THE ROLE OF SPATIAL CONSISTENCY IN DUAL-TASK DETECTION: IMPLICATIONS FOR AUTOMATIC AND CONTROLLED SEARCH.

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THE ROLE OF SPATIAL CONSISTENCY IN DUAL-TASK DETECTION:

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The goal of this dissertation is to understand what enables successful dual-task performance when one of the component tasks continuously requires attention. Simultaneously performing two tasks is extremely challenging. When first attempting to dual-task, performance tends to be effortful and error prone even when both tasks have been trained extensively in isolation. Although single-task practice is helpful, dual-task practice is necessary in order to learn how to coordinate, integrate and prioritize component tasks. Dual-tasking is cognitively resource intensive and therefore it is critical to automate as much task related processing as possible. When one of the component tasks continuously requires attention, such as a varied-mapped (VM) task, it presents an additional challenge. Schneider and Fisk (1982a) demonstrated that the attention-consuming VM task must be prioritized throughout training in order for the performer to learn to dual-task without cost. Furthermore, they demonstrated that cost-free dual-tasking is only possible when the attention-consuming VM task is paired with an automatic consistently-mapped (CM) task.

Hill and Schneider conducted pilot research demonstrating that participants were unable to prioritize the attention-consuming VM task despite intention and extensive training. The current study is an attempt to understand the source of this failure. Three hypotheses were tested, 1) CM target pop-out enables CM-VM proficient dual-tasking, 2) consistent spatial search across task load enables proficient dual-tasking 3) distractor segregation impedes proficient dual-tasking. Four experiments were conducted in which participants attempted to learn to perform a CM-VM dual-task without cost. All participants were instructed to prioritize the attention-consuming VM task; however some experimental groups incurred greater dual-task interference. The behavioral data suggests that both CM task pop-out and consistent spatial search across task loads enable CM-VM dual-task performance without cost. The result highlights the importance of minimizing confusability and implementing multiple levels of consistency when attempting to train a cognitively intensive high workload skill.

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1.0 INTRODUCTION

The adage goes, "Practice makes perfect!" Practice is necessary for skill acquisition or improvement; however not all practice is beneficial. Only under conditions of sufficient and appropriate practice does skilled behavior manifest itself and advance. Understanding the underlying processes that support skilled performance is essential to the development of effective training (Rogers, Rousseau & Fisk, 1999).

The goal of this dissertation is to understand what enables successful dual-task performance when one of the component tasks continuously requires attention. For the purposes of this work, successful dual-tasking is defined as performing each component task simultaneously with the same level of accuracy as when performing the same tasks in isolation. This can be a very challenging goal. One factor that contributes to success is dual-task practice. Without extensive dual-task practice, people typically suffer a performance cost (in accuracy, reaction time or both) in one or both tasks when attempting simultaneous performance (Detweiler and Lundy,1995; Hill and Schneider, 2006; Schneider and Detweiler, 1988). This cost occurs even when the performer is highly adept at performing the two tasks separately, and can be quite persistent even in the face of concurrent practice. Another factor that contributes to success is establishing task priority, aka task emphasis. The dual-task employed in this dissertation requires the participant to simultaneously perform two tasks; one of the tasks can be automated while the other task requires cognitive control. Successful dual-tasking is contingent on the performer being extensively trained to prioritize the task that requires attention over the automatic task. Schneider and Fisk (1982a) have demonstrated that if the priority is reversed and the automatic task is treated as the primary task, performance on the non-automatic task will be extremely poor despite extensive dual-task practice. Although Schneider and Fisk's participants were able to successfully dual-task as a consequence of practice and task priority, Hill and Schneider were unable to replicate this result (see section "Dissertation Rationale" below and see appendix D) and therefore additional factor(s) may contribute to a successful outcome. The goal of this dissertation is identify factors that enable success— that is, factors that either attenuate or prolong dual-task cost.

1.1 DUAL-TASK TERMINOLOGY

The terms "dual-tasking", "concurrent search/performance" and "timesharing" will be used interchangeably, and these terms specifically refer to simultaneous target search of two component tasks, in this study the component tasks are number- and letter-search. Dual-tasking ability will be evaluated relative to single-task ability (see appendix A). "Dual-task costs", "co-occurrence costs", "dual-task deficits" and "interference" will be used interchangeably to refer to dual-task performance that is less accurate than single-task performance.

1.2 DUAL-TASKING PARADIGMS

Dual-task paradigms have been used traditionally to investigate human attention. There is a substantial body of literature regarding dual-tasking; a sizable portion of this work is devoted to task switching, and psychological refractory period (PRP) paradigms. This thesis will not employ either of these tasks. Instead, a multiple-frame visual search task will be used (Hill and Schneider, 2007; Schneider and Fisk; 1982a; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977). Each of the paradigms mentioned are unique and therefore training principles may not generalize to all tasks. For example, stringent task priority is a source of interference in PRP tasks (Schumacher et al., 2001) where as in a task pairing automatic and controlled search, controlled search task priority is required for concurrent performance without cost (Schneider and Fisk, 1982a). However, understanding the source of dual-task interference in various paradigms informs our understanding of human cognition and can be applied to real-world situations such as dynamic decision making (Gonzalez and Thomas, 2008). Dual-task cost, and the efficacy of efforts to reduce it through practice, is highly relevant to real-world performance. Understanding how best to train humans to multi-task can reduce training costs, increase training gains and potentially increase training safety in the acquisition of high risk skills such as piloting (Rogers, Rousseau & Fisk, 1999).

1.3 DISSERTATION RATIONALE & PILOT STUDIES

Hill and Schneider conducted several studies (see appendix D) with the goal to identify and remediate a minority of participants who are especially poor at learning to dual-task. The ultimate goal was to ascertain the underlying source of the problem preventing skill acquisition[1]. These studies were predicated on the assumption that dual-task practice and prioritizing the task which required attention was sufficient for dual-tasking success. The basis of this assumption was the aforementioned study by Schneider and Fisk (1982a) in which their participants were able to learn to dual-task without cost. In striking contrast to Schneider and Fisk (1982a) none of the Hill and Schneider participants were able to learn to dual-task without cost, despite prioritizing the task that requires attention (see appendix D for task details). Although there were differences between the tasks employed by each study, this widespread failure was unanticipated. Furthermore, Hill and Schneider had previously trained participants to dual-task without cost on a version of their task in which both component tasks were automatic tasks. In other words, participants were able to learn to dual-task successfully as long as neither of the component tasks continuously required attention.

The purpose of this work is to understand what factor or factors contributed to widespread failure in the Hill and Schneider's Visual Multi-Task (VMT) given its similarity to the Schneider and Fisk task (SFT-1982); specifically both tasks were comprised of an automatic- and controlled-search task pair. Failure to replicate the Schneider and Fisk task strongly argues that dual-tasking success must not *only* depend on prioritizing the controlled search task, i.e. the task that requires attention. Four experiments were conducted in order to identify which task-specific features enable or impede dual-task learning (see section 1.7 Experiment Overview and Hypotheses). Experiment 1 replicated the Schneider and Fisk result, the VMT was morphed into a task that was highly similar to the SFT-1982. Experiment 2 took the newly modified VMT and reverted a subset of the modifications with the goal of reintroducing training failure.

[1] Schneider and Detweiler (1988) refer to this phenomenon as a failure to let go of controlled processing.

Experiments 3 and 4 tested the hypothesized source of failure by training participants on two other variants of the VMT.

The remainder of this chapter reviews the following topics: 1) dual processing theory, 2) research that pertains to the role of automaticity in concurrent performance and 3) the differences between the VMT and Schneider and Fisk (1982a) tasks. Finally, an overview of the dissertation hypotheses are provided.

1.4 DUAL PROCESSING MODELS OF ATTENTION

One approach to understanding dual-task performance decline is to focus on the qualitative differences in attention that tend to occur with the development of skills in general. Dual processing theories propose that there are two qualitative states underlying cognitive and motor behavior: controlled processing and automatic processing. These states have different but complementary characteristics. Controlled processing is capacity limited, effortful, slow, serial and under conscious awareness and volition (i.e., it is highly modifiable). Automatic processing, on the other hand, is not strictly capacity limited, it is effortless, fast, parallel, and only indirectly (and with some difficulty) under conscious control.

Controlled processing is the default state for the execution of most tasks from discerning instructions to attempting to perform the task at hand. For example, consider learning to drive a car. The learning of a new skill such as driving is effortful and error prone, particularly in the face of distraction; responsiveness is slow (e.g., in transition from accelerating to braking); and the driver is conscious of executing all the necessary steps. All of these are hallmarks of controlled processing. With sufficient practice, automaticity develops; the driver experiences a marked decrease in effort and is no longer consciously rehearsing how to control the car; performance becomes robust to distractions such as music; and errors decline. Not all processing is automated; control processing is engaged in responding to unexpected events, such as hydroplaning, and in novel circumstances such as driving an unfamiliar route.

Consistent practice is necessary to produce a shift from the default state of controlled processing to the developed state of automatic processing. Schneider and colleagues (Schneider and Fisk, 1982b; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) have studied this phenomenon by focusing on task consistency in terms of stimulus-response mapping (S-R) in visual search tasks. A task is operationally defined as *consistently-mapped* (CM) if the presence of a stimulus always evokes the same response (e.g., “press the button when ‘X’ appears”). Conversely a task is *varied-mapped* (VM) if the presence of a stimulus evokes difference responses throughout the task (e.g., in trial one “do not respond to ‘Y,’” and in trial two, “press the button when ‘Y’ appears”). Novel tasks and tasks which employ varied-mapping are controlled processed and therefore under attentive control. Tasks which are consistently-mapped and sufficiently practiced are automatically processed and therefore do not require attention. Although these definitions suggest an all-or-none phenomenon, automaticity has been regarded as a continuum (Cohen, Servan-Schreiber, McClelland, 1992; Kahneman and Treisman, 1984; Logan and Knapp, 1991; MacLeod and Dunbar, 1988) and in practice a task is more likely to be composed of a mixture of processes rather than purely automatic or controlled (Schneider, Dumas and Shiffrin, 1984); however discrete states have been proposed and may depend on the type of skill (LaBerge, 1975; Posner & Snyder, 1975). The continuum and mixture view both apply to the current work in the sense that the amount of practice impacts the degree of automaticity, and complex tasks such as dual-tasks are certainly composed of both types of processes.

1.5 CONSISTENCY & LOAD EFFECTS

The development of automatic processing is necessary in order to dual-task without cost because attention is a capacity limited resource. In addition to being engaged in varied-mapped tasks or untrained single-tasks, controlled processing is also involved in dual-task coordination and integration (Schneider and Detweiler, 1988). This is evidenced by the initial co-occurrence cost that occurs even when two *automated* CM tasks are timeshared (Schneider, 1985; Hill & Schneider, 2006, Hill & Schneider, 2007; Detweiler and Lundy,1995). CM/CM dual-tasks and CM/VM dual-tasks both require practice to attenuate co-occurrence cost; however the inclusion of a VM task presents an additional challenge due to overloading controlled processing.   The following studies (Logan, 1979; Schneider & Fisk, 1982a; 1982b) involved training participants to timeshare a VM task.

1.5.1 Logan (1979)

A study by Logan (1979) demonstrated that dual-task ability is limited to one attention-demanding task. The study participants were trained on two tasks, (1) a short-term memory (STM) task involving the recall of 8 digits in order and (2) a stimulus-response mapping (S-R) letter task in which participants had to make a specific button press paired with a *single presented letter*. Depending on the trial, participants were required to learn 2, 4 or 8 stimulus-to-button response mappings; the stimuli were letters. The S-R task was trained alone as well as embedded in the STM task such that a) 8 to be remembered digits would appear followed by b) one S-R letter requiring the appropriate button response and c) the recall period for the digit task.

Reaction time (RT) on the S-R task was greater both as the number of mappings increased from 2 to 4 to 8 letters and when the load increased (i.e., when the S-R task was embedded in the STM task); furthermore these factors interacted, producing disproportionately slow RTs for the 8 S-R conditions when it was embedded in the STM task. With practice there was a reduction in the slope of the best fitting line connecting the RTs of the different S-R mappings. This indicates that with practice the additional time required to respond in the 8 vs. 4 vs. 2 letter condition is minimized, indicating the development of parallel processing - a hallmark of automaticity (Logan, 1978; Sternberg, 1966; Schneider and Shiffrin, 1977; Shiffrin, 1988; Shiffrin and Schneider, 1977). In addition, reaction time decreased over six days of practice both when the S-R task was performed alone and also when it was embedded in the STM task. Additionally, toward the end of training, the interaction between mapping and memory load dissolved. Importantly, on the seventh day of training when new response mappings were assigned to the letter producing a varied-mapping situation, reaction time increased and the interaction between mapping and load reemerged. Task performance resembled the first day of training. The first experiment demonstrated the importance of CM practice on dual-tasking ability. Consistent-mapping allowed the development of automaticity in the S-R letter task as RT became insensitive to the memory set size. And consistent dual-task practice reduced the interaction between mapping and load; consistency was critical because practice alone did not prevent the interaction from reemerging when mapping was varied.

In a follow-up experiment participants performed the S-R and STM tasks over seven days, the same as before, except the S-R letter task was varied-mapped throughout testing. Again there was an interaction between number of mappings and load; however, this time the interaction did not diminish with practice. The second experiment further supports the necessity of consistent practice in the development of automaticity.

1.5.2 Schneider & Fisk (1982b)

Perfect consistency is not required for automaticity to develop. In a study by Schneider and Fisk (1982b) participants were trained on a visual search task in which consistency was varied across targets. There were five conditions, 10:0, 10:5, 10:10, 10:20 and 9:61, where the first number indicated the number of times a letter appeared as a target and the second number indicated the number of times a letter appeared as a distractor in a block of testing. For example 10:0 was the most consistent condition because the target letter appeared ten times as a target and never as a distractor where as 9:61 was the most varied condition because the target letters appeared nine times as a target and 61 times as a distractor. They defined 10:0, 10:5, 10:10 and 10:20 as "CM"[2] conditions where as 9:61 was defined as the VM condition. After extensive training, 840 trials for each target, they found that the most consistent conditions improved the most with practice (Experiment 1).

