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PRACTICE AND MEMORY LOAD IN A DUAL VISUAL WORKING MEMORY TASK

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ABSTRACT

PRACTICE AND MEMORY LOAD IN A DUAL VISUAL WORKING MEMORY TASK

By

Joshua L Hoelter

This experiment was conducted to assess the effects of practice on working memory for both rotated letters and novel objects. The purpose was to replicate and extend the work of Hyun and Luck (2007), who argued that mental rotation was more of an object memory problem than a spatial memory problem. Forty-five participants were divided into four conditions including mental rotation alone, object memory alone, a dual object memory and mental rotation task, and an alternating task. Support was found for the Hyun and Luck proposition that mental rotation involves object memory.

Keywords: Mental Rotation, Dual-Task, Working Memory

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Introduction

This thesis follows the format prescribed by the APA Style Manual and the Department of Psychology.

Human cognition is based on a complex interaction of systems, including working memory, attention, and perception. This study examines the nature of visual working memory. The study aims to replicate and extend the Hyun and Luck (2007) work which suggests that mental rotation of an object relies on object memory more than spatial memory within the working memory systems. The rationale is to set up a pair of tasks which both use the same type of working memory to see if performing these two tasks simultaneously will impair performance as would be expected if both tasks utilize the same components of working memory. Evidence that the tasks both rely on object memory will come from performance deficits when doing two tasks simultaneously, relative to each single task. The work is a partial replication of Hyun and Luck's (2007) within-subject design using a between-subject design and an added control condition. Doing two tasks simultaneously is called a dual-task. This introduction will review the assumed working memory system and tasks before drawing up a hypothesis.

Literature Review

Functional Structure of Memory

Two distinct components of memory have been identified through research and are described in models of memory: long-term memory and working memory (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974; Tulving, 1985). Working memory is often referred to as short-term memory; however short-term memory is part of a simpler and earlier conceptual model (e.g., Atkinson & Shiffrin, 1968).

Short-term memory was defined by a set of performance criteria. For example, Waugh and Norman (1965) suggested the duration of STM is less than half a minute without further rehearsal. Additionally, short-term memory was limited in how much information could be stored and used at any given time. Miller (1956) suggested that this amount of information is roughly seven items plus or minus two, but also found that people chunk bits of information together in order to expand this size. For example a telephone number can be thought of as three pieces of information as opposed to ten digits. The number 555-678-9001 can be turned into five hundred and fifty-five, six hundred and seventy-eight, and nine thousand and one. These chunks represent distinct pieces of information (area code, prefix, and four numbers), any one of which might be well known and integrated into a single piece of information. Miller's original experiment used binary numbers, 0's and 1's to show that 001-1001-111-0 is easier to remember then 00110011110.

Short-term memory was also thought to be limited in what types of information could be stored or held. Conrad and Hull (1964) demonstrated that acoustic information was often misinterpreted, because similar sounds disrupted each other from being either perceived or remembered properly. The initial idea behind this position was that short-term memory was primarily verbal and relied on verbal rehearsal. By confusing the similar sounds being encoded, participants had trouble understanding what they were hearing or trouble holding onto that information in memory.

In 1968, Lee Brooks examined how similar short-term memory tasks can interfere with each other. Brooks had a memorization task that was followed by a response task. These tasks could be spatial or verbal. When participants had to hold in mind something spatially and respond spatially, performance dropped dramatically by a factor of two relative to cross modal responses. Holding in mind a sentence and having to answer by speaking was slower than holding in mind a spatial diagram and responding by speaking. Thus, clearly there seemed to be visual and spatial aspects of short-term memory, which could be experimentally separated.

Theories of interference were also studied by Murray (1968), who found that verbal repetition of something very simple disrupts learning of words but less so when the subjects are able to see the words. Murray's phenomenon is now called articulatory suppression. Baddeley (Baddeley et al., 1975; 1984) also found this suppression when having participants repeat "the" while trying to learn a sentence. The explanation given for this suppression was that verbal storage has limitations. These findings give weight to the multi component view of the working memory system described by Baddeley and Hitch (1974).

The working memory model is an extension on the short-term memory model, and suggests that people must hold onto and manipulate memories in a way that allows for use in problem solving or question answering (Baddeley & Hitch, 1974). The working memory model includes a set of sub components, including the central executive, the phonological loop, and the visuo-spatial sketchpad, that allow incoming information to be held and rehearsed, and old memories to be retrieved from the long-term memory storage to be used.

The sketchpad is used for image and spatial storage in working memory while the phonological loop stores words and numbers. Conrad's, Brooks', Murray's, and Baddeley's research all pointed to the idea of a component system. They found that by overloading with one type of information you would decrease what could be held onto or recalled in that one system.

The central executive is functionally different from the loop or the sketchpad. There seems to be a limit to how much information we can attend to within any amount of time. The primary function of the central executive is to assign attention and control how we switch between tasks (Baddeley 1996; Robbins et al., 1996). In order to direct the flow of information the central executive must be the first part of the working memory system that any information encounters. The central executive may also direct where and how encoded information is held; either in the sketchpad or the loop (see Figure 1).

Brooks (1968) demonstrated the relative independence of spatially and verbally encoded information. This provides support for a separation of the visuo-spatial sketchpad and the phonological loop. Information, like a read sentence, may be represented in both because you are reading (visual) and comprehending (auditory/semantics). The study also demonstrated that the sentence, after initial processing, is held more in phonological loop by the reaction time difference: having to say an answer took longer than pointing to an answer

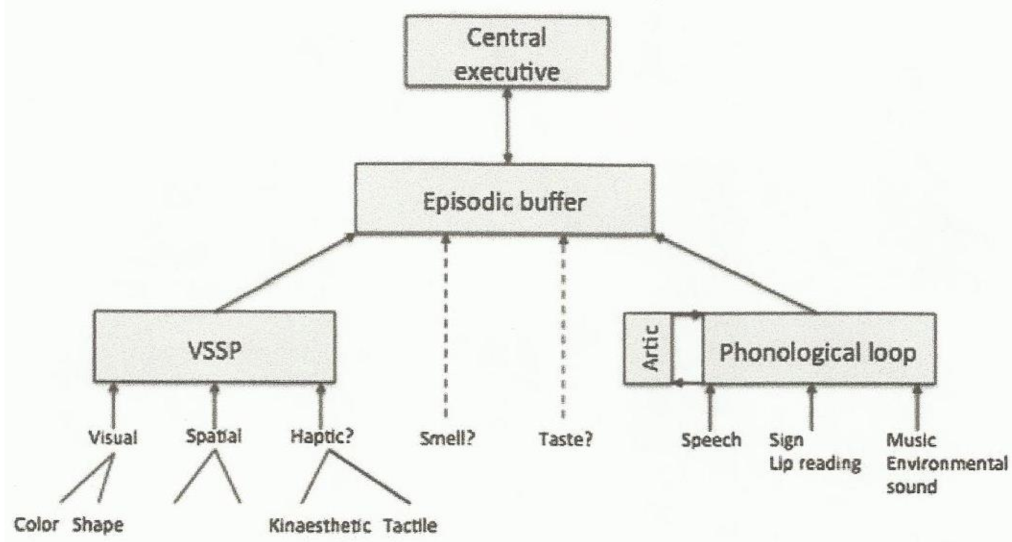

Figure 1. Baddeley's (2012) most current representation of the working memory system.

Baddeley (2012) has suggested that within the sketchpad we may allocate a limited set of resources for colors, objects, locations, and possibly more. This elaborate system seems to be supported by Hyun and Luck (2007). Objects may be separated from their spatial location even when you are attempting to manipulate them in your mind. In Hyun and Luck's experiment, subjects recognized letters while either recalling color objects or locating a certain stimulus on a computer screen. They found a performance difference in reaction time and accuracy between memory for objects, and memory for location while also doing a mental rotation task. They concluded that mental rotation has more to do with recalling an object than remembering a location because the object memory task was more impaired than the location task.

Working memory has taken a dominant position in the theories of human memory. It is most likely this memory that we use to perform mental rotation and recall tasks that occur over a very short period of time. When an individual tries to use the same working memory system for two tasks, interference is caused, decreasing the performance on one or both of those tasks.

Attention

Attention is the ability to focus on only a part of incoming sensory or perceptual information. With the limited amount of information that can be processed in working memory at any given time, it becomes important to determine how we allow information to be encoded and how much we can encode at one time. A person is able to attend to a limited amount of information at any given time. Divided attention is the term used when a person attends to more than one task at the same time. Usually dividing one's attention impairs performance. Practice on divided attention tasks can improve overall performance on the tasks (Shiffrin & Schneider, 1977; Spelke et al., 1976). Extended practice may lead to what is functionally automatic processing on a specific task, which results in the task using very little processing capacity so that it becomes a "low load" on the system. The amount of practice necessary to attain automatic processing is immense, 85 hours for Spelke's subjects and 900 trials for Shiffrin and Schneider's. Shiffrin and Schneider further suggest that the most difficult tasks can never become an automatic process, no matter how much practice is done.

