do with the semantic information presented to the participant. The finding that proportion correct by side shows a reversed trend as proportion correct by location demonstrates the fact that this is a valid consideration and must be considered critically when designing studies to explore this property of working memory.

The transfer hypothesis is where a degree of complexity begins to enter in the results of this study in particular. As a means of addressing the fact that the prospective memory function did not have a clear location within the framework of working memory as outlined by Baddeley (2000), articulatory suppression techniques were employed here in an attempt to understand whether the phonological loop may be the reason for this function. Although the Session 1 results indicated that based on pure training there is a significant interaction between the trial type, the retention interval, and the training condition, this only went so far as to imply that the protective function may be more powerful in some versions of the task than in others. When examining the Session 2 data, this interaction is lost, and it can be noted that the protective function no longer exhibits a sense of discrimination amongst the different training styles, thus exemplifying that the protective function may not exist within the phonological loop. As both techniques utilized for auditory suppression in this study have been proven to eradicate the phonological loop to a meaningful extent, the fact that no difference was noted after a period of delay indicates that the protective function is not a skill that has to be trained. Additionally, the transfer block demonstrates that this same concept within the protective function as the ratio of difference between prospective and retrospective trials in both short and long delay from prompt to response is not affected in a meaningful way by the level of difficulty otherwise introduced by the oral condition to which subjects were assigned.

Although there was no significant support for the desirable difficulty hypothesis within the context of this study, some of the findings explored seemed to be approaching significance. Within the Session 2 data, the indication of a trend began to exhibit itself as subjects who were trained in the most difficult condition, the counting condition, numerically outperformed their peers despite the fact that overall accuracy on the transfer blocks was still noted to be lower for counting than for the simpler conditions. This resultaligns with the current theories of apparent learning versus retention and transfer and it would be interesting to note whether this same numerical advantage may carry through to some longer period of decay. For the most part, there was not a large expectation that these results would be significant as the sample size was far too small. As this hypothesis was introduced during the process of testing subjects, no modifications to the methodology could be made at that time and thus there were only a meager 12 subjects per experimental condition to be examined in the support of this hypothesis. The slight numerical trend, while non-significant, does lend some sense of hope to the idea that perhaps with a larger sample size in a future study, these results may become significant. If, though, the statistical findings within this study are correct and the numerical advantage is eradicated, it may simply align with current findings of “undesirable difficulty” and the secondary task may simply not have helped the subjects learn any new memory process, instead inhibiting their performance with no tangible benefit.

To an extent, these findings need to be taken with a grain of salt though due to the difficulty experienced experimentally with establishing an interaction with the oral condition assigned to each subject. Although all subjects were demonstrated an example of how the trials should be approached by the experimenter before the session began, in practice many of them exhibited differential approaches to each of the articulatory suppression techniques. Although some individuals may have uttered a consistent stream of “the’s,” others paused between utterances, introducing a level of variability. In the case of counting, some individuals were able to consistently and accurately count downwards while others had long pauses as they considered the next number or were simply inaccurate in their counting, adding another level of variability. Although when subjects deviated significantly from the expectations of the testing protocol a researcher did step in to correct them, there was still a level of variability that was not corrected so as to minimize the effect of operator interference in the study. As such, some subjects may have experienced more phonological loop suppression than others.

An additional consideration that must be taken into account when viewing the results of this study is that a majority of participants expressed, and colleagues affirmed, that the procedure used in this experiment was extremely mentally taxing. As a means of avoiding any sort of ceiling effect and to really emphasize differences between the response types, this study was purposefully designed to be difficult in its most basic form and the addition of suppression techniques only exacerbated that difficulty. Although there was very little between test attrition (with the assumption that subjects may not have wanted to return to the testing space due to the difficulty of the study), a good amount of within test attrition was noted as some subjects had to be asked to not click randomly on the screen when it became obvious that they were not paying attention to the prompts and simply trying to quickly finish the block that they were in. Due to overall difficulty, this random clicking was most observed with subjects who were trained in the counting condition and was largely noted in Session 1, as the lack of variability in challenge likely also led to a sense of boredom that may have negatively affected testing outcomes.