They conducted a follow-up experiment to determine the effect of prior graded consistency (i.e., 10:0 – 10:20 "CM" conditions) on dual-task ability. The targets from each of the "CM" conditions in Experiment 1 became fully consistently-mapped, that is throughout the

[2] Only the 10:0 condition would be considered a true CM condition since targets never occur as distractors. Each of the CM conditions had one letter that served as a target where as the VM condition had five letters that served as targets.

course of the experiment all previously partially consistent targets were now changed to an 8:0 target-to-distractor ratio per block; therefore the targets never appeared as distractors. The previous 9:61 condition remained varied-mapped; however, the target-to-distractor ratio for its five target letters changed to an average of 5.6 target presentations to 32.6 distractor presentations per block. There were 4 task conditions, single-task CM, single-task VM (searching for one target per trial), single-VM (searching for two targets per trial) and CM/VM dual-task. When performing the dual-task condition, the participants where instructed to prioritize the VM task which means that they were required to treat VM detection as a primary task and CM detection as a secondary task. In other words, when dual-tasking they were instructed to focus on the VM task in order to maintain the same level of accuracy as when performing the VM single-task at the expense of CM task accuracy.[3] Schneider and Fisk found that previous training consistency (Experiment 1) had an effect on CM single-task detection (there was a 15% drop in detection from the 10:0 to 10:20 condition) and CM dual-task detection (there was a 30% drop in detection from the 10:0 to 10:20 condition) even though none of the CM targets appeared as distractors during Experiment 2 testing. Participants were complying with the VM priority instructions because the difference between single-task VM detection and dual-task VM detection was not statistically significant. Furthermore, CM dual-task performance improved by 39% with practice. This improvement is not the result of allocating attention to the CM task because single-task VM detection dropped by 25% on trials with two VM targets. This indicates that the VM task was resource limited; in other words, processing the VM task (with a single VM target) did not leave sufficient attentive resources to allocate to a secondary task and therefore CM dual-task improvement reflects automaticity. Consistent with

[3] Prioritizing the VM task in a CM/VM dual-task is necessary for dual-tasking without cost. For more details see the next section. "Schneider and Fisk (1982a)".

the result of Experiment 1, the more consistent the training the more improved the performance when dual-tasking.

The work of Logan (1979) and Schneider and Fisk (1982b) demonstrated the importance of consistent mapping both for automating single-tasks and reducing cost associated with dual-tasking. In the case of Logan, practice did not eliminate the effect of load; that is throughout training the S-R letter task was performed slower when it was embedded in the STM task. However, practice reduced the interactive effect of increasing mapping and load. Schneider and Fisk (1982b) demonstrated that practice reduced the cost associated with dual-tasking but they did not demonstrate that they could eliminate it. In their 1982a study they demonstrated that practice can produce cost-free dual-tasking when one of the tasks is attention-demanding (i.e., VM).

1.5.3 Schneider & Fisk (1982a)

Schneider and Fisk (1982a) trained participants to dual-task without cost which is in stark contrast with performance on the Visual Multi-Task (VMT, see appendix D). Their task required participants to search for number and letter targets in a rapid 12 frame trial (a frame consisted of a probe display and a blank). The task could be performed in three speeds, probe stimuli would appear for 50, 130 or 200 ms followed by a 50 ms interstimulus interval (ISI). VM items were used as target and distractors; CM items only appeared as targets. There were three conditions - single-CM, single-VM and CM/VM dual-task; mapping was crossed with search type counterbalancing the design across subjects. Stimuli appeared in four search locations. Participants were required to press one of four buttons indicating the location of the singly presented target. There were seven letters and numbers which served as CM/VM targets (i.e., the memory set). During single-task trials, participants searched for one target which was indicated by the instruction screen. During dual-task trials, the instruction screen displayed the current VM target and two periods. The periods indicated that any of the CM targets could appear; participants were given 30 seconds to memorize the memory set before each trial. On all trials including dual-task trials only one target could appear. The type of search and task emphasis was manipulated over several experiments. In Experiment 1 CM and VM targets could appear in any location and participants were instructed to prioritize the VM task. In Experiments 2a, 2b, 2c and 3 there were separate VM and CM target diagonals; participants were instructed to prioritize the VM diagonal in Experiment 2a, 2c, and 3 and prioritize the CM diagonal in 2b. In Experiment 4 participants timeshared a VM/VM dual-task.

Schneider and Fisk concluded that prioritizing the VM task was necessary to produce cost-free dual-tasking in a CM/VM dual-task. In Experiment 1 when targets could appear in any location and the VM task was emphasized, the CM task operated at a 1% deficit and the VM task operated at a 3% deficit relative to single-task detection rate; these differences where not significant. When the CM task was prioritized in Experiment 2b and CM/VM targets appeared on separate diagonals, the CM task was operating without a deficit (exactly 0%) while the VM task was operating at a 52% deficit; furthermore, three out of four participants were operating at chance level. In Experiments 2a and 2c[4] when VM priority was reestablished[5], the CM task was operating at a significant deficit, 14% and 17% respectively. Schneider and Fisk concluded that the drop in CM detection that accompanied restricting targets to mapping specific diagonals was the result of a criterion shift, A' analysis revealed no difference in single- and dual-task

[4] These experiments had different target probabilities and 2c included to-be-ignored CM targets on half of the VM single-task trials.
[5] The same participants performed in Experiments 1, 2a, 2b, 2c & 3.

sensitivity (Experiment 3). In Experiment 4, when two VM tasks were timeshared, dual-task performance was quite poor. VM/VM accuracy was 66% in the single-task condition, 44% in the dual-task condition and 30% in the dual-task condition when one of the tasks had two targets. Participants shifted emphasis between the two VM tasks. Although there was a drop in accuracy in the emphasized condition (from 64% to 57%) the un-emphasized task had a severe drop in detection (13% for the one target condition and 4% for the two target condition). There was also a substantial drop in sensitivity when performing the dual-task.

1.6 THE VISUAL MULTI-TASK & THE SCHNEIDER AND FISK (1982A) TASK

Pilot data collected on the Visual Multi-Task (VMT) suggest that VM task priority is not sufficient for cost-free dual-tasking. Hill and Schneider extensively trained participants on the VMT, a rapid paced multiple-frame search task that is similar to the Schneider and Fisk task. Despite the instruction to prioritize the VM task in a VM-CM dual-task pair, VM target detection did not improve with practice and for some participants VM detection declined with practice, see appendix D. The Schneider and Fisk (1982a) study has not been replicated, and in light of the different outcome of these recent experiments one conclusion is that differences between the two tasks may determine dual-task proficiency. There were several differences (see the Methods section for a complete list) between the tasks and training methods; two differences, the distractor set and search locations were predicted to be critical for learning. The Schneider and Fisk study used only VM items as distractors while the Hill and Schneider study used CM and VM items as distractors for the CM and VM task, respectively. Additionally, the Schneider and Fisk study allowed CM and VM targets to appear in any of the search locations which will be referred to as *free search*. Since the Hill and Schneider study used separate CM and VM distractors that were constrained to mapping-specific locations, CM targets could only appear in CM locations and VM targets could only appear in VM locations which will be referred to as *restricted search*. Schneider and Fisk implemented restricted search with VM target priority (Experiments 2a, 2c and 3); although participants produced a deficit ranging from 14-17%, this dip was attributed to a criterion shift as there was no difference in CM sensitivity when dual-tasking (Experiment 3). However it is important to note that Schneider and Fisk trained participants on free search first; that is, the same participants performed in Experiments 1, 2a, 2b, 2c and 3, and therefore order effects may be contributing to equivalent CM sensitivity across task load.

Using only VM items as distractors may also benefit learning by producing a *pop-out effect* for CM targets. For example, if the VM task is letter search then any number that appeared in the display would be a target; this is not the case in the VMT in which number targets would have to be discriminated from number distractors. Searching for CM-number targets when all the distractors were VM-letters may result in automatic or more readily automated detection of the CM number targets.

Searching all locations may also aid single-task to dual-task transfer due to the fact that there is a *consistent spatial context*. For example, when CM and VM items are constrained to separate, specific locations as in the Hill and Schneider task, only half of the locations are searched at any given time in the single-task condition (i.e., search only the number locations during the number single-task trials and similarly search only the letter locations during letter single-task trials); however, once dual-task training commences now all locations, both number and letter must be searched simultaneously. Single-task search may entail learning to allocate attention to specific locations and learning to ignore stimuli in non-relevant locations; this learning may result in automated location search. This single-task location-specific learning may hinder performance in the dual-task condition since formerly non-relevant locations are now part of the relevant search space. Schneider and Fisk participants first learned to search all locations which may have enabled them to maintain sensitivity when search was restricted to mapping specific diagonals[6].

Another factor contributing to dual-task deficit is distractor segregation that is, assigning the CM and VM distractors to separate diagonals. According to the CAP model of automaticity (Schneider, 1999; Schneider and Chein, 2003) *trained* CM and VM items have different *priority*, that is, probabilities of attracting attention[7]. A stimulus with high priority is likely to automatically trigger attention without the aid of controlled processing. An example of a high priority stimulus is a person's name; one's name can often be distinguished in a noisy atmosphere (i.e. the Cocktail Party effect, Moray, 1959). Priority is determined by consistency and practice. Novel stimuli have moderate priority; priority can increase or decrease with training. If a stimulus is consistently trained as a target its priority will increase and may eventually automatically attract attention (e.g. try not to be aware of someone calling your name). If a stimulus is consistently trained as a distractor (e.g. something to be ignored) its priority will decrease. If a stimulus is varied-mapped its priority will minutely fluctuate around a moderate priority score depending on whether it is a target or distractor; if a VM item is subsequently trained as a CM target its priority will slowly increase.

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[6] Previous consistency can affect subsequent learning (Schneider and Fisk, 1982b).

[7] Priority in this sense is distinguishable from task emphasis in which a person can focus on or prioritize one task over another task (Schneider and Fisk, 1982a). Prioritizing a task is akin to endogenous control in which the object of attention is cued by instruction. A stimulus' priority or its likelihood of attraction attention without intention is akin to exogenous control in which the stimulus itself attracts attention (e.g. a flashing light or siren).

By separating CM and VM distractors, stimuli with moderate and low priority are assigned to different diagonals. It is possible that inhomogeneity in distractor priority can contribute to dual-task interference. Acquiring the ability to dual-task involves learning how to coordinate tasks and learning to prioritize the various stimuli (Schneider and Detweiler, 1988) and therefore distractor processing may also play a role in skill development. This may be particularly true in high workload tasks such as the VMT in which 600 stimuli must be processed during a 'slow' trial and 800 stimuli must be processed in a 'fast' trial. If distractor processing contributes to dual-task interference then using only VM items as distractors or allowing CM and VM distractors to appear in the same locations would produce a homogenous landscape with regard to stimulus priority and should reduce interference.

Finally, another important difference between the tasks is the number of search locations. The VMT had twice as many search locations (four CM and four VM) as the Schneider and Fisk task that had four total locations. Doubling the search location increased task difficulty particularly for VM search. In the modified VMT the number of search locations will be reduced to four. By reducing the search locations, VM priority may be possible in all of the proposed experiments, resulting in post-training deficits only in the CM task. In the original VMT both the CM and VM task maintained post-training deficits.

To reiterate, successful dual-task learning in the Schneider and Fisk (1982a) task may be attributable to[8] 1) CM target pop-out against the VM distractor set, 2) automated location-based search due to consistent spatial context across the single- and dual-task conditions aka free search or 3) *not* segregating distractors according to mapping, thereby homogenizing stimulus priority across location. This leads to the following general predictions: 1) Post-training deficit scores should be less when *targets can appear in any location* than when CM and VM targets are

[8] Reducing the number of search locations is assumed to reduce dual-task cost but this will not be explicitly tested.

constrained to specific diagonals. 2) Post-training deficit scores should be less when there is a common spatially integrated distractor set, that is, a distractor set comprised of either VM-only distractors or one that is comprised of a mixture of VM and CM distractors. Learning should be impaired when separate CM and VM distractors are assigned to specific locations.

1.7 EXPERIMENT OVERVIEW AND HYPOTHESES

This dissertation aims to replicate Schneider and Fisk (1982a, Experiment 1) and to extend their work with new experiments (see Figure. 1) that identify which factors facilitate or impede CM-VM dual-tasking ability. The goal of Experiment 1 is to replicate the Schneider and Fisk result, in which cost-free dual-tasking was achieved, by adding free search and VM only distractors to the VMT. The goal of Experiment 2 is to replicate the failure that was experienced in the original VMT task by reinstating restricted search through separate VM & CM distractors in the modified VMT. The goal of Experiment 3 is to determine the effect of CM target pop-out on dual-task deficit scores by contrasting performance to Experiment 1. The task employed free search using a distractor set that is a mixture of CM and VM. The mixture distractor set precludes CM target pop-out that is possible (in Experiment 1) as the result of utilizing a VM-only distractor set. The goal of Experiment 4 is to determine the effect of distractor segregation; the task employed free search with separate distractor diagonals; that is, despite the fact that CM distractors and VM distractors will be on separate diagonals all targets can appear in all locations. In addition to Experiment 4, Experiment 2 also segregates distractors based on mapping (consistent vs. varied) while Experiments 1and 3 do not. Finally contrasting Experiments 1, 3 and 4 to Experiment 2 will determine the effect of consistent spatial search.

Experiment 2 is the only experiment that employed restricted search and as a result only half of the search locations are relevant during single-task trials while all locations are relevant during dual-task trials.

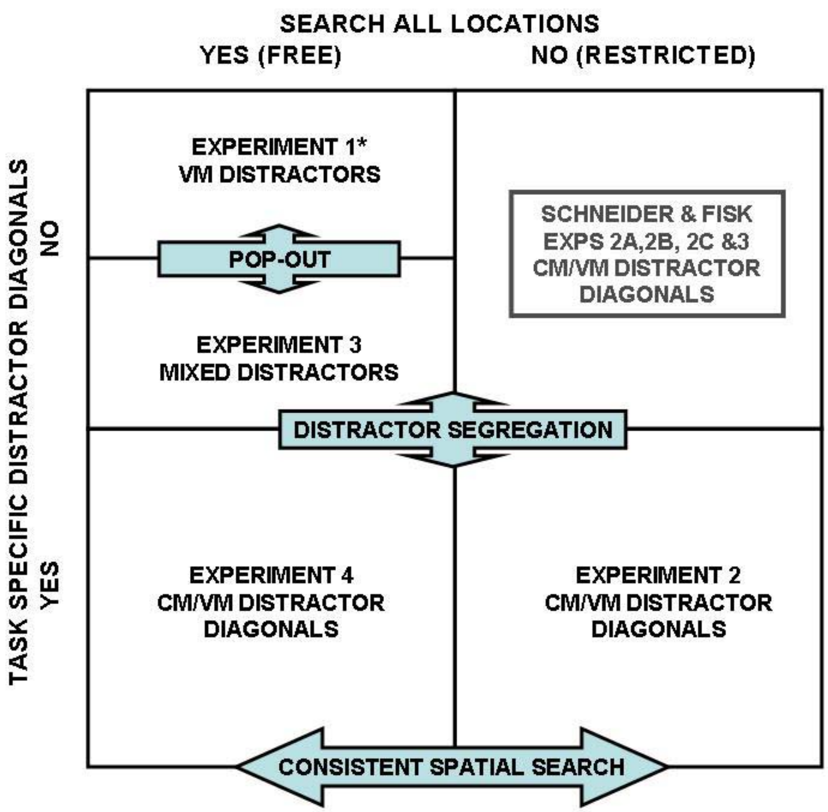


Figure 1. Experimental factors[9]

[9] Experiment 1 is a replication of Schneider and Fisk (1982a Experiment 1).