In the Hyun and Luck study (2007), automatic processing may have played a role in performance on the tasks. Subjects can be expected to automatically process letters of the English alphabet, even when asked to mentally rotate them, because of the vast experience in everyday life that people have with rotated as well as canonical images. Since Hyun and Luck ran two experiments and different levels of disruption, (i.e.

different levels of performance) were found between the object and spatial tasks, we can presume that processing was not fully automatic.

Along with a limit on the number of items that can be processed in working memory, the complexity of information also impacts the processing limits of working memory. Research has examine whether it is only the number of objects that contribute to how much memory capacity is needed for them or if it is also how many features an object has (Alvarez & Cavanagh, 2004; Woodman, Vogel, & Luck, 2001). As stimuli become more complex they may require more processing capacity from working memory, as a result people may only be able to hold onto a very small amount of complex information.

In addition to only being able to remember small amounts of complex information, holding onto it may also disrupt performance on other stimuli trying to be processed simultaneously (Logan, 1979). According to Logan this could be due to the attention required to switch between the demands of the two tasks and not just the memory load. However, it seems clear (Alvarez & Cavanagh, 2004) that there are stimuli that use up memory capacity faster and, therefore, these stimuli are only able to be memorized in smaller quantities. These high load tasks may become low load with enough practice, increasing the efficiency of how they are retained. This allows for more of those stimuli to be stored and/or integrated, similar to how automatic processing happens in attention, allowing information to be encoded faster, and in higher amounts in shorter times.

Anything that uses cognitive resources, such as memory load and attention, reduces the amount of available working memory resources. When one task is added to another and then another until it exceeds our available resources; our system becomes unable to hold onto critical information, to switch attention, or to complete multiple tasks at the same time. A system where tasks converge on the same processing component (instead of being processed at the same time by parallel processing components), has been called a bottleneck (Pashler, 1994). In a bottleneck situation it becomes necessary to attend to one task at a time, until that task is completed. Van Selst and Jolicoeur (1994), investigated the bottleneck problem in a dual-task between mental rotation and a tone-frequency discrimination task, and found evidence that some people had problems with the dual-task while others did not. This suggests that at least some people can perform mental rotation simultaneously to another task without having to finish the other task, and that for them the bottleneck does not occur. It could also mean that for those subjects mental rotation was performed automatically. Tasks that can be performed automatically use minimal attention resources.

In all of the studies in the previous section, attention was a determining factor in how well the participants could perform the tasks set to them. This study needs to take measures to ensure that attention is not a factor in how well the subjects perform on the tasks they complete.

Dual-Task Procedures

Testing on a dual-task has often been used in cognitive research to demonstrate the effects of memory load on cognitive performance or to infer different memory pathways (Brooks, 1968; Hyun & Luck, 2007; Van Selst & Jolicoeur, 1994). If two tasks use the same memory system they should impede a person's performance on each task. Likewise, if they use the same pathways, it should be difficult to perform both simultaneously. Brooks (1968) demonstrated this by requiring subjects to perform two tasks that presumably should occupy the same type of memory system, and the same pathway in the brain, creating a performance deficit when compared to performing two tasks that should occupy different paths or use different systems. This performance deficit was taken as evidence that these two tasks utilize the same cognitive paths. In the Hyun and Luck (2007) paper a mental rotation task was performed while also performing an object recognition task or a spatial task. The results suggest that mental rotation is, in fact, more of an object working memory task and less a spatial task.

A dual-task experiment can cause interference between tasks which can be intentional or unintentional (Leonhard et al, 2011; Van Selst & Jolicoeur, 1994) so researchers have to plan for this. In a working memory task it is possible that information may be lost for two reasons. One reason is that the time delay between the encoding and the recall is long enough that it causes the memory to decay; the second is that crossing over between the two tasks leads to interference or competition, and information is lost because there is a heavy memory load on the same system. Even if a subject must switch between tasks, it has been shown that they are able to do this with very little change in effectiveness (Just et al., 2001) if the load is not too great or the task too complex.

Dual-task procedures that lead to interference are actually a good way to measure memory load. By using one task to put a tremendous load on resources, as Brooks (1968) did, and then imposing another task and measuring how well that task is performed, we can learn about how the tasks affect each other while occupying memory. Doing two tasks can be used to prevent rehearsal, allowing for a true test of short-term memory and not of long-term memory or rehearsal, as in the use of counting backwards by threes in a short-term memory task (Keppel & Underwood, 1962; Peterson & Peterson, 1959).

Dual-tasks can cause interference in one or both of the tasks involved. This interference does not always mean what we want it to mean though. To be careful that we get interference only if the same memory system is used, we need to create circumstances that should have the same work load for our cognitive systems but that do not create the same interference effects.

Mental Rotation

Mental rotation is the act of holding an object in mind and then manipulating it into a new orientation. Shepard and Metzler (1971) had subjects view 2-dimensional pictures of side by side 3-dimensional objects, one being the standard shape and the second one a comparison. Half the time these images could be manipulated to show they were identical, and half the time they were different (Figure 2). Subjects pulled a lever

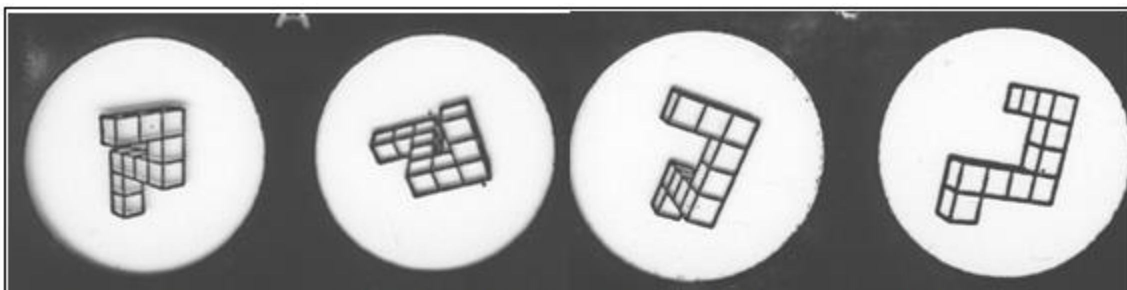

Figure 2. Shows a same pairing on the left and a different pairing on the right of the Shepard and Metzler objects.

with their right hand for same images or a lever with their left for different images. Shepard and Metzler found a distinct pattern of learning and performance (Figure 3). This linear relationship between time to respond and angle of rotation has been taken as evidence of mental rotation. Bethel-Fox and Shepard (1988) performed this on a cathode-ray tube and an Apple II Plus microcomputer with two-dimensional objects that were rotated only on one plane, and they found similar results. Today the stimuli are commonly presented on a computer monitor with responses being a button push and with an automatic recording of the reaction times to make a decision. The stimuli can be relatively abstract like Shepard and Metzler's (1971), Bethel-Fox and Shepard's (1988), and Cooper's random polygons (1976), or they can be any object that is not symmetrical like simple letters from the English alphabet.

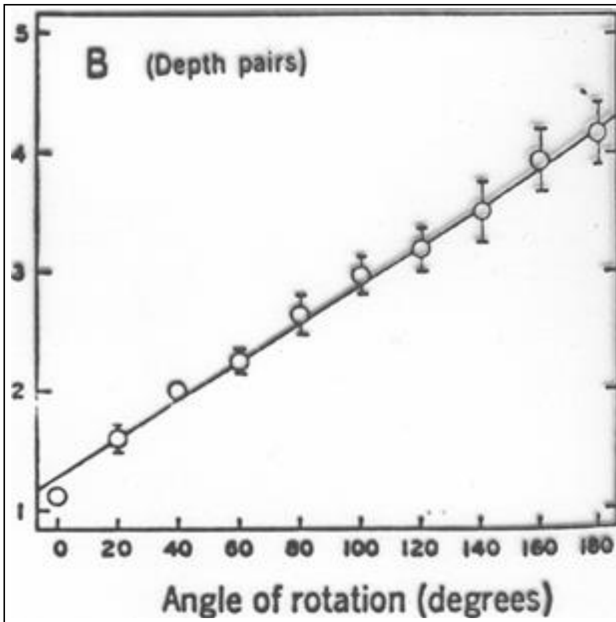

Figure 3. Shepard and Metzler's finding. As the degree of rotation increases so does the time to decide whether the two stimuli were the same or different.

Hyun and Luck (2007) used a modified version of mental rotation. A letter from the English alphabet was presented at different rotated angles and was either rotated or flipped and rotated. When doing a dual-task experiment with a relatively simple display, a single letter may be used for rotated letters, because the standard upright letter is well known by the participant.

Mental rotation tasks provide evidence of a visual representation of objects in the mind. They demonstrate that the subject is able to take the object in their mind and rotate it in order to match the stimulus to some standard. Shepard and Metzler's study (1971) showed reaction times where, as the size of the angle of rotation increases, it takes longer to rotate images in a linear fashion, suggesting actual rotation in some mental space. Bethel-Fox and Shepard (1988) demonstrated how even complex images can become familiar with practice, suggesting that unfamiliar objects become more easily rotated with practice. Thus, we would expect well known simple objects, such as letters, to be processed easily or almost automatically.