As well, the overall framing device used for the experiment, due to the fact that the program that was used for this experiment was originally designed for NASA astronauts, had no perceived relevance to the participant population used within this study. Although subjects were informed that their data would be employed by NASA as well, there was a variable engagement with this idea and overall, the study did not provide a rationale with which college students would be easily able to identify. Although this may have had the effect of further pronouncing the differences in working memory between prospective and retrospective memory, it would be useful for a future study to examine these sets of data in a framework more actively relevant to the participant population as it may be possible that the ability to construe information within a self-relevant form of cognition could have some effect on the protective function explored within this study.

In conclusion, the findings in this study help to support the evidence that has come to suggest that even within the current theory of working memory, there are quite a few nuances yet to be explored. There is distinct evidence to support the idea that intention to respond in a special way does protect information in memory from decay although more research will need to be done on what exactly is facilitating that function. What this study can add to that discussion is that based on the principles of transfer, the phonological loop does not seem to play a major role in the protective function. Additionally, the visuospatial sketchpad does not appear to play a role either, although this finding would be benefitted by a more focused approach in future research. Evidence to support the idea of desirable difficulties with regards to the protective function of prospective memory are currently inconclusive but may someday be benefitted by studies with a larger sample size to see if the protective function can be improved within the framework of more difficult training scenarios.

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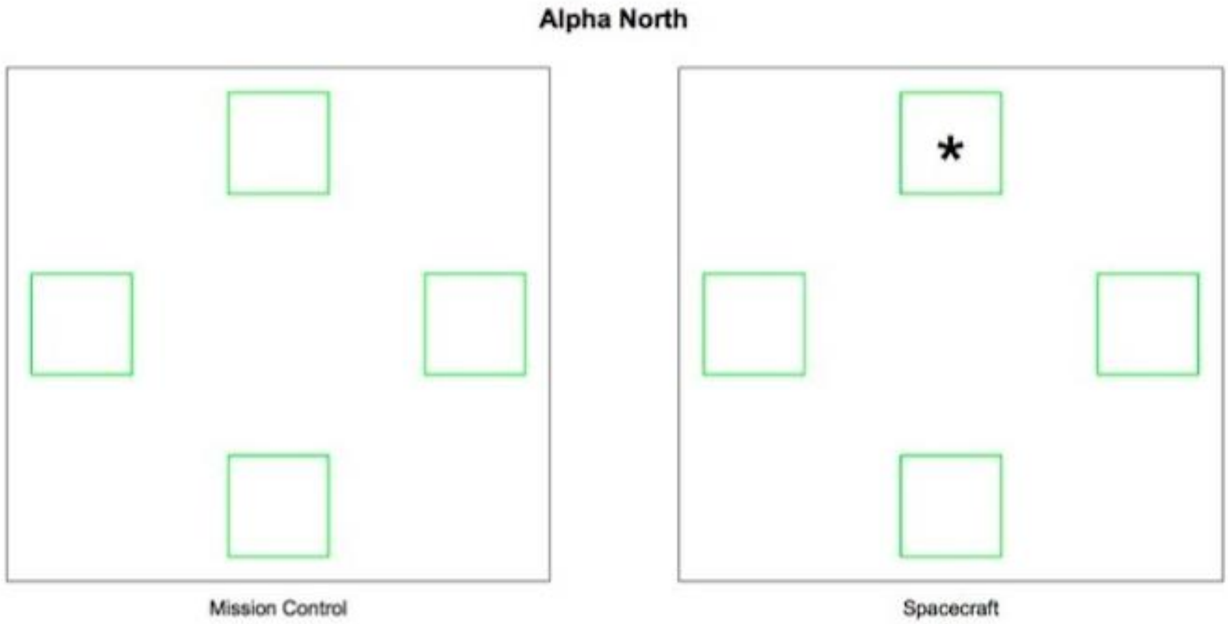

Figure 1. Example of screen displayed during trials. In this case, a retrospective memory prompt is depicted with the correct response shown. Name and direction combo at top of screen may also appear in green for prospective memory prompts, or as XX [name] XX in blue as indication that the square aligned with the previous direction in the correct location for the previous color of that name should be clicked.