Different participants will be used in each experiment to eliminate the confound of previous training that was introduced by Schneider and Fisk (1982a). Three hypothesized sources of persistent dual-task deficits are listed below:

1. Exclusive Pop-out (PO) Hypothesis. If cost-free detection is *exclusively* dependent on pop-out then participants should learn Experiment 1 with minimal deficits post-training and all other experimental participants should exhibit comparable, severe post-training deficits.
2. Exclusive Distractor Segregation (DS) Hypothesis. If cost-free detection is *exclusively* dependent on distractor segregation than Experiments 1 and 3 should have minimal post-training deficits while experiment 3 and 4 should have severe deficits.
3. Exclusive Spatial Consistency (SC) Hypothesis. If cost-free detection is *exclusively* dependent on spatial consistency across task load than Experiments 1, 3 and 4 should have minimal post-training deficits while Experiment 2 should have severe deficits.

All or some subset of these factors may contribute to persistent dual-task deficits (see Table 1); however, two factors are considered more likely to contribute to dual-task success-- CM target pop-out out and spatial consistency. Low confusability between targets and distractors can eliminate load effects (Shiffrin, 1988). Therefore it is reasonable to assume that using a VM-only distractor set is beneficial for CM target pop-out. Additionally, practiced consistent relationships lead to automatic processing, theoretically automaticity is not restricted to stimulus-response mappings (Logan, 1988; Schneider, Dumas and Shiffrin, 1984). Therefore the following is hypothesized to be the source of dual-task deficit in the VMT pilot studies:

4. Pop-out and Spatial Consistency Hypothesis. If pop-out and spatial consistency *both* contribute to cost-free detection then Experiment 1 participants should have minimal post-training deficits while Experiment 3 and 4 participants should have moderate post-training deficits and Experiment 2 participants should have severe post-training deficits.

1.7.1 Experiment 4 partial-CM/VM pop-out

Experiment 4 will employ free search with mapping-specific distractor diagonals. As a consequence of this design, *potentially* CM targets can pop-out when they appear on the VM diagonal and *potentially* VM targets can pop-out when they appear on the CM diagonal. Given the quick pace of the task, the participants may not be able to capitalize on CM pop-out; furthermore they are even less likely to capitalize on VM pop-out. In order to determine if the participants are benefiting from partial-CM/VM pop-out their single-task session one detection scores will be compared to Experiment 3 participants. Experiment 3 also employs free search; however, due to the mixed distractor set, pop-out of any kind is not possible. Therefore if Experiment 4 participants have higher CM or VM detection rates, it would suggest that they are utilizing pop-out to aid target search. If pop-out is being utilized, this must be taken into account when interpreting the overall pattern of deficit scores across experiments. In Table 1, the hypotheses are associated with different predictions when pop-out is assumed to play a role in performance, see column “Exp 4 (PO)”, and when it is not, see column “Exp 4”.

Table 1. Hypotheses and Predicted Dual-Task Deficit Scores

	Exp 1	Exp 2	Exp 3	Exp 4	Exp 4 (PO)
PO	minimal	severe	severe	severe	min
DS	minimal	severe	minimal	severe	severe
CS	minimal	severe	minimal	minimal	minimal
PO & DS	minimal	severe	moderate	severe	moderate
PO & CS	minimal	severe	moderate	moderate	minimal
DS & CS	minimal	severe	minimal	moderate	moderate
All	minimal	severe	moderate	mod-sev	moderate

2.0 GENERAL METHODS

2.1 PARTICIPANTS

The participants were recruited from the http://brain.pitt.edu web site, which requires an affiliation with any university or educational institution that provides e-mail addresses ending in '.edu'. Participants ranged in age from 18 to 35, and were screened for epilepsy because the task required viewing rapid flickering images. Participants were also screened for action/adventure video game experience; participants that did not play video games were given preference. Participants that had played infrequently (25 hours or less) in the six months prior to testing were eligible to participate as long as they were not currently playing and they did not evaluate their ability as “good” or “expert.”

2.2 PROCEDURE

The majority of participants tested twice a day for three consecutive days. Some participants were not available to test every day twice a day and therefore were scheduled for a combination of once and twice a day. Each session lasted one hour; the sessions were scheduled to include a break that was a minimum of one hour between the first and second session of the day. For all four experiments, the first session consisted entirely of single-task training, while the remaining sessions included both single- and dual-task training.

2.2.1 The Visual Multi-Task (VMT)

The modified version of the VMT task incorporated many of the features of the Schneider and Fisk (1982a) search task. The goal was to replicate dual-task learning in the VMT task by including all features that potentially contribute to effective learning. The details will be elaborated below.

The task involved searching for number or letter targets in four locations continuously over the duration of a thirty-second trial (see appendix C). Each trial contained either eight or ten targets; the participant was not informed of the number of target presentations. Targets appeared randomly, but were spaced apart by a minimum of 2000 ms, to preclude any psychological refractory period effects (that is, potential executive capacity limitations to respond to two tasks in close succession). Responses were only counted if made between 200 and 1000 ms after the presentation of the target; responses faster than 200 ms were coded as false alarms, and responses after 1000 ms were coded as both false alarms and misses. Constraining the response window was necessary due to the rapid nature of the task and the high processing load: there are 600 stimuli in a “slow” trial, and 800 in a “fast” trial. Responses were made with a left-handed response glove, the middle finger was used for responses to number targets, and the index finger was used for letter targets. During dual-task trials, responding to a target with the wrong task key was coded as a false alarm.

The task was composed of alternating stimuli and blank interstimulus intervals. Each stimulus display had four search locations arranged in a square around a center fixation. The text stimuli were displayed in black, 24 point bold Times New Roman font on a gray background (RGB: 192,192,192). The task was performed at two speeds. At both speeds, the probe (stimulus display) was presented for 50 ms, while the fixation was presented for 150 ms during the slower speed and 100 ms during the faster speed. One task, either the number or the letter search, was variably-mapped while the other task was consistently-mapped; this was counterbalanced across subjects. Each consistent-mapped (CM) trial required the participant to search for two targets (letter task targets ‘A’ or ‘C,’ with distractors: ‘K,’ ‘Z,’ ‘H,’ ‘Y,’ ‘D’ and ‘U’; number task targets ‘1’ or ‘8,’ with distractors: ‘3,’ ‘6,’ ‘5,’ ‘2,’ ‘7’). Importantly, CM target items were never used as distractors. During the CM trial, only one of the targets appeared at any given time (so, for example, ‘A’ and ‘C’ would never simultaneously appear), and each target appeared an equal number of times over the course of the testing session. On variably-mapped (VM) trials the participant searched for one target item at a time, but this item changed on each trial. As a result, target items appeared as distractors on subsequent trials. Five of the items served as both VM targets and distractors while an additional three items served as VM distractors only (‘A,’ ‘C,’ ‘K,’ ‘Z’ and ‘H’ were both targets and distractors, while ‘Y,’ ‘D’ and ‘U’ were distractors only; ‘1,’ ‘8,’ ‘3,’ ‘6’ and ‘5’ were both targets and distractors, while ‘2,’ ‘7’ and ‘9’ were distractors only). Blocks consisted of five trials, and each VM target was selected as the target for one trial; during the remaining trials, this item was included as a distractor.

Each trial began with a 2500 ms instruction screen consisting of the letter “N” or “L” centered on the screen, indicating a single-number or single-letter trial respectively, and, in the first session, the current target or targets were displayed below that letter. For the remaining sessions the CM targets were implicit, with two dots appearing in place of the two targets. The participants were reminded of their CM targets at the beginning of session two and were informed that the two dots were to serve as a reminder to search for the CM targets, but that the targets themselves would no longer appear on the instruction screen. This was done to be consistent with the Schneider and Fisk (1982a) procedure. They believed that implicit CM instructions would help participants to prioritize the VM target during a dual-task trial by not allocating processing resources to CM targets. The trial automatically began after the presentation of the instruction screen. The target items or dots were displayed at the top of the screen, and four search locations were centered on the screen below. Each trial consisted of 30 seconds of continuous flickering of alternating stimulus probes and blank interstimulus intervals. Participants were required to respond with the appropriate key whenever a target appeared.

At the end of the trial a percent accuracy score (see appendix A for calculation) and the number of wrong keys were presented for 3000 ms. To prevent participants from excessively responding a warning message was displayed for 10,000 ms in place of the feedback if more than 5 false alarms were made on a single-task trial, or more than 8 on a dual-task trial. The warning message read, “You have too many false alarms. You are responding with the wrong key, responding too often or responding too slowly. Please respond as fast as possible while remaining accurate.” If a participant received this message more than twice they were warned that they could be excluded from the study. In addition to the trial-level accuracy feedback, the participants received block-level feedback on the VM task performance during dual-task trials. For example, if the VM task was numerical, this feedback would be specific to the number task performance *during the dual-task trials*. Performance was evaluated as “excellent”, “good”, “fair” or “poor.” This rating was determined in relation to the highest detection block score obtained during session one for the VM task at the two speeds. If a bonus was earned it would be displayed on the feedback screen. The criteria for the slow/fast speed were: “excellent”

(95/90% or greater), “good” (less than excellent and 85/80% or greater), “fair” (less than good and 75/70% or greater) and “poor” (less than fair). For example, if a participant’s best detection block-level score for their VM task at the fast speed was 70% during session one, a detection score of 63% or higher (70 * .90 = 63) would be necessary to receive and ‘excellent’ rating for the VM task under the dual-task condition. The participants were informed in advance that ‘performing well’ on the VM task during dual trials would result in a $.25 bonus per trial. In order to earn the bonus the participant had to score in the excellent range (detection >= 90% during fast trials and detection >= 95% during the slow trials); however, they were never explicitly told what constituted “performing well”. Some participants inquired and they were told that “well” was relative to their performance and not an absolute measure. The bonuses were in addition to study payment. Participants were paid $7 per hour/session with a $3 per hour/session bonus for completing all study sessions. The base pay was either $60 or $70 depending on whether participants required one or two sessions of single-task training prior to commencing the dual-task training phase of the study.

2.2.2 Session one: single-task training

There were four single-task conditions: fast VM, slow VM, fast CM and slow CM. Half of the participants performed the number task as CM and the letter task as VM, while the other half performed the letter task as CM and the number task as VM. There were sixteen total blocks and each condition was run for four blocks. There was an optional 20-second rest period between blocks and a mandatory five minute rest at the half way point. Each condition was randomly presented. Participants were given verbal instructions for how to perform the single-tasks during session one. Two practice trials were given one of each trial type. Participants were monitored to make sure they were performing the task correctly. Participants that performed poorly on session one were given an additional session of single-task training. Those who continued to perform poorly were asked to leave the study. To remain in the study, participants were required to score 55% or higher in the VM slow condition and 50% or higher in the VM fast condition for at least one block in either one or two sessions of single-task training.

2.2.3 Sessions two through six: single- and dual-task training

Six conditions were tested: the four single-task conditions from session one, for 2 blocks each, as well as dual CM-VM search, slow and fast, which were tested for 4 blocks each. Dual-task conditions were tested for 4 blocks each, compared to 2 for the single-task conditions, to ensure that there were equal numbers of mapping/task specific targets across the single- and dual-task in sessions two through six. The same break periods are provided as in session one. Randomization of the conditions by block was again employed.

The participants were read instructions prior to commencing session two (see appendix B). They were told that their goal was to learn to perform the dual-task while continuing to also perform the single-tasks. During dual-task trials, participants were told to prioritize the VM task by focusing their efforts on that task and responding to the CM targets whenever they happened to notice a CM target. They were also told about earning bonuses based on performing well on the VM targets that appear during the dual-task trials, and of the implicit CM target instructions. The experimenter verbally explained that the dual-task trials were not to be treated as single-task trials in an attempt to maximize bonuses. Although the VM task was to be prioritized, some attempt was required to be made to respond to CM targets. Participants were informed that their performance was being monitored, and that those who made no attempt to respond to the CM task would be asked to allocate additional effort to the CM task. Participants who continued to completely ignore or minimally respond the CM task would be asked to leave the study. This was done to minimize the chance that participants would adopt a severe criterion against the CM targets as in the case of Schneider and Fisk (1982a, Experiment 3) and to minimize the chance that participants treated the VM dual-task as a VM single-task in order to earn as much bonus pay as possible. This instruction was added during Experiment 2 when five participants made almost no responses to the CM task during the dual-task trials over two sessions. These participants were excluded from the study.

2.2.4 Differences between the VMT and the SFT-1982

The Visual Multi-Task (VMT) and the Schneider and Fisk task (SFT-1982) are rapid paced visual search tasks; however, the type and duration of the search are different. In the VMT, participants respond to multiple targets by pressing the mapping specific response key. In Schneider and Fisk, participants respond to a single target (on both single- and dual- task trials) by pressing a button indicating the *location* of the target. The VMT has a longer trial (30000 ms); the modified VMT is composed of either 200 frames (fast speed) or 150 frames (slow speed). The SFT-1982 trials are shorter (~2000 ms) and composed of considerably fewer (12) frames. In the original VMT, the dual-task was not trained at multiple speeds; however, to be partially consistent with their procedure, the VMT was trained at two speeds. Schneider and Fisk's rationale for training their participants at three speeds was to ensure that performance was not at ceiling (W.W. Schneider, personal communication, December 18, 2009). These procedural differences are not expected to be the source of poor dual-task performance and therefore the VMT trials remained longer, multiple-target detection/identification trials.

2.2.5 Experiment 1: free search with VM distractors

The modified Visual Multi-Task in Experiment 1 was altered to be as similar as possible to the SFT-1982 (Schneider and Fisk, 1982a). As in the SFT-1982 (Experiment 1), the VMT used VM-items as distractors during all conditions. For example, if the VM task was number, then the distractor items would be numbers for the single-number search, the single-letter search and the dual letter-number search (see Figure 2). Letter and number targets could appear in any of the four locations. A successful outcome (i.e. minimal deficit scores) in Experiment 1 would indicate that one or more of the modifications are contributing to dual-tasking ability.