Study Rationale

Hyun and Luck (2007) used a dual-task procedure to pair mental rotation of letters with an object memory task. Their procedure had subjects remember a geometric object over an interval during which subjects also had to judge whether a rotated letter was a canonical or mirror image. They found that compared to a single task condition, the mental rotation task interfered with object memory in terms of accuracy (percent correct). They did not report object memory reaction time. They also found that while holding an object in mind, mental rotation accuracy decreased and mental rotation reaction time increased, relative to the mental rotation alone trials.

If the Hyun and Luck (2007) study is an accurate picture of interference between color object memory and mental rotation, then the current study will also see decreased performance when subjects perform in a dual-task rather than the control tasks. If the dual-task is creating more difficulty for the subjects by demanding attention shifts and not by memory system interference, then an alternating task should create the same difficulty effect because it is not a matter of using the same systems simultaneously, but of rapidly switching attention during a given period of time.

This experiment had four testing conditions: two control conditions where subjects just perform mental rotation or they performed just color object recall; one dual-task condition where the two tasks are performed simultaneously, and an alternating task where subjects have the same memory load and fatigue but operations are performed in an alternating, or successive fashion to prevent memory system interference.

If the Hyun and Luck (2007) study presents an accurate picture of the nature of color object memory and mental rotation, then the dual-task should cause interference in the form of reduced accuracy and increased reaction time when compared to the control tasks which should include the alternating task.

The current study is designed to replicate and extend the single task versus dual-task comparison of performance on color object memory and mental rotation of letters task. It contains the same parameters of performance as the original experiment including reaction time measures, as well as accuracy measures for both tasks, but it adds between subject design, training on both tasks, and a second control group.

Practice on both tasks was added because it has been demonstrated (Bethel-Fox and Shepard, 1988) that mental rotation performance is dependent on learning. Subjects require a set of 6 or more trial blocks before their performance is consistent (S. Burns & C. Leith, personal communication, October 11, 2011). In the Hyun and Luck study, not only did subjects have no apparent practice trials, but because of the design of their study subjects saw all the test trials all the time, whether they were responding to them or not. Being able to see the test trials all the time could mean that subjects were able to implicitly practice on the tasks they were not responding to as they completed the ones that they did respond to. Switching to a between subject design rather than a within subject design lets you control for this implied practice.

The additional control group has subjects alternating the object memory task and mental rotation during test trials. This was a check on whether just the alternation of attention between tasks would interfere with accuracy and reaction time on the test trials in the same way that doing the tasks simultaneously did in the Hyun and Luck study. This controls for the presence of a second task during the testing procedure. This control equates the number of responses and duration of the testing trials of the dual-task, and any fatigue which may result.

Hypothesis. In the Hyun and Luck dual-task subjects are competing for the same memory system as well as switching between two tasks. In the alternating control, subjects are switching between the two tasks, but the tasks are not competing for the same memory systems. This will show that subjects are not showing signs of interference from task difficulty, but that the dual-tasks actually compete for space in the same memory systems.

Method

Participants

Participants were recruited from Introduction to Psychology classes at Northern Michigan University. They received no compensation or payment other than course participation credit. There were a total of 45 participants, 19 males and 26 females, after 6 were removed from the analysis.

Tasks

Five different tasks were used during the study: button training (BT), Mental Rotation (MR), Hyun and Luck object memory (HL; Hyun & Luck, 2007), an alternating Mental Rotation and Hyun and Luck task (ALT), and a dual Mental Rotation/Hyun and Luck task (Dual). During all tasks other than the button training, participants continuously repeated "1-2-3" to suppress verbal encoding.

Button Training. The words "Yes" and "No" were presented on the laptop screen and the subject was asked to press the matching yes or no response button as quickly as possible. The reaction, or response, time was recorded in milliseconds. This task was used to train participants on the apparatus and to use the response keys that were necessary for the experiment. Reaction times and errors were recorded for analysis.

Mental Rotation. The Mental Rotation (MR) task asked participants to distinguish between same-object (a Yes response) and mirror-image (a No response) presentation of letters displayed at different angles of rotation. Images for this task were single letters of the alphabet; capital G, L, P, and lowercase t for the training and capital R, J, Q, and F for the testing. They were presented at angles of 0°, 30°, 60°, 90°, 120°, and

150˚ (see Figure 4). A block of trials included randomly varying the order of the different letters in the six possible degrees of

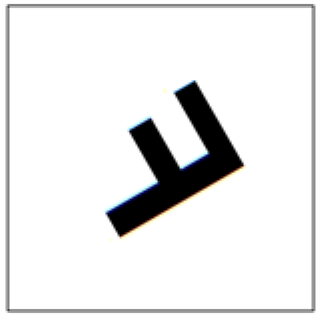

Figure 4. Shows a Mirror image F rotated 60˚.

rotation. For each trial both accuracy and reaction time were recorded for analysis. Each block of trials included 48 individual displays; each letter at each angle in both same and mirror presentations. Order of the figures was randomized by the computer program to prevent participants from memorizing the answers.

Hyun & Luck Object Memory Task. The Hyun and Luck memory task is a test of object memory taken from their paper (Hyun & Luck, 2007). The object is a square flanked by four additional squares of smaller size attached to its corners (see Figure 5).

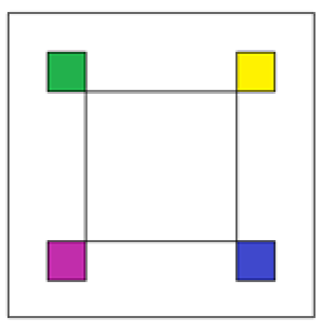

Figure 5. Shows an actual color object as it was seen by the participants.

The four smaller squares each have a different color in them. The objects were presented for 500ms and participants were asked to remember the first object through a delay of

500ms followed by an additional varying delay filled with a random unrelated shape (see Figure 6). The delay was for 500, 1,000, or 1,500ms. These delays were chosen to

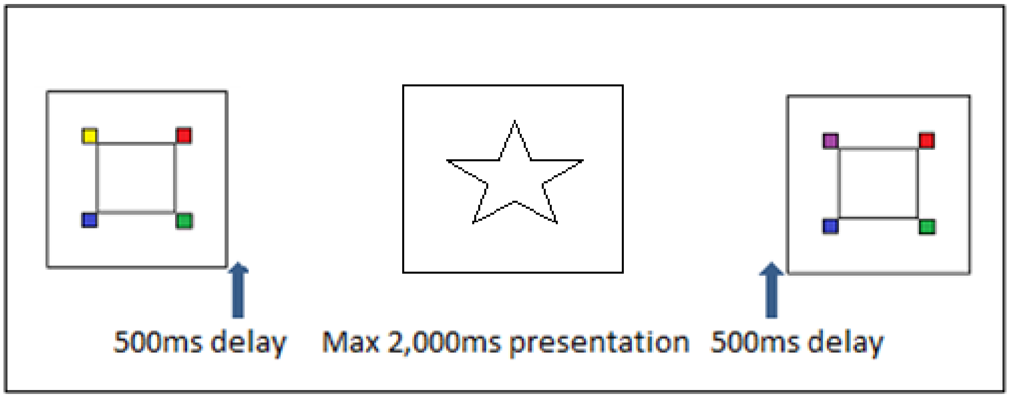

Figure 6. Shows the HL task with random figure during the delay between initial presentation and the presentation requiring a response.

approximate the delays of performing mental rotation in the dual-task condition. After the delay had passed, a second object appeared on the screen that was identical or nearly identical to the first. Participants were asked to respond to that second "test" image, whether all the colors were the same as before (a Yes response) or if one of them was different (a No response). Both accuracy and reaction time were recorded for analysis. One of the colors was changed for half of the trials (indicating to press the RED button/ a No Response), and the colors stayed exactly the same for the other half of the trials (indicating to press the GREEN button/ a Yes response). Order of the same/different presentations was randomized by the computer. All positions and several different colors were used to prevent the participants from memorizing the answers.

Dual Mental Rotation/Hyun and Luck Task. This was the HL color object task but with an MR trial replacing the unrelated shape between the two delays. Thus, for 500ms the first HL image would appear, this was followed by a delay of 500ms and then the MR trial came onto the screen. Subjects had to make a button response to this, which was then followed by another 500ms delay. Finally, the test image for the HL figure was presented and the subject makes another button response to that image (see Figure 7).

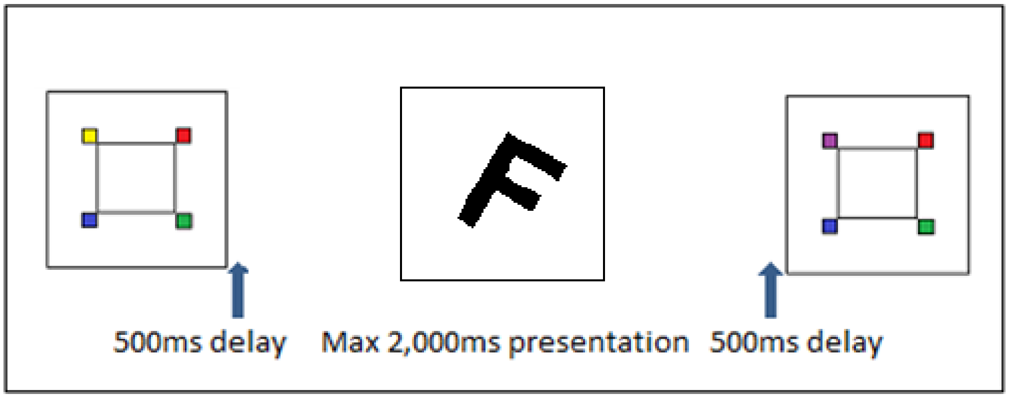

Figure 7. Shows the dual-task where subjects respond to a rotated letter during an HL trial.