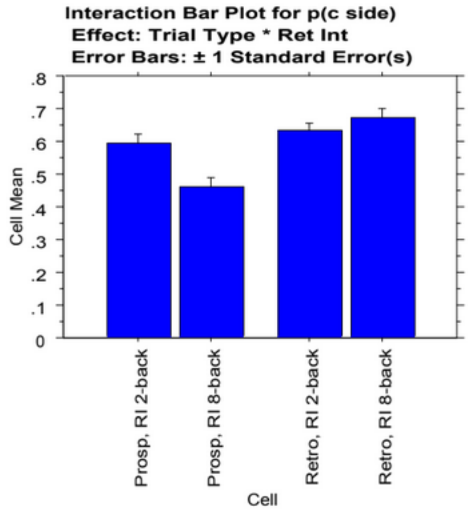

Figure 2. Session 1 data for proportion correct based on answering the correct side of the screen regardless of the correct location. Higher cell means indicate higher accuracy. Retrospective trials show improvement due to default answering.

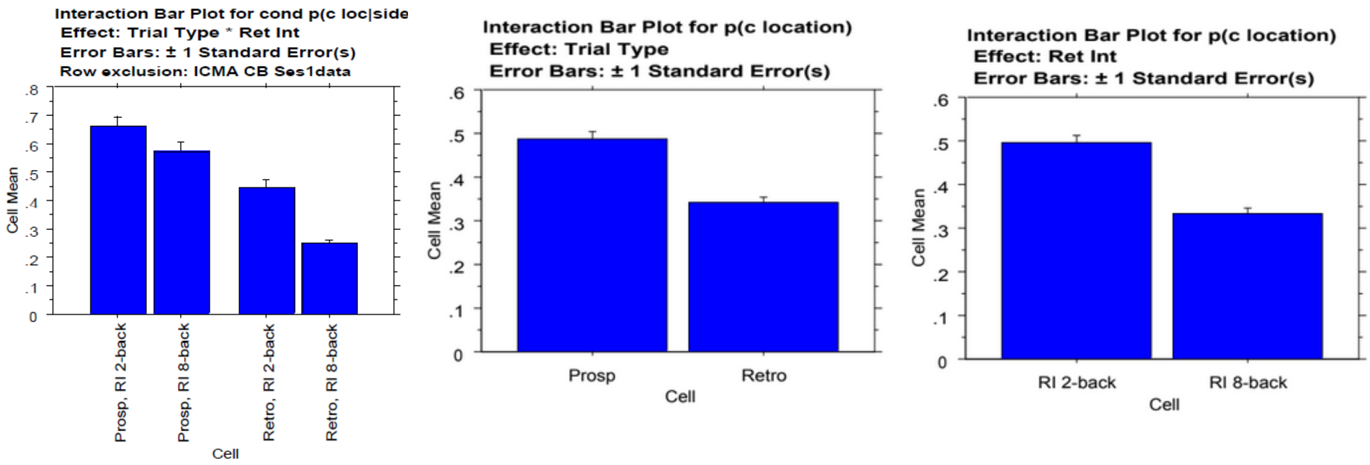

Figure 3. Session 1 data for proportion correct based on answering the correct location of the screen regardless of the correct side. Higher cell means indicate higher accuracy. This pattern of data is consistent with Session 2 trials as well.

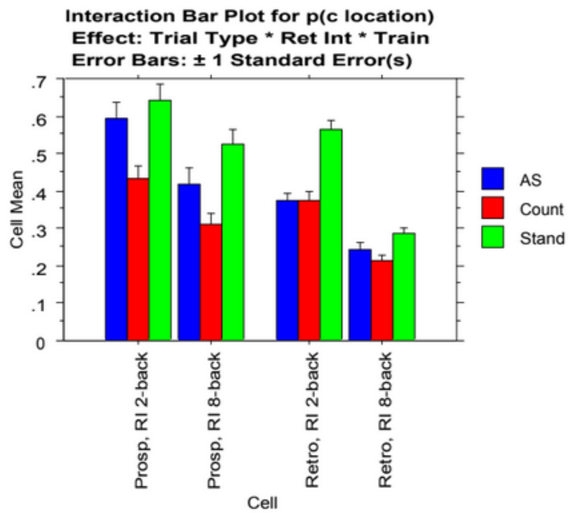

Figure 4. Session 1 data for the interaction of Trial Type X Retention Interval X Training Condition based on answering correctly for location regardless of correct side. Higher cell means indicate higher accuracy. Interaction is significant.