2.2.6 Experiment 2: restricted search with separate VM and CM distractors

The second version of the VMT was similar to the original VMT. Each task appeared on one of the diagonals; the letters appeared on the upper left to lower right corner diagonal and the numbers appeared on the upper right to lower left corner diagonal. Letter targets could only appear on the letter diagonal and number targets could only appear on the number diagonal. One task served as CM while the other served as VM.

2.2.7 Experiment 3: free Search with mixed VM and CM distractors

The third version of the VMT used a mixture of CM and VM distractors (i.e. both number and letter distractors) in all four locations. Letter and number targets could appear in any of the locations.

2.2.8 Experiment 4: free search with separate VM and CM distractors

The fourth version of the VMT had separate distractor diagonals; the letter distractors appeared on the upper left to lower right corner diagonal and the number distractors appeared on the upper right to lower left corner diagonal. Letter and number targets could appear in any of the locations.

2.2.9 Modified VMT trial structure

Appendix C contains a detailed illustration of the VMT trial. Figure 2, see below, shows examples of each of the experimental probe displays. A trial consists of either 600 or 800 probes separated by interstimulus intervals. Counterbalancing is employed in the study, crossing mapping with stimulus type. In the examples presented in Figure 2, the VM condition is number search (right column) and the CM condition is letter search (left column). The current target or targets are presented at the top of the screen (i.e. "A & C" or "6") and the targets must be detected amongst the four distractors presented below. Targets can appear in any of the four locations during free search. Targets can only appear on the mapping-specific diagonal (i.e. letter-CM or number-VM) during restricted search.

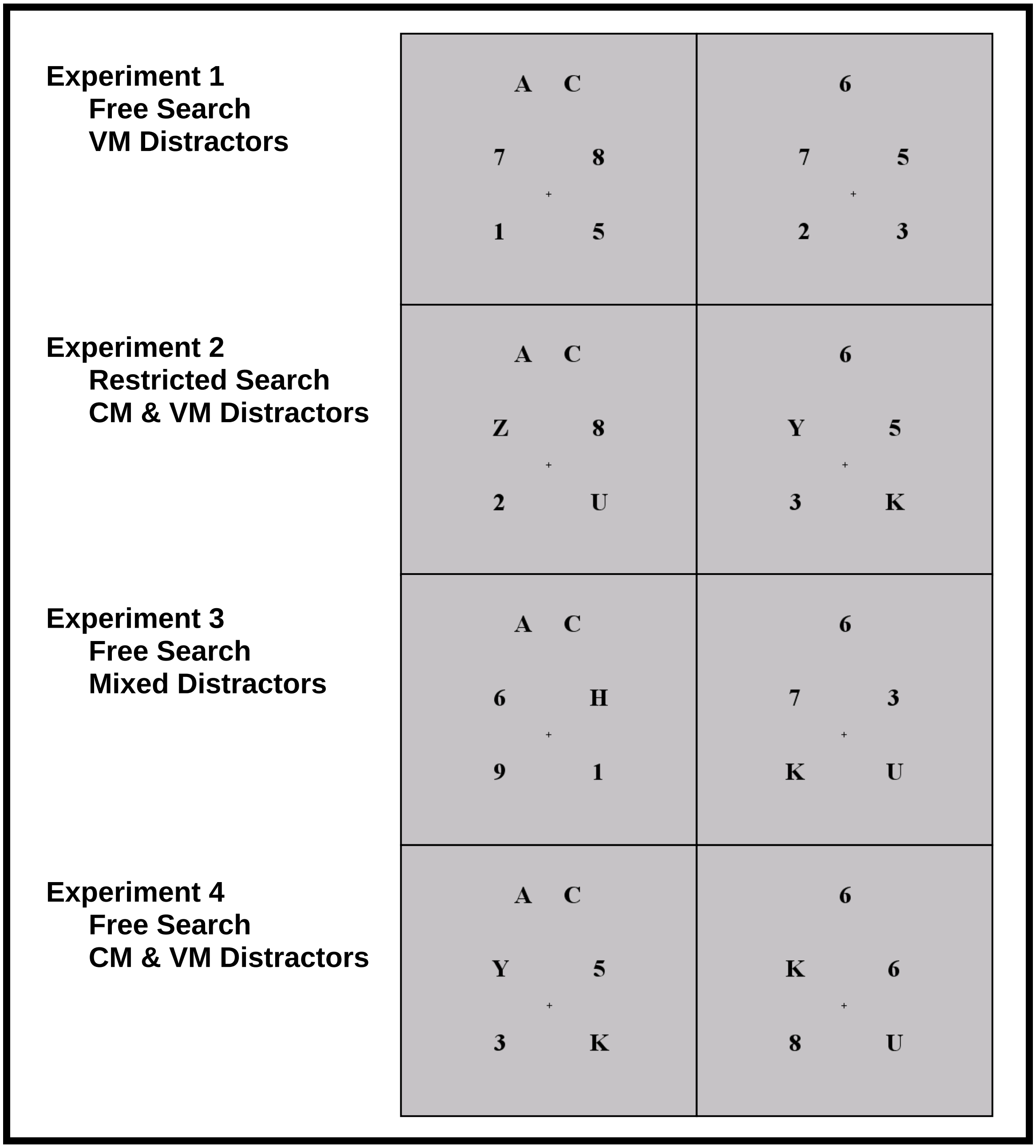


Figure 2. Experimental stimuli probe screens

3.0 EXPERIMENT 1: FREE SEARCH WITH VM DISTRACTORS

3.1 RATIONALE

The goal of Experiment 1 is to replicate Schneider and Fisk (1982a) in which participants learned to perform a search task without cost. The VMT was modified to resemble Schneider and Fisk's experiment 1 in which targets could appear in any location (free search) and distractors were selected from the VM task. The original VMT had separate search locations for the CM and VM task with each task employing mapping specific distractors.

Other modifications were made to conform to Schneider and Fisk: 1) reducing the number of search locations to half, 2) the task would be performed at two different speeds, 3) single-task training would continue throughout all sessions instead of only the first session, 4) from session two on CM targets would no longer explicitly appear on the instruction screen, 5) the VM dual-task would receive additional feedback. All of these modifications were included in all four experiments.

Of the modifications, a VM distractor set and searching all locations were considered most likely to contribute to the large dual-task deficit experienced in the original VMT[10]. Pop-out effects, resulting from utilizing a VM-only distractor set, may aid target detection and therefore reduce dual-task interference. Pop-out is typically demonstrated in the context of

[10] Reducing the search locations will reduce tasks demands and reduce that amount of training necessary to develop dual-task proficiency. This modification will be held constant across all experiments and therefore the effect of reducing search locations will not be tested.

feature search, which is search based on a single distinctive feature such as motion (Treisman and Gelade, 1980). However, pop-out can also occur in situations when there is low confusability between targets and distractors, such is the case in the current experiment. Under conditions of extremely low confusability, load and consistency effects may be eliminated (Shiffrin, 1988). Searching all locations may also reduce dual-task interference. Maintaining a consistent spatial search context across the single- and dual-task conditions potentially facilitates component task coordination and integration.

Finally, continuing to train the single-task and training the task at two speeds may also contribute to dual-task proficiency as introducing variability in training is beneficial in skill acquisition (Gopher,1993; Schneider, 1985; Schmidt & Bjork,1992). The role of training variability was not tested as it was held constant across all experiments. As a result of the task and procedural modifications, modified VMT participants are predicted to develop dual-task proficiency.

3.2 RESULTS

Separate analyses were conducted on the dual-task deficit scores and the single-task detection data for all four experiments. Deficit scores reflect dual-task target detection relative to single-task detection [100 *(dual – single) /single] with negative scores reflecting higher accuracy in the dual-task condition relative to single task condition with positive scores reflecting the reverse.

3.2.1 Dual-task deficit scores

A repeated measures multiple analysis of variance (MANOVA) was performed with mapping (CM, VM) and dual-task session (2 – 6) and frame rate (slow, fast) as within subjects factors. The dependent variable was dual-task deficit scores. In this analysis the data was collapsed across group (CM-number & VM-letter vs. CM-letter & VM-number). Group differences are not theoretically important; separate groups were created for the purpose of counterbalancing the mapping with task stimuli (i.e. numbers and letters).

A practice (i.e. session) effect is predicted with the onset of dual-task training (session one) producing detection deficits followed by the attenuation of deficits with additional training. A mapping effect and a potential mapping by session interaction are also predicted which would reflect that participants are able to prioritize VM dual-task detection at the expense of CM detection. There are no predictions in regards to frame rate and dual-task deficit scores. A frame rate effect would suggest excessive taxation of controlled processing.

There is a main effect of mapping (Wilk's λ = .665, $F(1,23)=11.59$, $p=.002$, $\eta_p^2 = .335$) and a main effect of session (Wilk's λ = .438, $F(4,20)=6.43$, $p=.002$, $\eta_p^2=.562$). There is no main effect of frame rate [Wilk's λ = .995, $F(1,23)=0.119$, $p=.734$, $\eta_p^2 = .005$]. There are no significant interactions; frame rate does not interact with mapping, Wilk's λ = .968, $F(1,23)=0.761$, $p=.392$, $\eta_p^2 = .032$ or session, Wilk's λ = .841, $F(4,20)= .943$, $p=.460$, $\eta_p^2 = .159$. There is no mapping by session interaction Wilk's λ =.724 $F(4,20)=1.91$, $p=.149$, $\eta_p^2 = .276$. The three way interaction between mapping, speed and session was also non-significant, Wilk's λ = .849, $F(4,20) = .891$, $p = .488$, $\eta_p^2 = .151$.

Participants are able to prioritize the VM task at the expense of the CM task, the CM deficit (starting at -9.8% and ending at -4.1%) is significantly greater than the VM deficit (starting at -3.4% and ending at 4.9%) throughout training. Furthermore, variations in speed did not affect the degree of dual-task deficit.

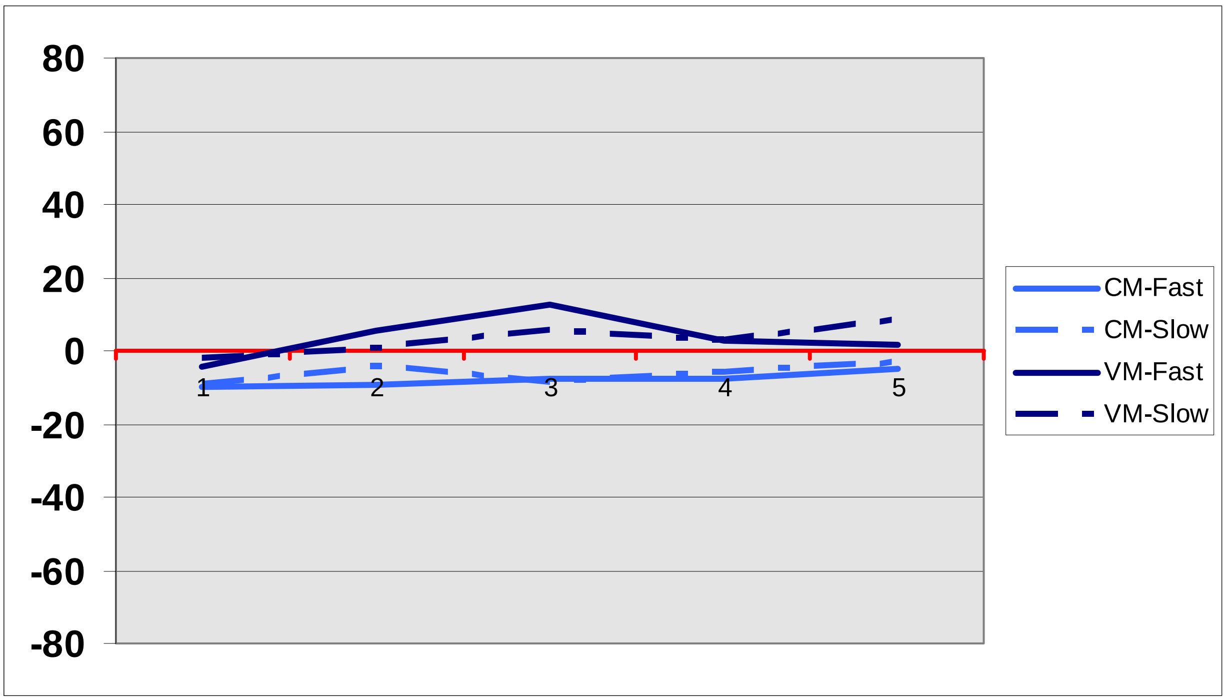


Figure 3 Experiment 1 dual-task % deficit scores

3.2.2 Single-task detection rate

Using dual-task deficit scores as the dependent measure revealed that practice improved detection by 8.3% for the VM task and 5.6% for the CM task. Deficit scores are calculated relative to single-task detection scores that occur during the same testing session. Therefore deficit scores can improve when 1) dual-task performance is improving or unchanged while *single-task performance is declining*, 2) dual-task performance is improving while *single-task performance is unchanging*, or 3) dual-task performance is improving while *single-task performance is also improving*. If declining single-task performance is producing "improved" dual-task detection then practicing a dual-task is not improving multitasking ability rather it is generally impairing[11] performance. Therefore it is important to establish that single-task detection is either improving or remaining constant throughout training sessions. To test this, a repeated measures MANOVA was performed with mapping (CM, VM), session (1-6) and frame rate (slow, fast) as within subjects factors. The dependent variable was single-task detection rate. Attenuated deficits scores are predicted to reflect improvement in dual-task detection without declining single-task detection. There is no prediction with regards to single-task improvement. Due to the relatively small amount of practice in session one both tasks may continue to improve; however, practice generally results in greater gains for CM tasks as the result of automaticity and therefore the CM task may improve more.

3.2.3 Single-task practice effects

There is a non-significant effect of session, Wilk's λ = .798, $F(5,19)$= .963, p= .465, η_p^2= .202. Overall detection did not improve with practice. There was a borderline significant mapping by session interaction Wilk's λ = .598, $F(5,19)$= 2.56, p=.063, η_p^2= .402. Therefore CM detection continued to improve reflecting the development of automaticity while the VM task did not

[11] Initial attempts at dual-tasking typically results in declining detection relative to single-task performance. Therefore initial dual-task ability is "impaired" and in the case of this example, detection would not improve with practice. Furthermore, single-task detection would be impaired if dual-task practice resulted in declining single-task detection.

improve with practice. There was a significant interaction between frame rate and session Wilk's λ = .464, F(5,19)= 4.39, p=.008, η_p^2= 536. The decrease in detection associated with the increase in task speed is reduced with practice again reflecting automaticity. In other words, CM detection becomes insensitive to the increase in processing load from task acceleration.