Both accuracy and reaction time were recorded, for both the MR trial and the test portion of the Color Object trial.

Alternating Mental Rotation/ Hyun and Luck Task. This condition displayed 48 MR and 48 HL trials, so subjects made a total of 96 responses with the same number of HL and MR responses. HL and MR trials were alternated. One trial of the HL task appeared on the screen as it did in the practice and control conditions. Subjects responded to this object memory task before they were presented an MR figure. Then one trial of the MR experimental set was shown. Subjects then had to respond to that figure. In this condition subjects constantly switched between completing the two types of tasks, as opposed to the dual-task where an MR trial was presented in between the HL figures. Task order was randomized by the computer so that multiple trials of MR or HL might be presented in a row, rather than strict alternation. Reaction time and accuracy were recorded for analysis for both the MR figures and the HL figures.

Apparatus

All tasks were presented on a Toshiba Satellite Pro laptop running Windows XP Professional and the Direct RT (Empirisoft) program. Subjects' made their response on a keypad with Green and Red buttons.

Design

The four group design is a combination of practice followed by four testing conditions. All subjects completed practice (two 48 trial blocks) of both MR and HL tasks. There were four possible experimental testing conditions. The first was mental rotation control condition, the second was the Hyun and Luck control condition, the third was the HL/MR dual-task, and the fourth was the MR/HL alternating task.

If object memory is important to the process of mental rotation then doing a dual-task should have increased time and errors in the mental rotation dual trials compared to the mental rotation control trials. If object memory is less important, then practice with the object memory should have produced reaction times that are similar between the dual and the control task. Practice in mental rotation should produce better results for mental rotation overall but the dual-task should still produce slower times and/or more errors. The control groups should show the best times and most accurate performance for the mental rotation and object memory trials. These control groups include the alternating condition, because as discussed earlier it should mimic the results of the MR and HL alone conditions.

Procedure

Upon entering the room subjects were greeted and asked to sit in front of the computer. Subjects then read through a consent form, and had to sign the sheet in order to confirm their voluntary will to continue before the experiment proceeded. If a subject had declined to continue, he/she would have been given the participation credit nonetheless. No subjects refused to participate. The experimenter then collected the consent form and continued on with the instruction describing what happened next during the experiment and what was expected from them as subjects.

After the consent sheet was signed, subjects completed button training during which they were instructed to "press the response buttons as fast as you can while trying to make as few mistakes as possible". Instructions about correct responding were given to the subject who was asked if they understood what was going to happen. They were told that they had to complete seven blocks of 48 trials. The seven blocks of trials included 2 blocks of HL training, 2 blocks of MR training, and 3 blocks of the test trials in one of the four experimental conditions. Each block of 48 trials took approximately 5-10 minutes to complete with the entire experiment taking between 40 and 60 minutes.

After running the button training and answering questions, subjects were practiced on both the MR and HL tasks with special emphasis on the counting out loud requirement. Practice order was randomized between subjects. Some received the two MR blocks first, and some received the two HL blocks first. Practice was followed by one of the four experimental conditions. Instructions during the practice covered the basic information for the mental rotation task and the object memory task as applicable.

Participants then went on to their randomly assigned experimental condition. This was the Mental Rotation task, Object Memory task, Dual-task, or the Alternating task.

After the three test blocks were completed the experimenter instructed the subject that the experiment was completed. The experimenter then went through a short list of demographic questions (see Appendix A) and then moved to the debriefing.

Debriefing. Finally the experimenter debriefed the subject, providing an explanation of what the order of the tasks might tell us and why the experiment was being run. One final time the subject was asked if he/she had any questions. After answering whatever queries there were, the experimenter provided a participation slip, copy of the consent sheet, and a copy of the debriefing sheet (see Appendix B) to the subject. The subject was thanked for participating and was politely escorted out of the room.

Results

A total of 51 participants were tested. Six were removed from the analysis for failing to count, not understanding the task, or due to experimenter error, leaving an N of 45 (26 females and 19 males): 11 in the mental rotation task, 11 in the color objects task, 11 in the dual-task, and 12 in the alternating task. The average age was 22.16 years old. A one-way Anova found no difference in mean age between the different task conditions, $F(3, 41) = .102$, $p < .5$. All analyses were performed using SPSS v 18.

As in the analysis used by Hyun and Luck (2007), across all conditions any reaction times above 3,000ms and below 100ms were removed. This functionally deleted what would otherwise be considered correct answers and could have had an impact on accuracy measurements and on reaction times as well, since higher times are now absent. For the current results analysis, high times were windsorized instead of trimmed, meaning that any times higher than 3,000ms were replaced with 3,001ms instead of being removed. Two variables were analyzed in the Hyun and Luck study: reaction time (RT) and percent correct responses (PC). All correct responses, same and different, were combined in the analyses for both RT and PC. The two training blocks were analyzed separately to evaluate any learning curve, especially in the mental rotation training. The three testing blocks were combined into one set of measures averaged over the three blocks following the procedure of Hyun and Luck, and then analyzed with separate blocks as a variable because the experimental design allowed for it.

Training Tasks

Hyun and Luck Task (HL) Training. Both RT and PC were analyzed in a two (Blocks) by four (Condition) by two (Training order) analysis of variance with blocks as a repeated measures variable. The overall average RT for the HL training was 1,005.86ms for the first block and 934.76ms for the second. This decrease in time was significant block effect $F(1, 37) = 12.406$, $p = .001$. Participants became faster with more practice. There were no effects of condition or training order, but there was an Order by Block interaction $F(1, 37) = 7.076$, $p < .05$, participants who received HL practice after MR practice started out slower but reached equivalent times by the end. Therefore, the groups can be considered equivalent on the HL RT after training (Figure 8).

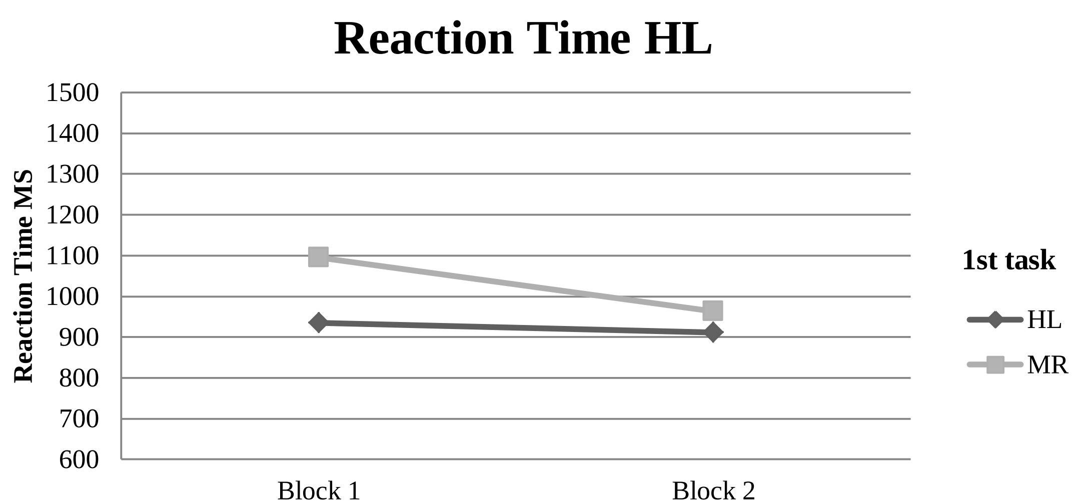

Figure 8. Shows the reaction time as a function of Practice Order and 2 blocks of practice on participants reaction speed for HL training. An interaction is seen as the two groups start distanced from each other but become equivalent after the second block.

The average PC for the HL training was 81.25% for the first block and 84.58% for the second. There was a significant block effect $F(1, 37) = 6.227$, $p < .05$, participants improved their accuracy over training (Figure 9). There were no effects of condition and no interaction but there was a between participants effect of Practice Order

$F(1, 37) = 5.276$, $p < .05$, participants who received HL training first performed better on it. Therefore, assignment to all the groups can be considered equivalent for HL PC at the end of the training blocks (Figure 10).