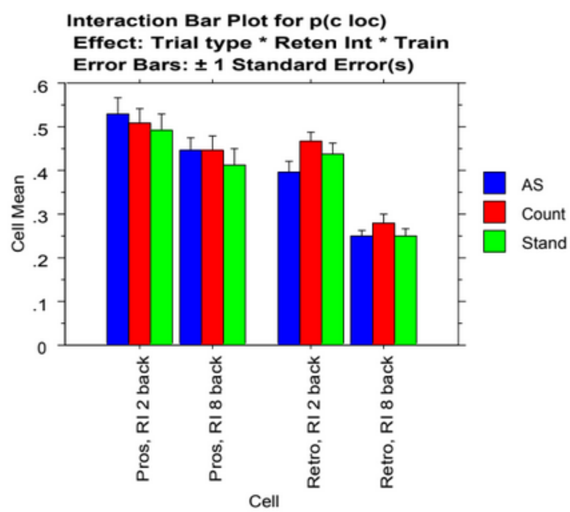

Figure 5. Session 2 data for interaction of Trial Type X Retention Interval X Training Condition based on answering correctly for location regardless of correct side. Higher cell means indicate higher accuracy. Interaction is not significant.

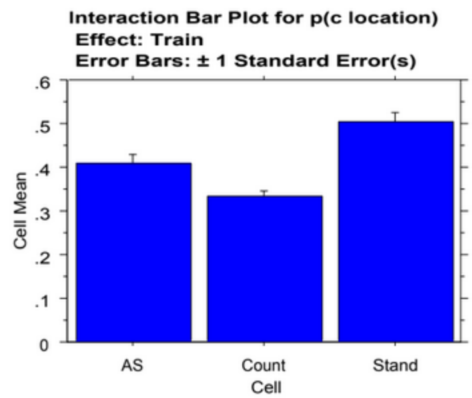

Figure 6. Session 1 data for the main effect of training condition based on answering correctly for location regardless of correct side. Standard, or no secondary task, has the highest accuracy while counting has the lowest.

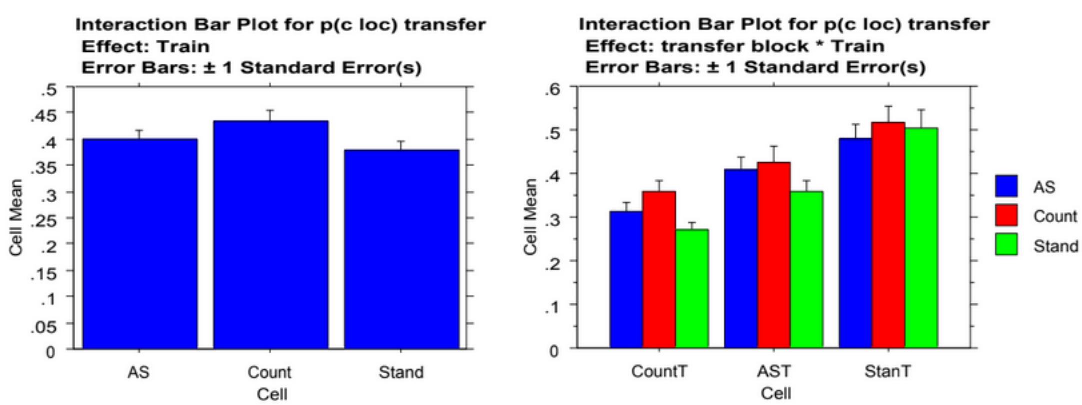

Figure 7. Session 2 transfer blocks data for the main effect of training based on answering correctly for location regardless of correct side. While not significant, subjects who trained in count (red bars) perform the best numerically on every transfer block. Higher cell means equal higher accuracy.