3.2.4 Single-task non-practice effects

There is a significant effect of mapping Wilk's λ = .056, F(1,23)=387.1, p<.001, η_p^2= .944 and frame rate Wilk's λ = .083, F(1,23)=255.6, p<.001, η_p^2= .917. Furthermore there is a significant mapping by frame rate interaction Wilk's λ = .334, F(1,23)=45.90, p<.001, η_p^2= .666, but the three-way interaction between mapping, frame rate and session is not significant Wilk's λ = .738, F(5,19) = 1.35, p= .286, η_p^2= .262. CM detection is greater than VM detection; furthermore, VM detection rates are more adversely affected by increasing task speed than CM detection rates. These differences reflect one of the qualitative differences between controlled and automatic processes; controlled processing is capacity limited.

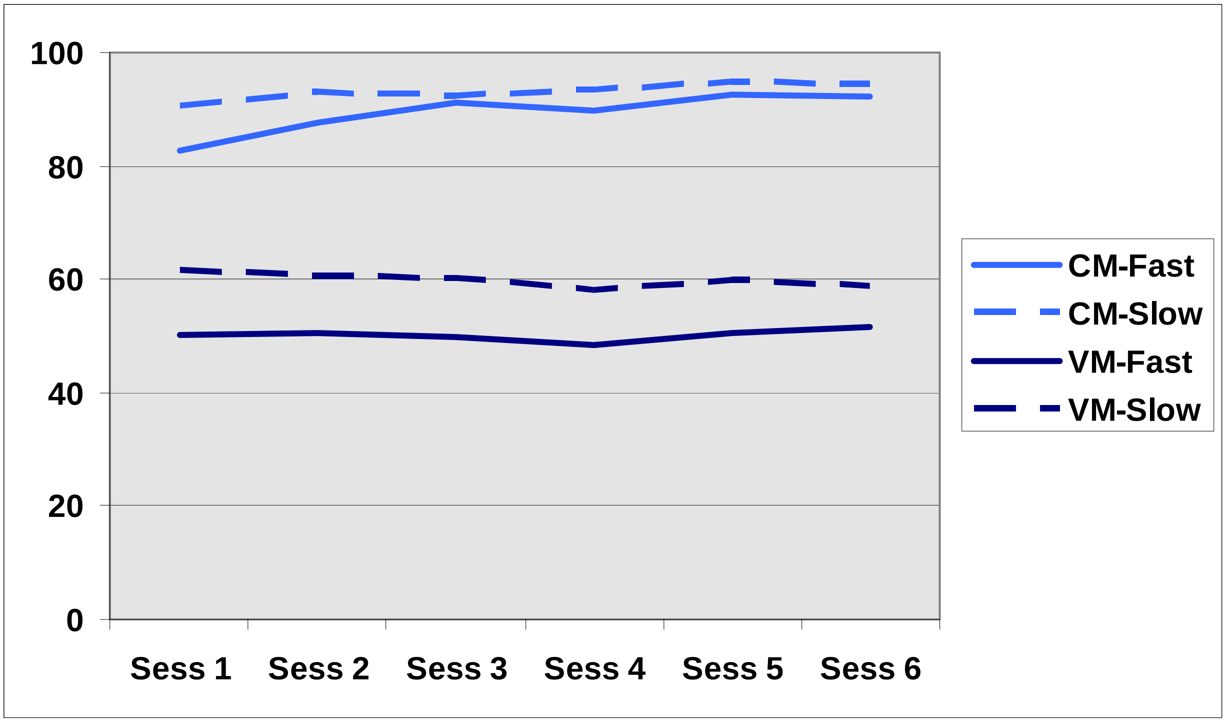


Figure 3. Experiment 1 single-task detection (% hit rate) across training session

3.3 DISCUSSION

The modified VMT has replicated the SFT-1982 search task[12]. In both studies the CM single-task continued to improve with practice while the single-VM did not. Both studies also report a significant effect of frame rate on single-task detection; however in the VMT there was also an interaction with mapping such that the VM task experienced disproportionate declines in detection with task acceleration. Practice improved CM and VM dual-task detection in both studies; however, the VMT CM task was operating at a 4.1% deficit at the end of training and

[12] Schneider and Fisk's dependent variable was percent correct for the single- and dual-task and since they did not generate deficit scores there are some differences in the analyses.

this drop relative to single-task detection is significant ($p < .041$). The VMT VM dual-task detection was operating at a 4.9% *increase* in detection but this difference was not significantly different relative to single-task performance ($p = .204$). The SFT-1982 task was operating at a 1% deficit for the CM task and a 3% deficit for the VM task; however, these differences were not significant.

Participants are able to improve both CM and VM detection with practice and are clearly approaching cost-free detection in the CM task. CM dual-task detection is increasing with training and therefore additional practice will likely eliminate this deficit. Differences in the task and training procedure may account for the fact that participants were able to perform the SFT-1982 without cost while VMT participants were operating with a CM deficit.

Schneider and Fisk's participants received more practice in terms of trials (SFT-1982: 5220 total trials, 1740 of which are dual-task trials vs. VMT: 480 total trials, 200 of which are dual-task trials). However; the SFT-1982 trials contain only 1 target compared to the 8-10 targets per VMT trial (SFT-1982: 1740 dual-targets, 870 of which are CM/VM vs. VMT: 8800 dual-targets, 4400 of which are CM/VM). Automaticity develops with target exposure indicating that the VMT should have a training advantage over the SFT-1982 task.

The VMT task, however, requires sustained attention and therefore is likely a more challenging task. The VMT trials are 30000 ms long while the SFT-1982 trials are ~2000 ms. Furthermore the SFT-1982 participants had up to 30 seconds to study the targets and potentially rest between trials which they could self initiate. In the VMT, trials automatically started after 2500 ms; targets were presented during this window allowing little time to rest. There was only a 20 second rest break between each block of five trials; however, there was five minutes of rest at the half way point in the session in the VMT.

Finally, the VMT training was highly compressed compared to the Schneider and Fisk study. The VMT was run in six 60 minute sessions in which participants tested twice a day for three consecutive days. Schneider and Fisk participants trained over 10 sessions; although they did not indicate if more than one session occurred per day, we can assume that testing was spread out over a longer period than the VMT. Spacing out training is beneficial to skill acquisition (Schmidt and Bjork,1992) and therefore likely to improved CM dual-task detection. The trial duration, block level timing and rest opportunities may have increased the level of fatigue in a highly challenging task; VMT participants must process 600 stimuli per "slow" trial and 800 stimuli per "fast" trial.

Controlled processing is highly susceptible to fatigue which may have slowed the development of automaticity in a CM/VM dual-task such as the VMT. Therefore the VMT participants would have likely achieved cost-free CM dual-task detection with additional training. Despite the differences in the task and training procedures, the participants performed qualitatively in a similar manner therefore Experiment 1 is considered to have successfully replicated Schneider and Fisk (1982a, Experiment 1).

4.0 EXPERIMENT 2: RESTRICTED SEARCH WITH SEPARATE VM AND CM DISTRACTOR DIAGONALS

4.1 RATIONALE

Experiment 1 replicated Schneider and Fisk (1982a) using a modified version of the VMT task. Participants were able to dual-task relatively without cost when targets were free to appear in any location and when distractors were members of the VM set. In Experiment 2, the task will revert back to a format that is similar to the original VMT, that is CM and VM tasks will occupy separate diagonals and as a consequence CM targets will be restricted to the CM diagonal and VM targets will be restricted to the VM diagonal. Experiment 2 will maintain all other modifications that were implemented in Experiment 1 such as training the task at two speeds, continuing to train the single-task beyond session one, etc.

Since Experiment 2 participants have no prior experience with learning to dual-task with out cost, they are predicted to incur greater initial dual-task interference as well as more interference post-training compared to Experiment 1. Schneider and Fisk participants *did* maintain a substantial CM dual-task cost when their tasks restricted targets to mapping-specific diagonals. However, when sensitivity was assessed in a follow-up study, participants were equally sensitive to CM targets in both the single and dual-task condition. Therefore dual-task deficits were the result of a criterion shift on the CM diagonal. Schneider and Fisk used the same participants in multiple experiments and therefore they had been trained to dual-task without cost prior to the sensitivity assessment (Experiment 3). Furthermore, in all of their experiments, the distractors came exclusively from the VM task.

Experiment 2 will assess the impact of restricted search with separate CM/VM distractor diagonals on dual-task detection. These changes will eliminate potential pop-out and spatial consistency effects, that is only half of the areas are searched in the single-task but all are searched in the dual-task. These changes are predicted to impede dual-task proficiency; however, it is possible that these modifications were not the source of interference. Reducing the number of task locations, introducing task variability or one of the other modifications could explain failure in the original VMT. These changes were made in Experiment 1 and continue to be implemented in the current methods. If performance is comparable to Experiment 1, then restricted search and separate CM/VM distractor diagonals should not contribute to dual-task interference.

4.2 RESULTS

4.2.1 Dual-task deficit scores

A repeated measures multiple analysis of variance (MANOVA) was performed with mapping (CM, VM), dual-task session (2 – 6) and frame rate (slow, fast) as within subjects factors. The dependent variable was dual-task deficit scores. In this analysis the data was collapsed across group (CM-number & VM-letter vs. CM-letter & VM-number). Experiment 2 has the same spatial characteristics as the pilot VMT task where participants continued to incur substantial deficits with practice. The VMT in experiment 2; however, has half as many search locations which should reduce the overall task difficulty. Furthermore, VM performance is sensitive to set size effects therefore reducing search location may result in a practice effect. If restricted search with separate distractor sets severely taxes controlled processing when dual-tasking, there should be an effect of frame rate and a frame rate by mapping interaction. As the task accelerates deficit scores should become increasingly negative and if participants are able to prioritize the VM task there should be a greater impact on CM detection. If participants are unable to prioritize the VM task, task acceleration should have a negative effect on both CM and VM tasks detection.

There is a main effect of mapping, Wilk's λ = .443, $F(1,23)= 28.9$, $p<.001$, $\eta_p^2= .557$ and session Wilk's λ = .218, $F(4, 20)= 17.94$, $p<.001$, $\eta_p^2= .782$. Furthermore, there is an interaction between mapping and session Wilk's λ = .529, $F(4,20)= 4.45$, $p=.010$., $\eta_p^2=.471$; CM deficit (starting at -51.0% and ending at -22.2%) is greater than VM deficit (starting at -13.6% and ending at -3.15%) throughout training. Both CM and VM tasks are improving with training; however the CM task is improving more rapidly. By the end of training the CM tasks have improved detection by 28.8% compared to the 10.5% improvement in VM detection. However, as stated above, VM task detection is superior to CM task detection throughout training. There is a main effect of frame rate, Wilk's λ = .653, $F(1,23)=12.22$, $p<.002$, $\eta_p^2= .347$ and a significant frame rate by mapping interaction, Wilk's λ = .390, $F(1,23)=36.0$, $p<.001$, $\eta_p^2= .610$. The three-way interaction between mapping, frame rate and session was not significant, Wilk's λ = .962, $F(4,20) = 1.29$, $p= .307$, $\eta_p^2= .205$. Together this demonstrated that VM detection is minimally affected by frame rate while CM detection is negatively impacted by increasing task speed. This suggests that participants are successfully prioritizing the VM task and as a result, VM dual-task detection is maintained in the face of increasing task demand at the expense of CM task detection. The frame rate effect on deficit scores indicate that Experiment 2 participants are experiencing greater demands on controlled processing than Experiment 1 participants.

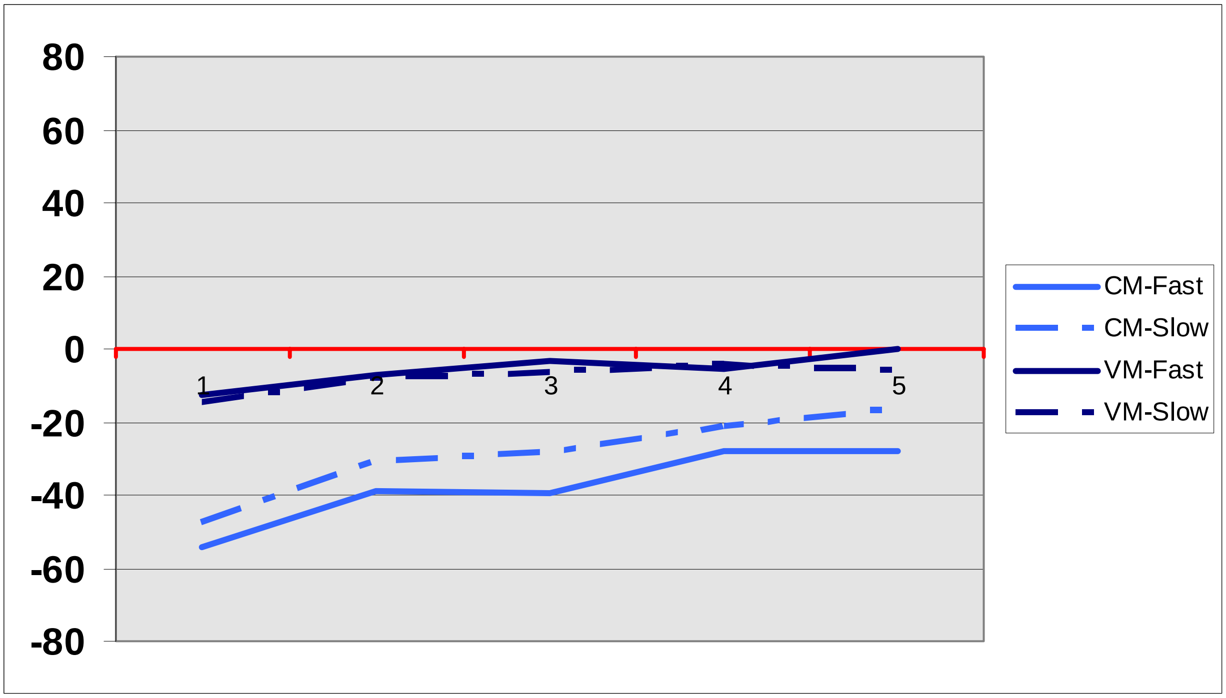


Figure 4. Experiment 2 dual-task % deficit scores

4.2.2 Single-task detection rate

Using dual-task deficit scores as the dependent measure revealed that practice improved detection by 10.5% for the VM task and 28.8% for the CM task. Deficit scores are calculated relative to single-task detection scores that occur during the same testing session. As in Experiment 1, it is important to establish that declining single-task performance is not producing "improved" dual-task detection. To test this, a repeated measures MANOVA was performed with mapping (CM, VM), session (1-6) and frame rate (slow, fast) as within subjects factors.