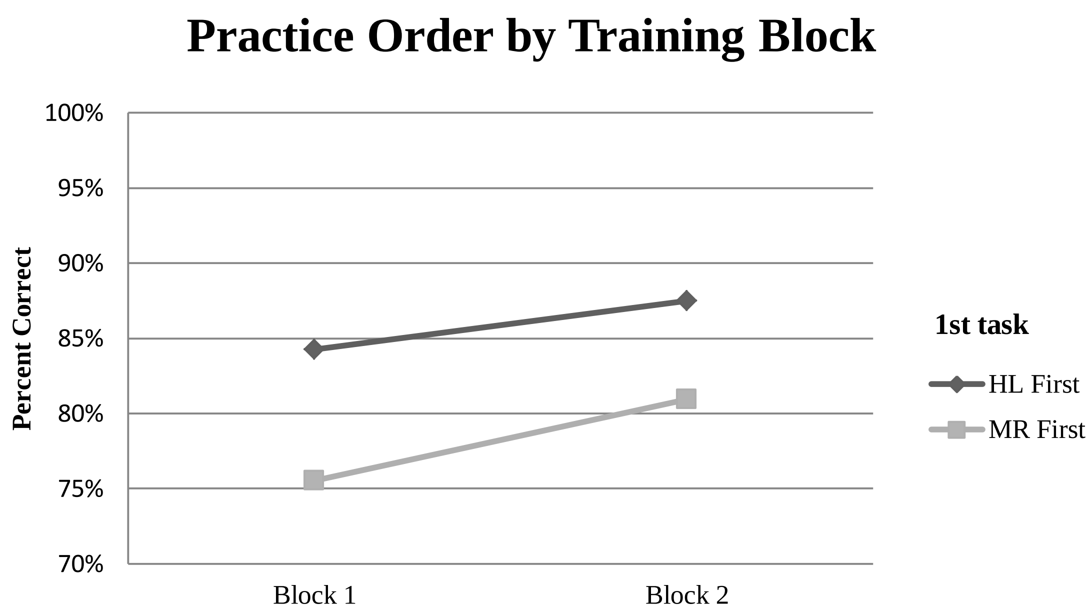

Figure 9. Shows the percent correct as a function of Training order and 2 blocks of practice of participants performance on the HL task. It shows that the two groups improve their accuracy and are statistically equal after block 2.

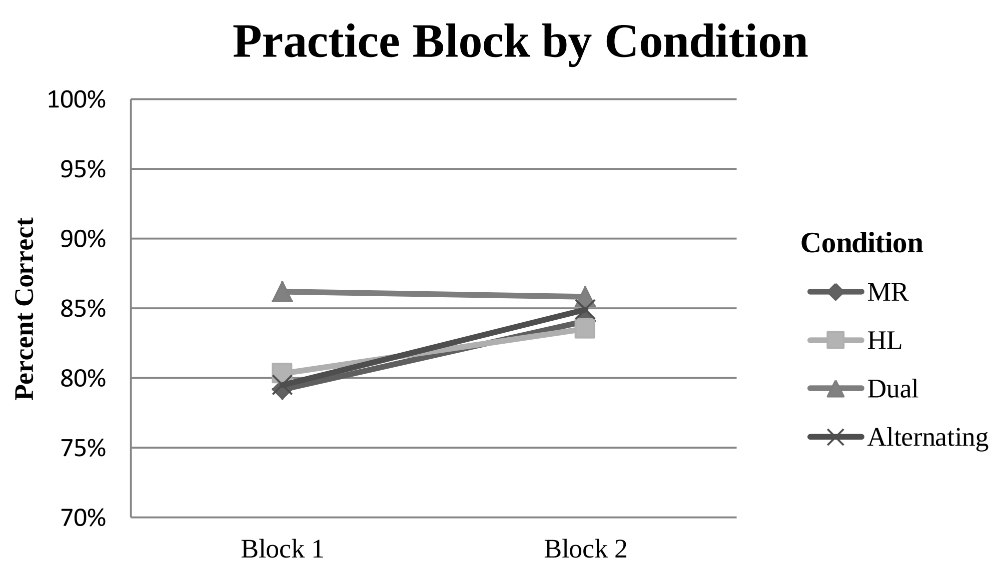

Figure 10. Shows Percent Correct as a function of Test Group Conditions and 2 blocks of practice of participants performance on the HL task. Groups are equivalent after the second block of practice.

Mental Rotation Task (MR) Training. Both RT and PC were analyzed in a two (Blocks) by four (Condition) by two (Training Order) analysis, with blocks as a repeated measures variable. The average RT for the MR training was 1015.64ms for the first block and 837.88ms for the second block. This was a significant Block effect $F(1, 37) = 30.272$, $p < .001$. Participants improved their reaction speed between the two blocks of training. There were no other main effects and no interactions. Therefore, the groups can be considered equivalent on the MR RT at the beginning of the experiment (Figure 11).

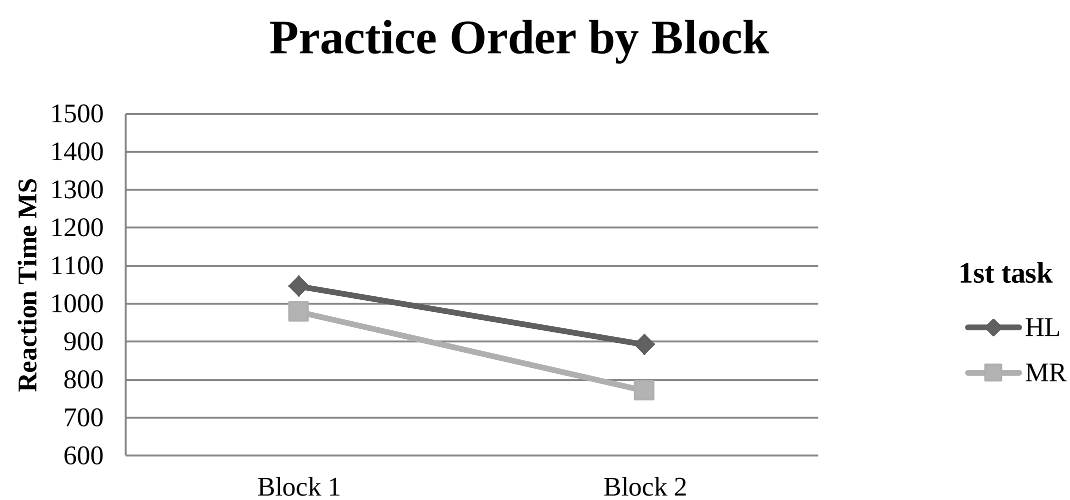

Figure 11. Shows the Reaction Time as a function of Practice Order and 2 blocks of training in participants reaction speed during MR training. participants improved over two blocks yet reamained near each others speed.

Additionally, in an analysis of the reaction times by 6 angles and over the 2 blocks a significant effect for the angle is found $F(5, 165) = 33.23$, $p < .001$, demonstrating the classic mental rotation effect that reaction time increases as the angle of rotation increases (Figure 12). This analysis also found no block by angle effect, $F(5, 165) = 1.452$, $p = .208$. Thus, there was improvement over all angles.

The average PC for the MR training was 88.6% for the first block of training and 94.4% for the second block leading to a significant block effect $F(1, 37) = 10.128$, $p <$

.05. Participants performed more accurately on the second block. There were no effects of training order or condition. The groups can be considered equivalent for the PC at the beginning of the experiment (Figure 13).

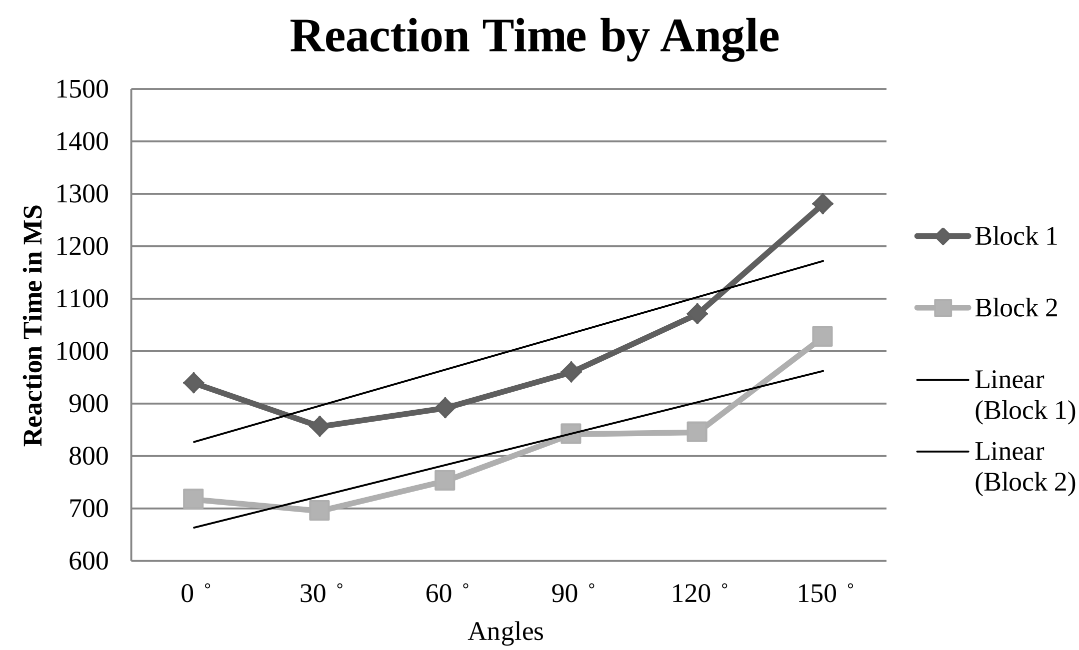

Figure 12. Shows the Reaction Time by Angles as a function of Blocks of practice on participants performance on the MR training task. This is a fairly typical curve for a Mental Rotation Task. It demonstrates that reaction times increase as the angle of rotation increases.