The dependent variable was single-task detection rate. Improvement in dual-task detection is not predicted to result from single-task detection declines.

4.2.3 Single-task practice effects

There is a significant main effect of session, Willk's λ = .475, F(5,19)= 4.20 p=.01, η_p^2= .525. There is a significant interaction between mapping and session, Wilk's λ = .303, F(5,19)= 8.74, p<.001, η_p^2= .697. VM detection rates remained relatively level compared to CM detection rates which increased with practice, a hallmark of the development of automatic processing. There is a non-significant frame rate by session interaction, Wilk's λ = .723, F(5,19)=1.46, p=.250. The three-way interaction between mapping, frame rate and session was not significant, Wilk's λ = .703, F(5,19)= 1.60, p= .207.

4.2.4 Single-task non-practice effects

There was a main effect of mapping Wilk's λ = .190, F(1,23)= 97.8, p<.001, η_p^2= .810; CM detection was greater than VM detection. There was an effect of frame rate Wilk's λ = .089, F(1,23)= 235.2, p<.001, η_p^2= .911 There was a significant mapping by frame rate interaction Wilk's λ = .494, F(1,23)= 23.53, p<.001, η_p^2= .506; Increasing task speed produced decreasing detection rates; furthermore, the VM task is more adversely affected by increasing task speed than the CM task.

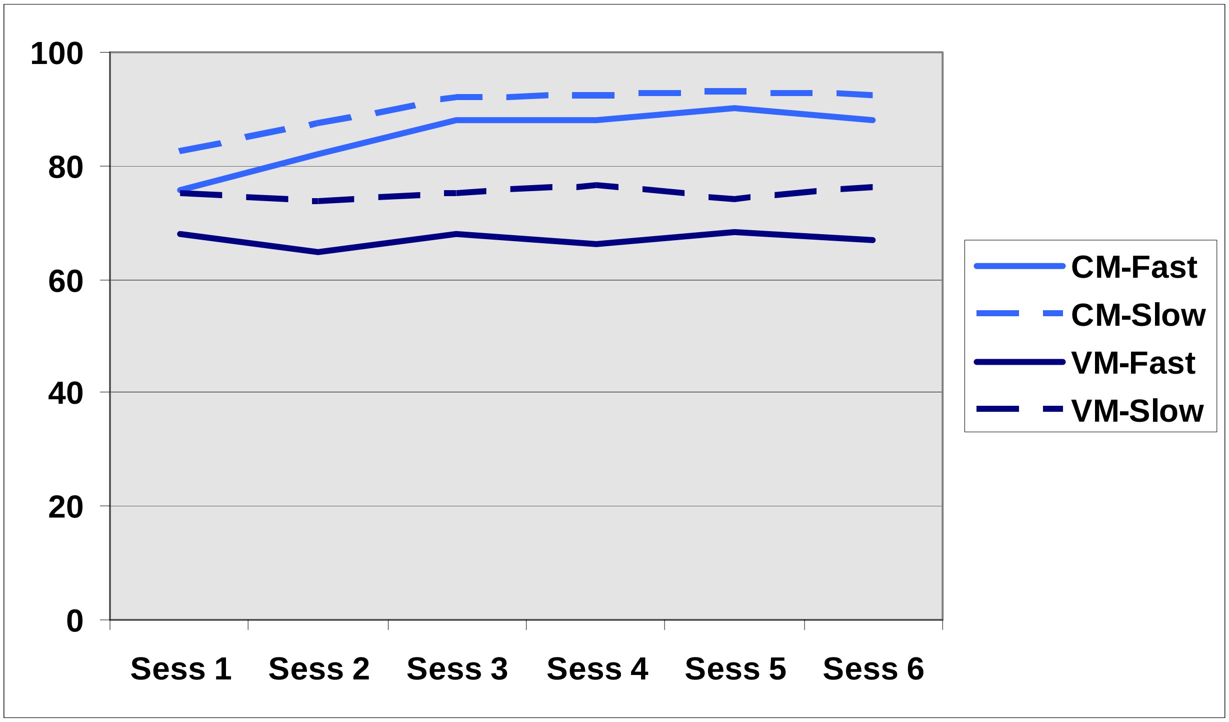


Figure 5. Experiment 2 single-task detection (% hit rate) across training session

4.2.5 Experiment 2 A' analysis

In Schneider and Fisk (1982a) participants had a substantial drop in CM detection when CM and VM targets were constrained to separate diagonals as in Experiment 2. In a follow up experiment Schneider and Fisk had participants perform a similar detection task. This time the participants had to indicate both the location of the target followed by whether the target was CM or VM. Not all trials contained targets therefore participants were also given the option to respond that no targets were present. The change in task design allowed sensitivity to be assessed by an A' analysis. They found no difference in sensitivity between the CM single and dual-task conditions as well as no difference between the single and dual VM condition. Therefore they concluded that the participants had adopted a criterion shift in which they had a bias against responding to the un-emphasized CM diagonal. Several things should be noted, firstly there were only four participants used in the study[13], secondly the same participants were used in Experiments 1, 2a, 2b and 2c prior to this experiment which means that the participants were given a tremendous amount of training. And finally, having first learned to dual-task without cost (Experiment 1) may have specifically enabled the SFT-1982 participants to be equally sensitive in the CM dual-task condition.

Different participants were used in all four experiments in the current study therefore order effects and amount of training were controlled for in the current research. In order to assess sensitivity an A' analyses was conducted on Experiment 2 participants (n=24). A' is a measure of the area under the receiver operating characteristic curve; a score of 0.5 indicates chance detection and a score of 1.0 is perfect detection. A' was used as a measure of sensitivity in order to be consistent with Schneider and Fisk (1982a). Furthermore the more prevalent sensitivity measure d' can not be computed when false alarm rates are low, which is the case in well practiced visual search tasks such as the VMT (Craig, 1979).

A' was calculated from the final training session from the single- and dual-task conditions for both the CM and VM conditions. The fast and slow frame rate data was grouped together in this analysis. A repeated measures MANOVA was computed on the A' scores with mapping (CM, VM) and load (single, dual) as independent variables. There was a significant effect of mapping, Wilk's $\lambda = .628$, $F(1,23) = 13.61$, $p = .001$, $\eta_p^2 = .372$ and load, Wilk's $\lambda = .300$, $F(1,23) = 53.56$, $p < .001$, $\eta_p^2 = .700$. There was also a significant mapping by load interaction, Wilk's $\lambda = .511$, $F(1,23) = 22.0$, $p < .001$, $\eta_p^2 = .489$.

[13] The A' analysis was conducted on only three participants due to the fact that one participant made no responses to CM targets at the fastest frame rate.

Participants were highly sensitive (A'> .9) at target detection in all conditions. CM sensitivity was greater than VM sensitivity. This analysis also confirms that participants were able to prioritize the VM task as the 0.6% difference between VM single- and dual-task detection is not significant ($p = .142$). However there is a significant drop in sensitivity (5.1% decline) for the CM task when dual-tasking ($p < .001$). Participants are equally sensitive when performing the CM and VM dual-task ($p = .791$) therefore the difference between CM and VM sensitivity is driven by greater CM single-task sensitivity (5.2%, $p < .001$).

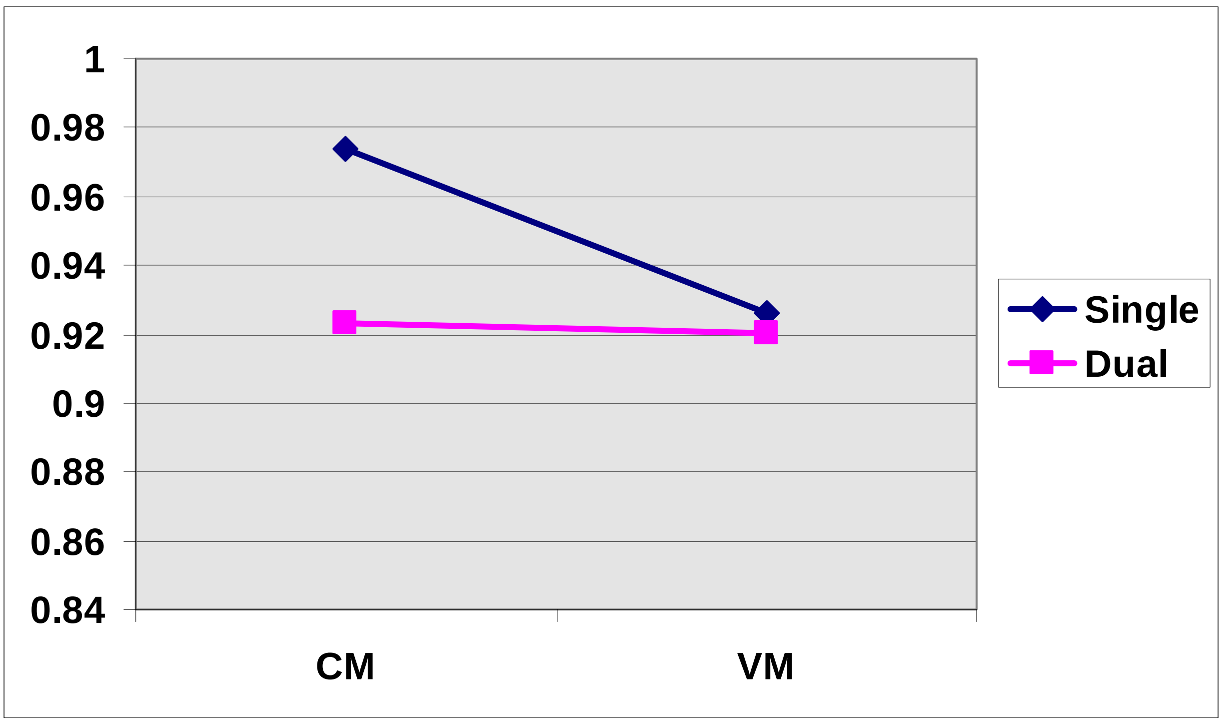


Figure 6. Target detection sensitivity (A')

4.3 DISCUSSION

In Experiment 2, participants performed the VMT with separate diagonals for the CM and VM task. This task was similar to the Schneider and Fisk task (Experiments 2a, 2c & 3) except that the CM diagonal was populated with CM distractors. The SFT-1982 used VM items exclusively for distractors.

VMT participants in Experiment 1 and 2 were able to prioritize the VM task, that is VM detection did not suffer in the dual-task condition relative to the single-task condition, and both groups were able to improve dual-task detection with practice. Schneider and Fisk did not report whether or not detection was affected by practice when diagonal search was employed; however they reported that participants were able to prioritize the VM task as evident by a non-significant drop in dual-task detection. Post-training VMT CM dual-task detection maintained a 22.2% deficit in Experiment 2 which is considerably greater than the 4.1% deficit in Experiment 1. SFT-1982 participants also maintained a 17% CM deficit in diagonal search compared to 1% CM deficit when participants searched all locations. Therefore in the VMT there was an 18.1% difference in CM detection between participants that searched all locations and participants that were trained with separate mapping-specific diagonals and distractors. There is a comparable 16% drop in detection when *the same participants* switched from having targets appear in any location to having targets restricted to mapping-specific diagonals in the SFT-1982. Critically the drop in detection is attributed to a bias against responding to the CM diagonal in the SFT-1982 (Schneider and Fisk, 1982a, Experiment 3) whereas in the VMT the difference in CM detection is attributed to a 5.1% drop in sensitivity to the CM diagonal.

The difference in outcome between the current research as Schneider and Fisk is likely due to prior dual-task mastery, i.e. the SFT-1982 participants were previously trained to dual-task without deficit in Experiment 1 where targets were free to appear in any search location. Furthermore, SFT-1982 participants were extensively trained on three experiments (Experiment 2a, 2b and 2c)[14] all of which trained diagonal search prior to sensitivity assessment of diagonal search in Experiment 3. Experiments 2a and 2c trained diagonal search with VM priority while Experiment 2b trained diagonal search with CM priority. Under CM priority, VM detection experienced a severe drop (i.e., 54%) while CM detection was equivalent to single-task detection. Schneider and Fisk concluded that VM priority is necessary for cost-free detection; however, there may be some training benefit for switching to the CM task. Task emphasis training, varying the degree of attention between dual-task component tasks has been beneficial to skill acquisition (Gopher, 1996; Gopher, 1993; Gopher, Brickner, Navon, 1982; Gopher, Weil, Siegel, 1989). Emphasis training is believed to develop the ability to flexibly allocate cognitive control. Since controlled processing can be allocated to an automatic process, adjusting priority may help participants to effectively prioritize the VM task by not allocating controlled processing to the CM task.

Priority emphasis training introduces variability into the training regime. As a principle, varying training facilitates skill acquisition (Schneider, 1985; Schmidt and Bjork, 1992). Experiments 2a and 2c used different mapping-specific probabilities; that is, the likelihood that any CM/VM target would appear in the single-task versus the dual-task was different in these experiments. Furthermore, in Experiment 2c during VM single-task search, participants had to ignore any CM targets that appeared on the CM diagonal; although the subjects were instructed to search for a VM target no VM target actually appeared on trials that contained a to-be-ignored CM target. This occurred on half of the VM-single trials and it was used as a control to

[14] Participants were trained for approximately 11 hours on Experiment 2a and 2 hours on Experiment 2b. The duration of training was not reported for experiment 2c.

determine if there was an effect of alternating between CM and VM targets on different trials. Experiments 2a, 2b and 2c introduced variability into the SFT-1982 and therefore may have facilitated dual-task detection, ultimately enabling participants to be equally sensitive to CM dual-targets in Experiment 3.