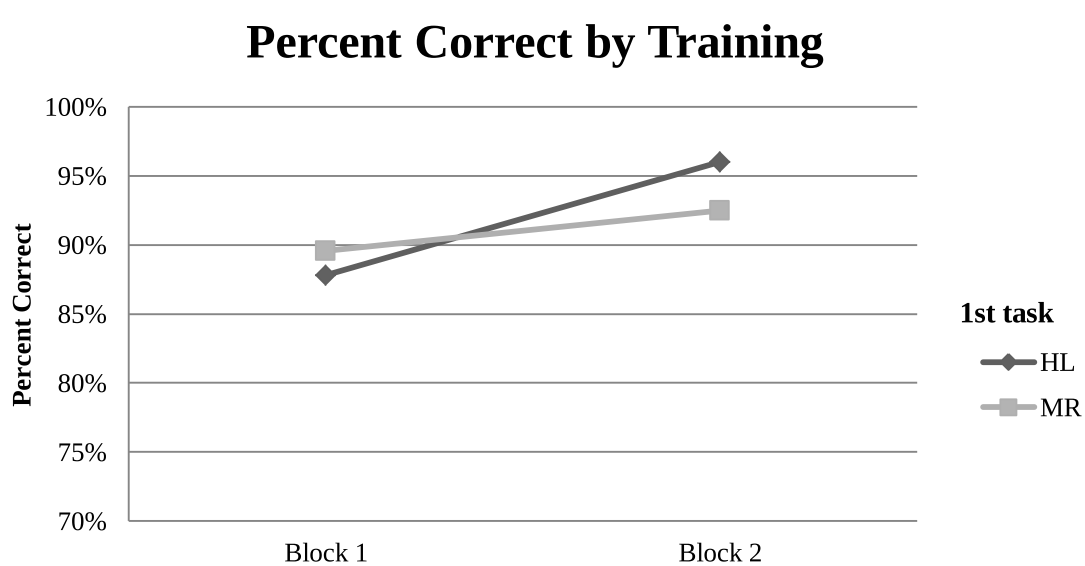

Figure 13. Shows the Percent correct as a function of 2 Blocks of Training and Practice Order on participants performing MR training. Groups remained farily equal throughout and improved over blocks.

Test Trial Analysis

Three characteristics of the test trial analyses should be noted. First, the results for the HL test performance and MR test performance are analyzed separately below. Each set of analyses includes three conditions because the single task controls (HL only and MR only) can only provide measures for one task. The dual and alternating tasks are included in each analysis. Second, practice order is left in these analyses as a factor to account for more of the variance. It was not a significant effect, but it did reduce variability and did not interact with the other factors. Finally, in several analyses a planned comparison was made. This comparison combined the single task condition with the alternating condition to compare against the dual task condition. This was deemed reasonable because both the single and alternating conditions are control groups.

Hyun and Luck Test Trials

Percent Correct. In the current study, a univariate Anova showed no significant differences in HLPC for the three test trials combined as a function of test conditions; Dual-task, Alternating task, or the HL control, $F(2, 28) = 3.014$, $p = .065$, with Dual M = 79%, Alternating M = 88%, and HL M = 83%.

Reaction Time. Even though this experiment failed to replicate the same interference effects on the HL PC measure as Hyun and Luck (2007), this experiment did find clear evidence of interference on the RT measure to color objects during the dual condition. This was the only testing condition where every rotated letter response was measured while participants were simultaneously holding the HL shape in object memory.

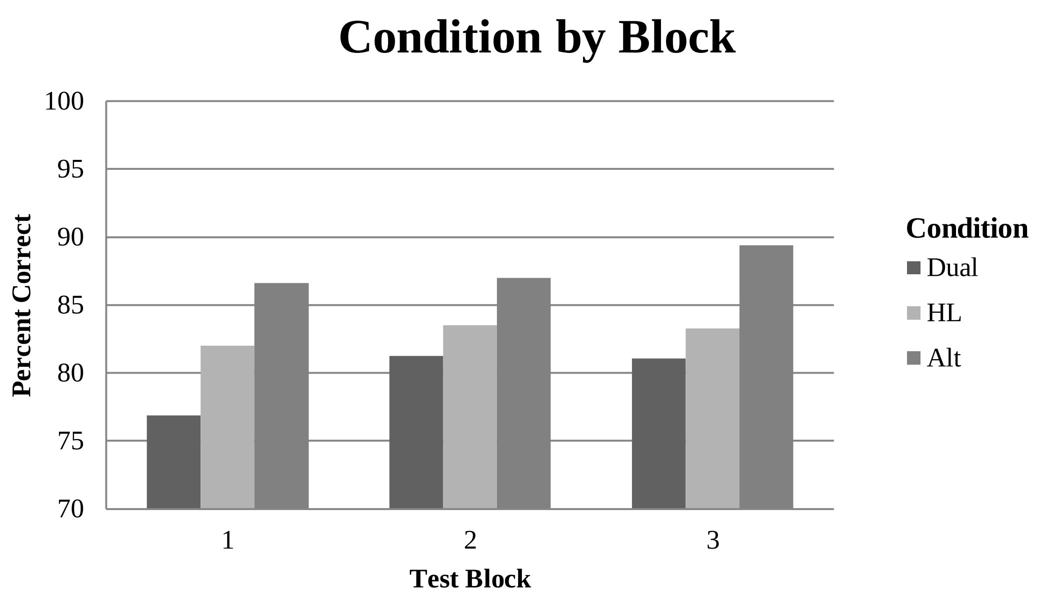

Figure 14. Shows percent correct as a function of three experimental groups for subjects performing the HL test trials over 3 blocks. The difference between the two groups fails to reach significance.

For reaction times on the HL task, Hyun and Luck analyzed only one block of trials. To parallel the Hyun and Luck analysis, in this study we pooled the results of the three blocks of testing and looked at a 3 condition by 2 practice order analysis of variance. This analysis failed to find significant effects $F(2, 27) = 2.48$, $p = .103$. To make a more sensitive test for difference we used a repeated measures Anova with the two comparison (HL alone and alternating) groups combined over 3 trial blocks. This analysis found a significant effect of condition $F(1, 30) = 4.239$, $p < .05$. The participants in the dual condition performed more slowly than the combined comparison group over the 3 trials (Figure 15) which is similar to the effect of condition found by Hyun and Luck.

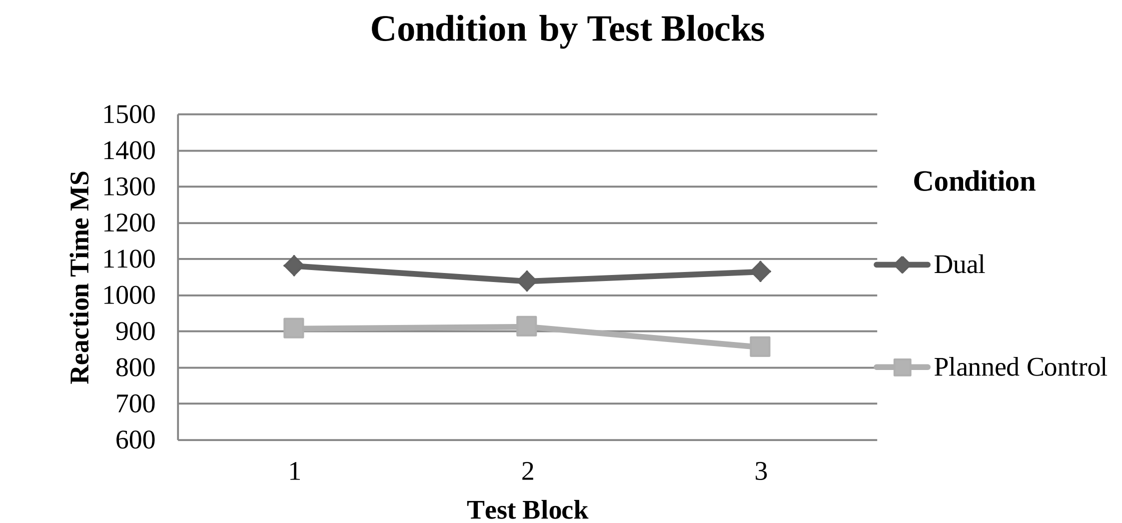

Figure 15. Shows the reaction time as a function of the planned comparison conditions over 3 test blocks for participants performance on the Color Object test trials. Participants in the dual condition performed significantly slower than the planned group.

Mental Rotation Test Trials

Percent Correct. Hyun and Luck found a significant decrease in MR PC as angle of letter rotation increased. This effect was larger in dual than the HL alone task. In the current study, analysis of PC over 2 test blocks in a univariate Anova of condition by practice order, condition was not significant, $F(2, 28) = 1.847$, $p =.176$, (Figure 16). The planned comparison of the dual task vs the combined control was significant in the predicted direction, the combined control groups were more accurate than the dual condition, $t(32) = 1.805$ $p = .04$, 1 tail.