The current study's participants were naïve performers of diagonal search. Despite equivalent amounts of training, Experiment 2 participants maintained a 22.2% CM dual-task deficit while Experiment 1 participants maintained a 4.1% CM dual-task deficit. Unlike participants in the Schneider and Fisk study, they were less sensitive to CM targets in the dual-task condition as determined by a significant 5.1% drop in A'. This drop in sensitivity may be due to the fact that mapping-specific search areas generate spatial-search inconsistencies between single-task search and dual-task search. When performing either the CM or VM single-task only half of the search locations are relevant since targets are restricted to appearing on mapping-specific diagonals. This is inconsistent with dual-task trials where all locations are relevant due to simultaneous search for CM and VM targets. The drop in sensitivity may also result from the fact that CM targets can not pop-out in Experiment 2 as they can in Experiment 1 in which VM items were exclusively used to populate the distractor set. That is, CM targets must be distinguished from CM distractors and VM targets must be distinguished from VM distractors. The search tasks were numbers and letters; each task was assigned to be either CM or VM. As a result, in Experiment 1 CM-numbers would be highly distinguishable from uppercase VM-letters and vice versa enabling search based on pop-out (Shiffrin, 1988). Consistent spatial search and/or pop-out may facilitate the development of automaticity in a CM/VM dual-task. The drop in sensitivity may also reflect interference from distractor processing that occurs from segregating CM and VM distractors. The subsequent experiments were conducted to clarify which task parameters enable automatic dual-task search for Experiment 1 participants but not Experiment 2 participants.

5.0 EXPERIMENT 3: FREE SEARCH WITH MIXED VM AND CM DISTRACTORS

5.1 RATIONALE

In Experiment 3 CM and VM targets will be free to appear in any location as in Experiment 1. Unlike Experiment 1, CM pop-out will not be possible because both CM and VM items will be used as distractors. The CM and VM distractors will be intermixed, thereby eliminating the mapping-specific diagonals that occurred in Experiment 2. If performance is comparable to Experiment 2, then CM pop-out can be assumed to enable automatic CM dual-task detection. If dual-task interference is reduced in Experiment 3 than spatial inconsistency or reduced distractor segregation may be the source of interference.

5.2 RESULTS

5.2.1 Dual-task deficit scores

A repeated measures multiple analysis of variance (MANOVA) was performed with mapping (CM, VM) and dual-task session (2 – 6) and frame rate (slow, fast) as within subjects factors. The dependent variable was dual-task deficit scores. In this analysis the data was collapsed across group (CM-number & VM-letter vs. CM-letter & VM-number). In Experiment 3 the

VMT employed a mixed distractor set, which prevents CM pop-out. Dual-task deficits are predicted to decline with practice in Experiment 3 as they have in the prior experiments.

There is a main effect of mapping, Wilk's λ = .624, $F(1,23)$= 13.85, p=.001, η_p^2= .376, VM detection (starting at -16.4% and ending at 0.3%) is greater than CM detection (starting at -33.4% and ending at -8.3%). There is a main effect of session, Wilk's λ = .135, $F(4, 20)$= 32.08, p<.001, η_p^2= .865 reflecting improved detection with training. There is a main effect of frame rate, Wilk's λ = .761, $F(1,23)$= 7.21, p=.013, η_p^2= .239; detection drops with task acceleration. There is a borderline significant mapping by frame rate interaction suggesting that CM detection may decrease more then VM detection when the task accelerates Wilk's λ = .850, $F(1,23)$= 4.05, p=.056, η_p^2= .150. All other interactions are not significant.

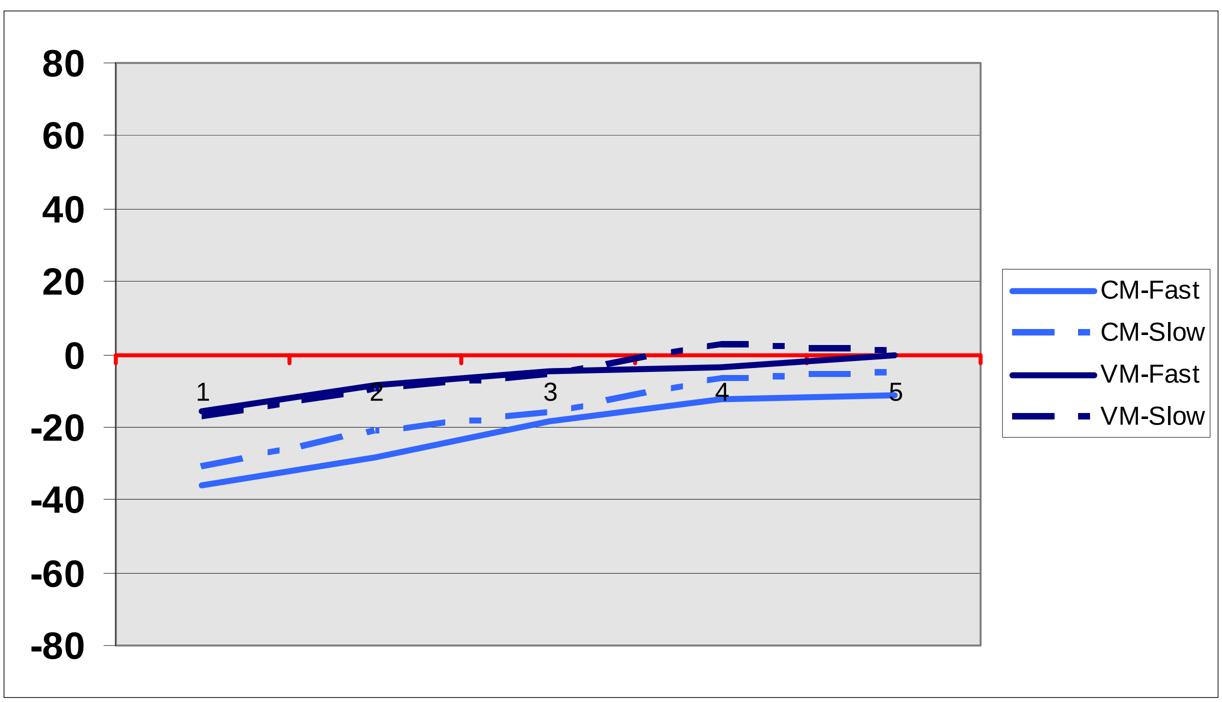


Figure 7. Experiment 3 dual-task % deficit scores

5.2.2 Single-task detection rate

Using dual-task deficit scores as the dependent measure revealed that practice improved detection by 16.7% for the VM task and 25.0% for the CM task. Deficit scores are calculated relative to single-task detection scores that occur during the same testing session. Again it is important to establish that declining single-task performance is not producing "improved" dual-task detection. To test this, a repeated measures MANOVA was performed with mapping (CM, VM), session (1-6) and frame rate (slow, fast) as within subjects factors.

5.2.3 Single-task practice effects

There is a main effect of session, Wilk's λ = .121, $F(5,19)=27.52$, $p< .001$, $\eta_p^2= .879$. There is a significant mapping by session interaction, Wilk's λ = .209, $F(5,19)= 14.38$, $p<.001$, $\eta_p^2= .791$. CM detection increases with practice while VM detection remains relatively level reflecting VM prioritization as well as VM insensitivity to practice. There is a non-significant frame rate by session interaction, Wilk's λ = .808, $F(5,19)= .905$, $p=.498$, $\eta_p^2= .192$). The three-way interaction between mapping, speed and session was not significant, Wilk's λ = .847, $F(5,19)= .687$, $p=.639$, $\eta_p^2= .153$.

5.2.4 Single-task non-practice effects

There was a significant main effect of mapping, Wilk's λ = .111, $F(1,23)=184.03$, $p< .001$, $\eta_p^2= .889$; VM detection was lower than CM detection. There is a significant main effect of frame rate, Wilk's λ = .051, $F(1,23)=431.55$, $p<.001$, $\eta_p^2= .949$. There was a significant mapping by frame rate interaction Wilk's λ = .762, $F(1,23)=7.17$, $p=.013$, $\eta_p^2 = .238$; task acceleration resulted in declines for both tasks, however, detection rates dropped more in the VM task.

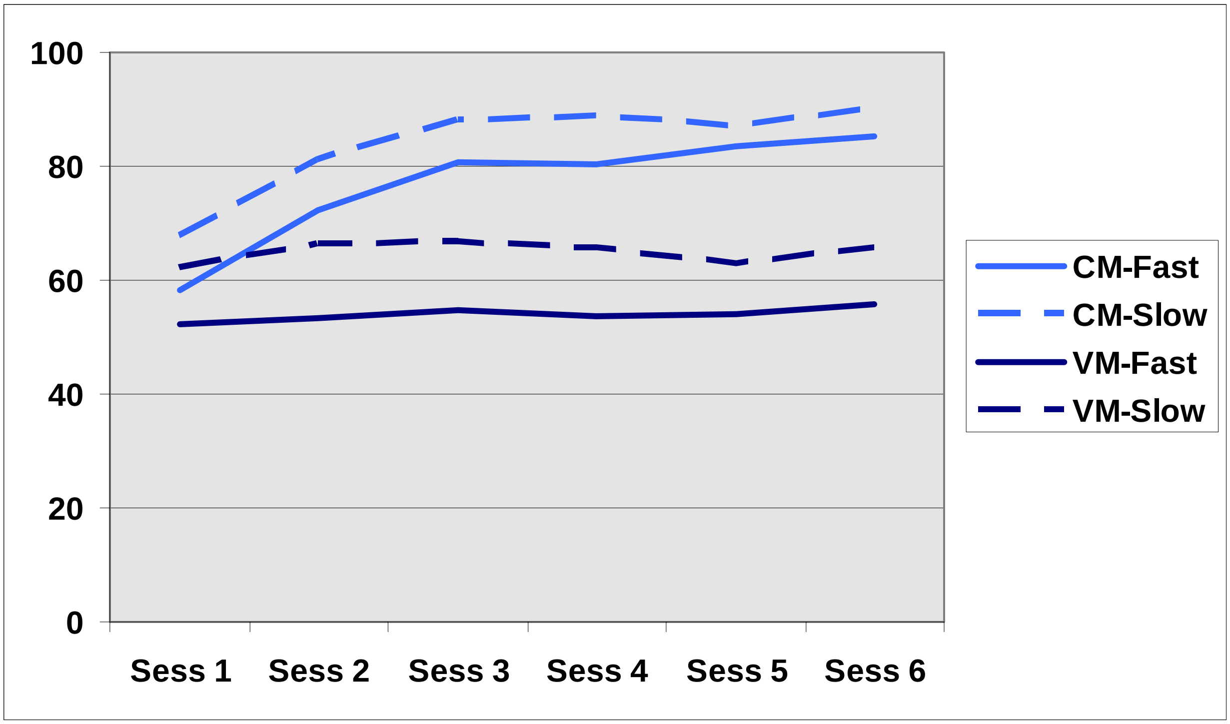


Figure 8. Experiment 3 single-task detection (% hit rate) across training session

5.3 DISCUSSION

As in Experiments 1 and 2, participants in Experiment 3 are able to prioritize the VM task and improve dual-task detection with training. VM detection is greater than CM detection throughout training which indicates that CM dual-task detection deteriorates as a consequent of allocating processing resources to the VM task. With practice CM detection partially recovers. Task acceleration produces greater dual-task interference, just as in Experiment 2, which suggests that this task places greater demands on controlled processing than Experiment 1. This may be due to the fact that combining the CM and VM distractor sets increased the processing load at each location. In all other experiments only one distractor set, CM or VM, could appear in any location. The greater number of items may have increased confusability, thereby producing a frame rate effect while dual-tasking.

6.0 EXPERIMENT 4: FREE SEARCH WITH SEPARATE VM AND CM DISTRACTOR DIAGONALS

6.1 RATIONALE

In Experiment 1 and 3 participants maintained a CM dual-task deficit at the end of training; however, the deficits were considerably smaller than experienced by participants in Experiment 2. In both of these experiments CM and VM targets could appear in any location and therefore consistent spatial search appears to facilitate automatic CM detection in a CM/VM dual-task.

In Experiment 4 VM and CM distractors are again constrained to specific diagonals as in Experiment 2. However, unlike Experiment 2, targets are free to appear in any location. As in Experiment 1, spatially consistent search and *potentially* pop-out are possible. Pop-out may be perceived whenever a VM target appears on the CM distractor diagonal and whenever a CM target appears on the VM distractor diagonal. If pop-out and spatial consistency are beneficial, interference should be less relative to Experiment 2.

Experiments 1 and 3 suggest that searching all locations enables automatic search. However in both experiments distractors were homogeneous; that is, any distractor could appear in any location. In the case of Experiment 1, only VM distractors were used and therefore any member of the VM set could appear in any location. The same is true in Experiment 3, although distractors were a mixture of VM and CM items, any distractor item could appear in any location.

Restricting mapping-specific distractors to different spatial locations is potentially a way to vary the attention allocation across space. With practice, CM distractor items elicit less attention (Schneider. 1999). VM distractors on the contrary are also target items and therefore detecting VM items (as targets) requires attention. The VMT requires a tremendous amount of distractor processing, 600 stimuli must be processed in the "slow" condition and 800 stimuli must be processed in the "fast" condition, only 8-10 of those items are targets. Given the large amount of distractor processing required in the VMT varying the spatial landscape of the task by segregating VM and CM distractors may produce dual-task interference. This would suggest that automatic dual-task search is impeded whenever task designs produce spatial differences in attention allocation, at least in tasks that are high workload such as the VMT. If dual-task interference is comparable to Experiment 2 then dual-task interference is purely the result of separating CM and VM distractors, and therefore inconsistency in search across load does not produce dual-task interference.

If dual-task interference is less than Experiment 2 several interpretations are possible:

1. If Experiment 4 interference is comparable to Experiment 1, this would suggest that free search and pop-out are facilitating dual-task detection while CM/VM distractor separation is not detrimental to dual-detection. In this situation partial CM/VM pop-out (i.e. CM pop-out on the VM diagonal and vice versa) would be assumed equally beneficial as CM-only pop-out.
2. If Experiment 4 interference is comparable to Experiment 3, this would suggest that both restricting search and separating distractors is producing interference. *However,*

there is an underlying assumption that participants are in fact able to capitalize on partial CM/VM pop-out (i.e. number targets appearing on the letter diagonal and vice versa) in Experiment 4. If the stimuli in fact do not perceptually pop-out, single-task performance should be comparable in Experiment 3 and 4; if dual-task performance is also comparable this would suggest that separating distractors does not produce interference (i.e. the distractor segregation hypothesis should be rejected).

6.2 RESULTS

6.2.1 Dual-task deficit scores

A repeated measures multiple analysis of variance (MANOVA) was performed with mapping (CM, VM) and dual-task session (2 – 6) and frame rate (slow, fast) as within subjects factors. The dependent variable was dual-task deficit scores. In this analysis the data was collapsed across group (CM-number & VM-letter vs. CM-letter & VM-number).