For analysis of angles and blocks, the angles were combined to produce average rotations similar to those used by Hyun and Luck. Their only angles of rotation were 0˚, 72˚, and 144˚. For this analysis 0˚ and 30˚ were combined for the small size angle as were 60˚ and 90˚ for the medium, and 120˚ and 150˚ for the large angle. This resulted in a 3 blocks by 3 conditions by 2 practice order analysis, with blocks and angles as repeated measures. There was a significant block effect $F(2, 56) = 14.258$, $p <.001$ (Figure 16), participants continued to improve over the 3 test blocks. In a 3 angles by 2 practice order by 3 conditions Anova, performance decreased as angle of rotation increased $F(2, 56) = 17.604$, $p = < .001$, (Figure 17), participants continued to rotate the images. There was no effect of condition $F(2, 28) = 1.847$, $p = .176$, or practice order $F(1, 28) = 1.00$, $p = .326$ and no significant interaction.

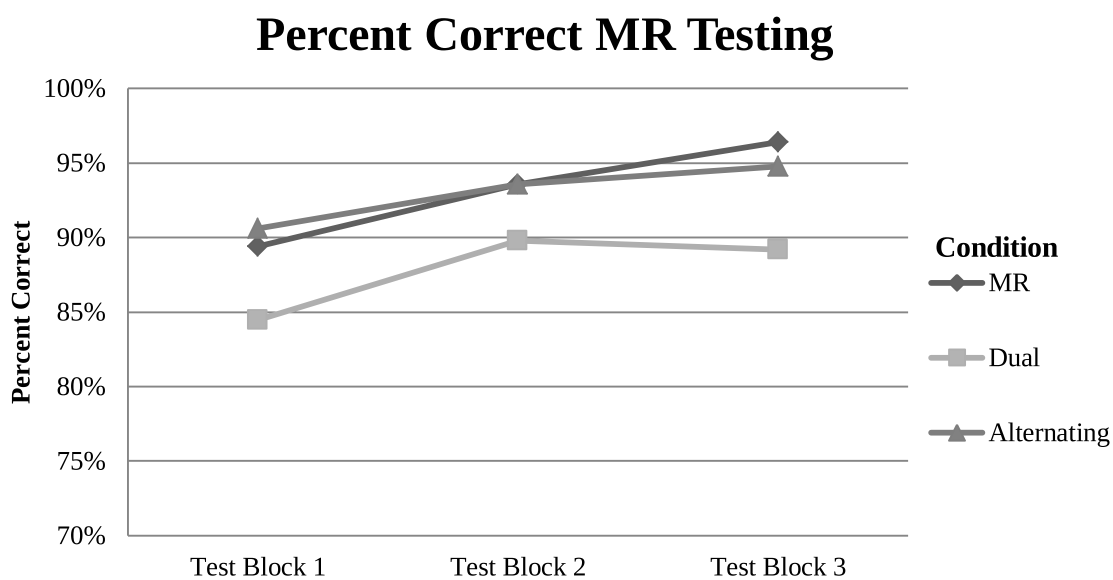

Figure 16. Shows the Percent Correct as a function of Testing groups over three blocks for participants performing the MR test trials. All groups continue to show learning as was seen in the training trials, while the Dual group hints at interference in their performance.

Again the planned comparison of the combined control vs the dual condition was run as an angel (3) by blocks (3) by practice order (2) by condition (2) Anova with repeated measures for blocks and angles. Blocks was significant, $F(2, 60) = 13.484$, $p < .001$, angles was significant $F(2, 60) = 18.241$, $p < .001$, but condition failed to reach significance, $F(1, 30) = 3.496$, $p = .071$. There were no other significant effects and no significant interactions.

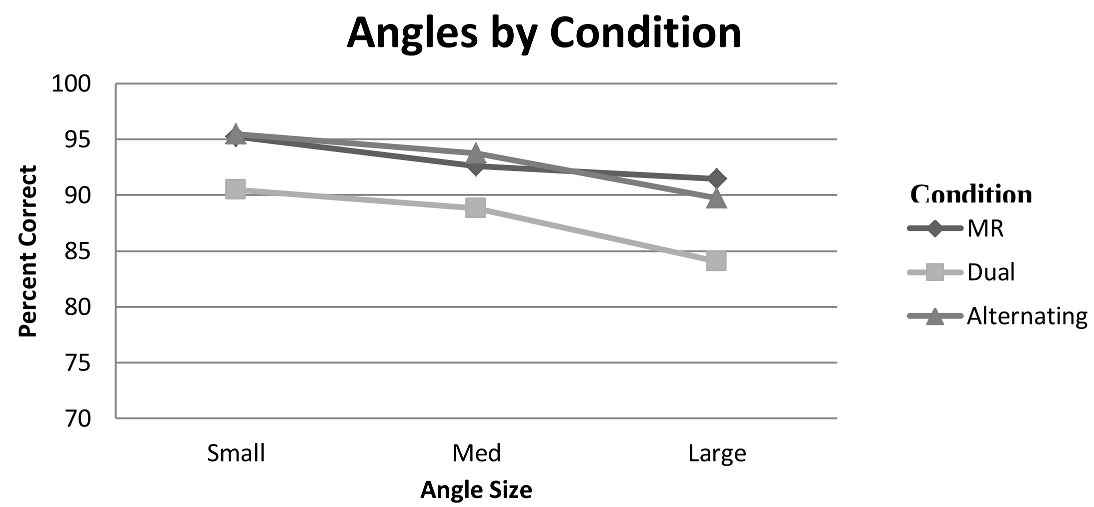

Figure 17. Shows the Percent Correct as a function of the three conditions and the angles divided into Small, Medium, and Large sizes for participants performing the MR test trials. Performance decreases as angle size increases and the Dual group does perform worse than the controls.

Because power was low (.44), individual t-tests between the two conditions (the combined control and the dual-task) on each block were run. There was no significant effect for the first 2 blocks, but there was a suggested difference on block 3, $t(11.458) = 1.973$, $p < .035$, 1 tail, equal variances not assumed. The combined control performance was better than the dual task on test block 3.

A similar set of t-tests were done for each angle size. There was no difference on the small and medium size angles between the combined control and the dual-task, $t(32) = 1.11$, for block 1, and $t(32) = .632$, for block 2. However, on block 3 there was a significant difference, $t(13.268) = 1.766$, $p = .05$, equal error variance not assumed. The combined control had a higher percent correct (M = 96%) compared to the dual-task (M = 90%) and the combined control variance decreased more over the three blocks (SD = 12.19, 9.22, 5.88) than the dual-task variance, which remained relatively large over the three blocks (SD = 12.27, 11.31, 10.22).

Reaction Time. Hyun and Luck found a significant effect of angle and an effect of condition (with a difference of 85ms), but they did not find an interaction between the two. The current study does not replicate these results, it failed to find a significant effect of condition $F(2, 28) = .047$, $p = .955$, (see Figure 18), so there was not a significant difference in the MR rate.

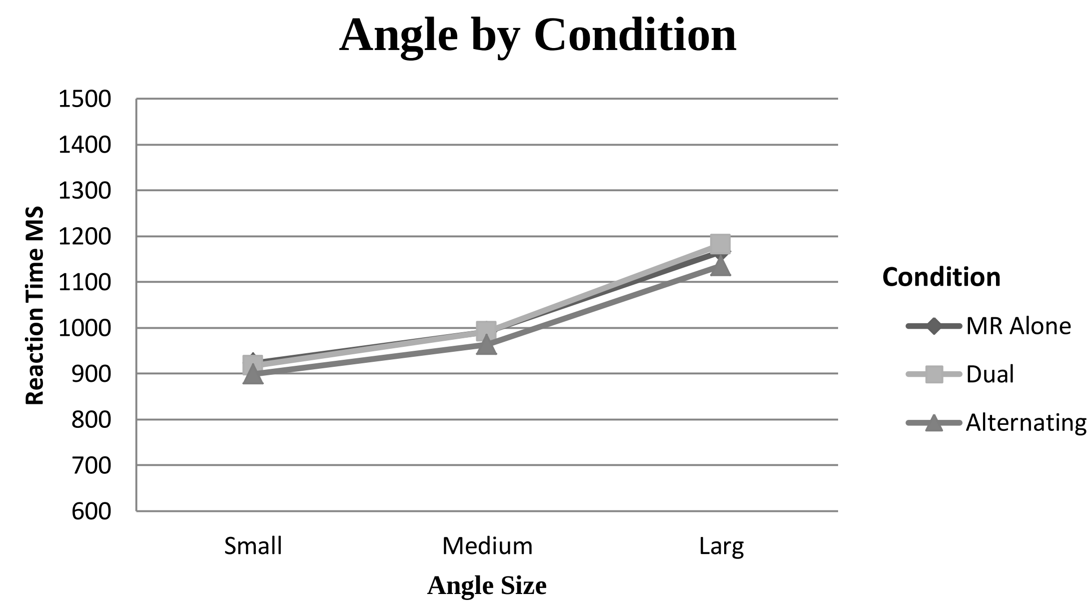

Figure 18. Shows the reaction time as a function of condition over three angle sizes for participants performing the MR test trials.

The current study did find significant main effects for test blocks $F(2, 56) = 6.874$, $p < .01$, and angle size $F(2, 56) = 69.702$, $p < .001$, demonstrating that participants are continuing to show evidence of learning and that they appear to be mentally rotating the figures (Figure 19).

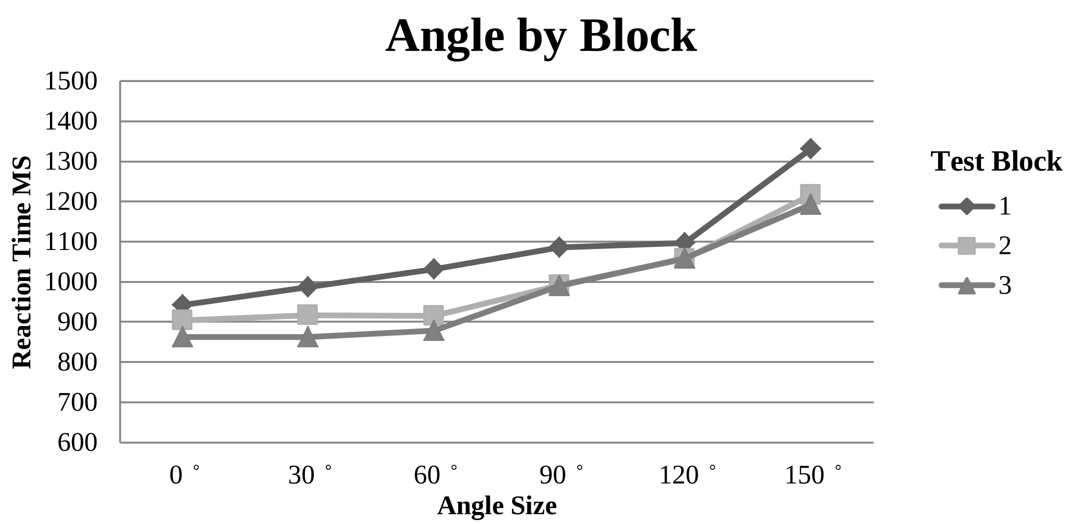

Figure 19. Shows the reaction time per angle as a function of test block for participants performing the MR test trials. There is a main effect for angle size and for testing block but there is not interaction.

Discussion

This experiment was looking at a possible relationship between object working memory load and mental rotation, a relationship that was suggested by Hyun and Luck (2007). They found that object recall task interfered with mental rotation performance and vice versa. Interference was suggested by the decrease in performance for reaction time and accuracy while mentally rotating and accuracy of recalling the objects. The current study departed from Hyun and Luck in several ways. This study included practice for both types of task, it separated the testing conditions, switched to a between subject design, and included an alternating condition. Table 1 provides a comparative summary of the results.

Table 1. Summary of Results.

Task	Dependent Variable	Measure	Hyun and Luck (2007)	2012 Study
Color Objects	PC	By Condition	Significant	Not Significant
		By Angle with Interaction	Significant	NA
	RT	RT Angle	NA	NA
		Overall RT by Condition	NA	Significant
Mental Rotation	PC	By Condition	Significant	Not Significant
		Condition x Angle Interaction	Significant	Not Significant

	RT	By Condition	Significant	Significant t-test

Color object recognition accuracy (PC) was not replicated. This study analyzed the reaction times for this task, which Hyun and Luck did not. These RT data support the interference found between mental rotation and object memory.

Mental rotation accuracy was superior in the combined control conditions relative to the dual task. There was no difference between the MR alone and the Alternating task. This suggests that switching tasks does not impair MR accuracy, but the dual-task, which presumably increases memory load through task difficulty, led to impaired performance, especially at the larger angles. The speed of mental rotation, for correct responses, was not affected by the conditions.

In addition to the performance tests that were done in the original study, this study also looked at learning performance on the tasks. Research on mental rotation (e.g., Bethel-Fox and Shepard, 1988) indicates that there is a significant effect from learning on performance in mental rotation tasks. Finding significant block effects throughout the entire experiment in addition to the replications strengthens the original study's relationship between mental rotation and object working memory.

The present study also looked at the possibility of the dual-task increasing the difficulty of the task but not actually causing interference. In order to remove the interference caused by the dual-task while keeping the difficulty the present study used an alternating condition where the two tasks were completed in sequential order, not just a simultaneously. Theoretically the alternating task should have ended up with similar performances as the control groups and it showed no detrimental effects on performance. This finding supports interference and not just increased difficulty.

The current study often failed to find the same significant differences as the Hyun and Luck study, while showing a suggestive trending of duplication. The small sample size meant that power was often low and smaller effects might not have been detected. In the future it would be feasible to run another study that is identical to the current one but with a larger sample size to possibly find more of the same significant results as Hyun and Luck.

Repeating this study in the future with a larger sample size is only one possible direction to take. It would also be a good idea to switch from rotated letters to a more difficult stimulus which should increase the effect sizes. With that same intent the color objects could be switched to a stimulus that could be more difficult but could also be less ambiguous as to whether it is colors or objects that are causing interference. Future experiments should be conducted to find the other things that cause interference while mentally rotating. Mental rotation is a very complex procedure for human cognition and may involve several different components of working memory.

In summary, this study replicates several of the main findings in the Hyun and Luck study and excludes switching tasks as a reason for the dual task performance deficits. The current study supports the idea that object memory is an important part of mental rotation, and had no findings that would refute the implications of the Hyun and Luck study.

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APPENDIX A

Subject Demographic Questionnaire

Subject Information Sheet Sub Number_______________

CONDITION____________ BL______

Sex: FEMALE or MALE

Handedness: Right Left Amb

Age: ______________

Eyesight: Normal Corrected to Normal

Other:____

Major: ____

Can you tell me something about how you solved the mental rotation task?

Can you tell me about any problems you had doing the task?

IF DUAL / ALTERNATING CONDITION: Did you feel the combined task was …..

More difficult Less Difficult The same ……as the individual practice trials.

Have you ever done mental rotation before yes no

APPENDIX B

Debriefing Sheet

Winter 2012

Practice and Memory Load in a Dual Visual Working Memory Task.

This is a study of basic cognitive abilities. You have just finished seven blocks of trials in tasks designed to test working memory and visual tasks. In order to prevent you from using your verbal memory as well we had you count out loud "1-2-3". By doing this we have studied how you perceive and use visual information in the world around you. We are having students manipulate rotated letters in their mind or hold onto color objects, or a combination of both where letters were viewed between the color objects or after them. You were randomly assigned the (mental rotation, color objects, dual, alternating) condition (experimenter will circle one).

A dual task is where one task is started and then another task is done before the first task can be completed. In this experiment some subjects will start the color object task and have to do a mental rotation trial before they are shown the second half of the color object task. The alternating task meant doing the color object task and mental rotation task but completing both separately.

The rotated letters have been shown to use similar memory pathways as the color objects. For this reason we had some students do just mental rotation trials, just color object trials, or both. If these two things use the same memory, then doing both (a dual task) at the same time should make them worse than doing just one or the other.

We thank you for your time and participation. If you have any other questions you may contact one of the following sponsors of this research:

Joshua Hoelter jhoelter@nmu.edu
Graduate Assistant, Psychology Department, 315 Gries Hall or 227-2935

or

Sheila Burns sburns@nmu.edu
Professor and Research Supervisor, Psychology Department, 330 Gries Hall
227-2246 or 227-2935

If you have other questions or concerns about this or other research at NMU, you may contact the institutional officer for research

Dr. Brian Cherry
Dean of Graduate Studies, Grants and Research and Continuing Education
bcherry@nmu.edu
906-227-2300

THANK YOU FOR YOUR PARTICIPATION

APPENDIX C

Thesis Approval

Memorandum

TO: Joshua Hoelter
Psychology Department

CC: Sheila Burns
Psychology Department

DATE: April 5, 2013

FROM: Brian Cherry, Ph.D.
Assistant Provost/IRB Administrator

SUBJECT: **IRB Proposal HS13-522**
IRB Approval Dates: 4/17/2012-4/17/2013**
Proposed Project Dates: 4/17/2012-8/31/2012
"Practice and Memory Load in a Dual Visual Working Memory Task"

**NOTE: This study was approved on 4/17/12 by an IRB expedited review committee, but was not issued a project number at that time due to an oversight.

The Institutional Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required.

A. You must include the statement "Approved by IRB: Project # HS13-522" on all research materials you distribute, as well as on any correspondence concerning this project.

B. If a subject suffers an injury during research, or if there is an incident of non-compliance with IRB policies and procedures, you must take immediate action to assist the subject and notify the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (bcherry@nmu.edu) within 48 hours. Additionally, you must complete an Unanticipated Problem or Adverse Event Form for Research Involving Human Subjects

C. If you find that modifications of methods or procedures are necessary, you must submit a Project Modification Form for Research Involving Human Subjects before collecting data.

D. **If you do not complete your project within 12 months from the date of your approval notification, you must submit a Project Renewal Form for Research Involving Human Subjects. You may apply for a one-year project renewal up to four times.

All forms can be found at the NMU Grants and Research website: http://www.nmu.edu/grantsandresearch/node/102

ljc