Experiment 4 employs free search with separate CM and VM distractor sets which appear on different diagonals. The task has a similar layout to Experiment 2 except that all targets can appear in all locations, which enables pop-out. For example, if a number appears on the letter-VM diagonal then it must be a target item and the converse is also true of a letter appearing on the number CM-diagonal. If pop-out and/or searching all locations facilitate the development of automaticity then performance should be similar to Experiment 1. In Experiment 1 there was a main effect of mapping and session therefore participants were able to prioritize the VM task and automate the CM task with practice. Furthermore there was no main effect of frame rate, therefore dual-task deficits were not negatively impacted by task acceleration which suggests that controlled processing was not overloaded. If there is no frame rate effect in Experiment 4 it would also support the theory that pop out and free search facilitate automaticity in a dual-task. On the other hand, it is possible that having separate spatially located CM and VM distractors could adversely affect detection. Segregating distractors by mapping would produce a task in which attention allocation is varied by location in terms of distractor processing. If separating distractors by mapping interferes with dual-task coordination or prioritization then a frame rate effect would be predicted.

There is a main effect of mapping, Wilk's λ = .549, $F(1,23)=18.89$,$p<.001$, $\eta_p^2= .451$, and session, Wilk's λ = .180, $F(4,20)=22.84$, $p<.001$, $\eta_p^2= .820$. There is a significant mapping by session interaction Wilk's λ = .510, $F(4, 20)=4.80$, $p=.007$, $\eta_p^2= .490$. CM detection (starting at -28.9% and ending at -7.1%) is lower than VM detection (starting at -13.2% and ending at 3.5%); furthermore, VM detection improves more rapidly than CM detection over the course of training, VM detection increases by 10.6% while CM detection increases by 7.4%.

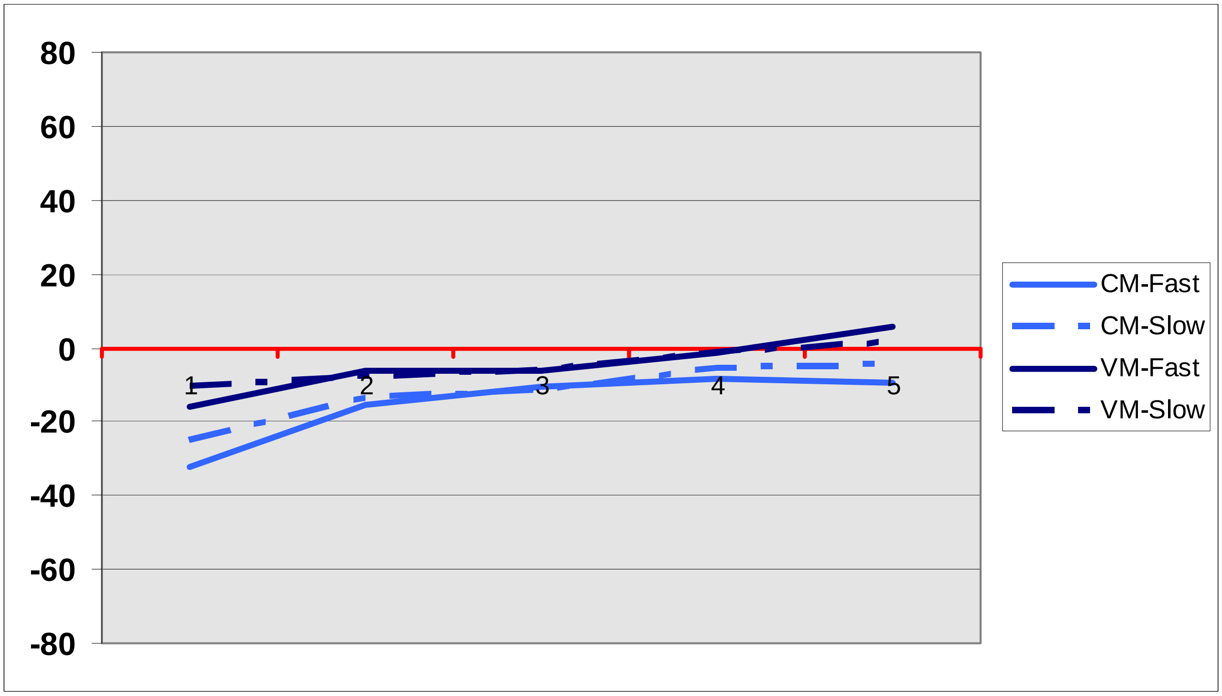


Figure 9. Experiment 4 dual-task % deficit scores

6.2.2 Single-task detection rate

Using dual-task deficit scores as the dependent measure revealed that practice improved detection by 16.7% for the VM task and 21.7% for the CM task. Deficit scores are calculated relative to single-task detection scores that occur during the same testing session. Again it is important to establish that declining single-task performance is not producing "improved" dual-task detection. To test this, a repeated measures MANOVA was performed with mapping (CM, VM), session (1-6) and frame rate (slow, fast) as within subjects factors. The dependent variable was single-task detection rate.

6.2.3 Single-task practice effects

There was a significant main effect of session, Wilk's λ = .097, $F(5,19)=35.53$, $p<.001$, η_p^2= .903 . There is a significant mapping by session interaction Wilk's λ = .278, $F(5,19)=9.85$, $p<.001$, η_p^2= .722, the CM task scores were greater and improved more rapidly than the VM task scores. There is a significant frame rate by session interaction; the reduction in detection rates associated with increasing task speed were minimized with practice Wilk's λ = .374, $F(5,19)=6.36$, $p< .001$, η_p^2= .626. The three-way interaction between mapping, frame rate and session is not significant, Wilk's λ = .671 $F(5,19)$ =1.86, p= .149.

6.2.4 Single-task non-practice effects

There was a significant effect of mapping, Wilk's λ = .227, $F(1,23)=78.20$, $p<.001$, η_p^2= .773, VM detection was lower than CM detection. There was a significant effect of frame rate, Wilk's λ = .096, $F(1,23)=216.25$, $p<.001$, η_p^2= .904, task acceleration decreased single-task detection rate. There was a non-significant mapping by frame rate interaction Wilk's λ = .969, $F(1,23)=0.734$, p=.401, both tasks were comparably affected by changes in task speed.

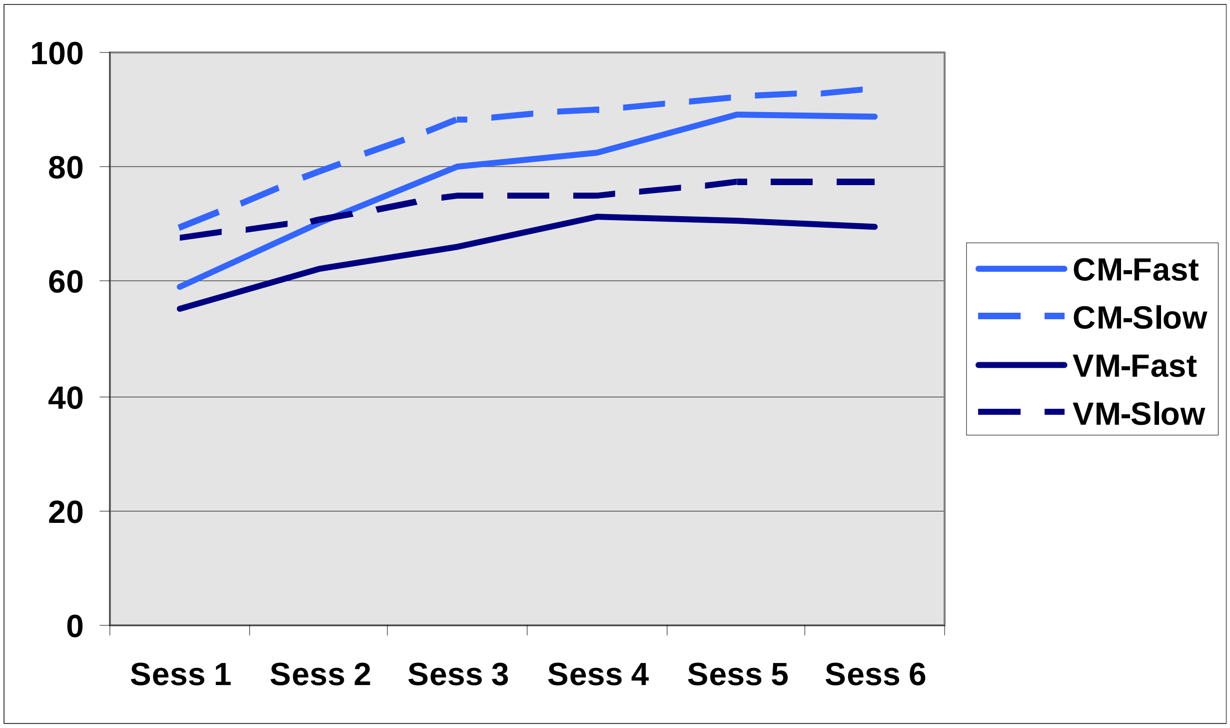


Figure 10. Experiment 4 single-task detection (% hit rate) across training session

6.3 DISCUSSION

In Experiment 4 as in all prior experiments, participants were able to prioritize the VM task, as a result VM detection was greater than CM detection and participants were able to improve detection with practice. In Experiment 4 distractors were assigned to separate diagonal based on mapping just as they were in Experiment 2. Experiment 4 participants had higher detection scores than Experiment 3 participants; their scores were similar to Experiment 3 participants.

6.4 EXPERIMENT 4: CM/VM POP-OUT

Post-training deficit scores were minimal for Experiment 1, moderate for Experiment 3 and 4 and severe for Experiment 2. Furthermore, dual-task performance in Experiment 3 and 4 are not statistically significantly different, see section 7.0 for full details. These results can both support and reject the distractor segregation hypothesis. This is the case because in theory, Experiment 4 participants experience target pop-out when a CM target appears on the VM distractor diagonal or when a VM target appears on the CM distractor diagonal. Determining whether or not Experiment 4 participants perceive pop-out is critical for the interpretation of the similarity in performance of Experiment 3 and 4 participants within the larger context of results. If Experiment 4 participants are not utilizing pop-out, then the overall pattern of results would support the hypothesis that pop-out and consistent spatial search are factors in dual-task mastery (see Table 1 in section 1.7.1, row PO & CS). If Experiment 4 participants are utilizing pop-out then the overall pattern of results would support the hypothesis that pop-out and distractor segregation are factors in dual-tasking mastery (see Table 1, row PO & DS). If pop-out is facilitating target detection, there should be evidence of this in the session one single-task data; single-task detection in Experiment 4 should be greater than in Experiment 3 where pop-out is not possible

A repeated measures multiple analysis of variance (MANOVA) was performed with mapping (CM, VM) as within subjects factors and experiment (1 – 4) as between subjects factors. The dependent variable was session one single-task hit rate scores. There was a significant effect of mapping, Wilk's λ = .359, $F(1,92)=164.3$, $p<.001$, $\eta_p^2= .641$ and a mapping by experiment interaction, Wilk's λ = .383, $F(3,92)=49.3$, $p<.001$, $\eta_p^2= .617$. Follow up t-test corrected for multiple comparisons (alpha = .004) revealed that all CM single-task scores were significantly different from each other ($p < .001$) except for Experiments 3 and 4, $t(23) = 0.391$, $p = .700$[15]. Follow up t-test corrected for multiple comparisons (alpha = .004) revealed that all VM comparisons involving Experiment 2 were significantly different from each other (Exp 1: $t(23) = 6.69$, $p < .001$, Cohen's d= -1.94; Exp 3: $t(23) = 5.0$, $p < .001$, Cohen's d= 1.44; Exp 4: $t(23) = 3.37$, $p = .003$, Cohen's d= 0.97). Consistent with the CM scores, CM single-task scores for Experiment 3 and 4 are not significantly different from each other, $t(23) = 1.42$, $p = .169$. Experiment 1 was not significantly different than Experiment 3, $t(23) = 0.674$, $p = .507$, or Experiment 4, $t(23) = 1.81$, $p = .083$.

In Experiment 1 when CM pop-out was possible, CM detection was greater than all other experiments, including Experiment 2 which required searching through half as many locations (i.e. restricted search) compared to the other experiments (i.e. free search), see Figure 11. In Experiment 1, *VM pop-out* is not possible due to the VM only distractor set and therefore there is no Experiment 1 VM advantage; in this case, Experiment 1 VM scores are significantly smaller than Experiment 2. Experiment 1 VM scores are not statistically different than that of Experiment 3 in which the mix distractor set also precludes pop-out. There is also no statistical difference between Experiments 1 and 4, or Experiments 3 and 4, in terms of VM detection, which indicates that the Experiment 4 participants can not capitalize on VM pop-out. That is, VM pop-out is not possible in Experiments 1 and 3 and since Experiment 4 detection is not statistically different from those experiments, the single-task data suggests that Experiment 4 participants do not perceive VM target pop-out on the CM distractor diagonal. There is also no statistical difference between Experiment 3 and 4 CM detection, therefore, Experiment 4

[15] Experiments 1 & 2: $t(23)= 4.07$, $p< .001$, Cohen's d= 1.25; Experiments 1 & 3: $t(23)= 9.63$, $p<.001$, Cohen's d= 2.88; Experiments 1 & 4: $t(23)= 8.86$, $p< .001$, Cohen's d= 2.59; Experiments 2 & 3: $t(23)= 5.06$, $p< .001$, Cohen's d = 1.46; Experiments 2 & 4: $t(23)= 4.67$, $p < .001$, Cohen's d= 1.35.

participants are also not able to perceive CM target pop-out on the VM distractor diagonal. Furthermore, this result is consistent with subject debriefing; some participants remarked that CM targets in general began to pop-out with practice particularly during the single-task, a hallmark of automatic processing, but no participants remarked that CM targets appeared to pop-out on the CM diagonal or that VM targets appeared to pop-out on the VM diagonal.

Single-task performance on session one suggests that Experiment 4 participants did not experience pop-out while single-tasking. It is therefore unlikely that there was a pop-out advantage while dual-tasking. Furthermore, since dual-task performance was comparable in Experiment 3 and 4, the distractor segregation hypothesis can be rejected. This is because the overall pattern of results, minimal Experiment 1 deficits, severe Experiment 2 deficits and moderate Experiment 3 & 4 deficits are consistent with the following hypotheses: 1) CM Pop-out against a VM-only distractor set and 2) consistent spatial search facilitating dual-task mastery. Again, this conclusion is only supported when the Experiment 4 performance is not a consequence of CM/VM pop-out, see Table 1 in section 1.7.1. Spatially separating distractors in Experiment 4 did not produce more interference than when distractors were mixed in Experiment 3. This suggests that restricted target search produces dual-task interference.

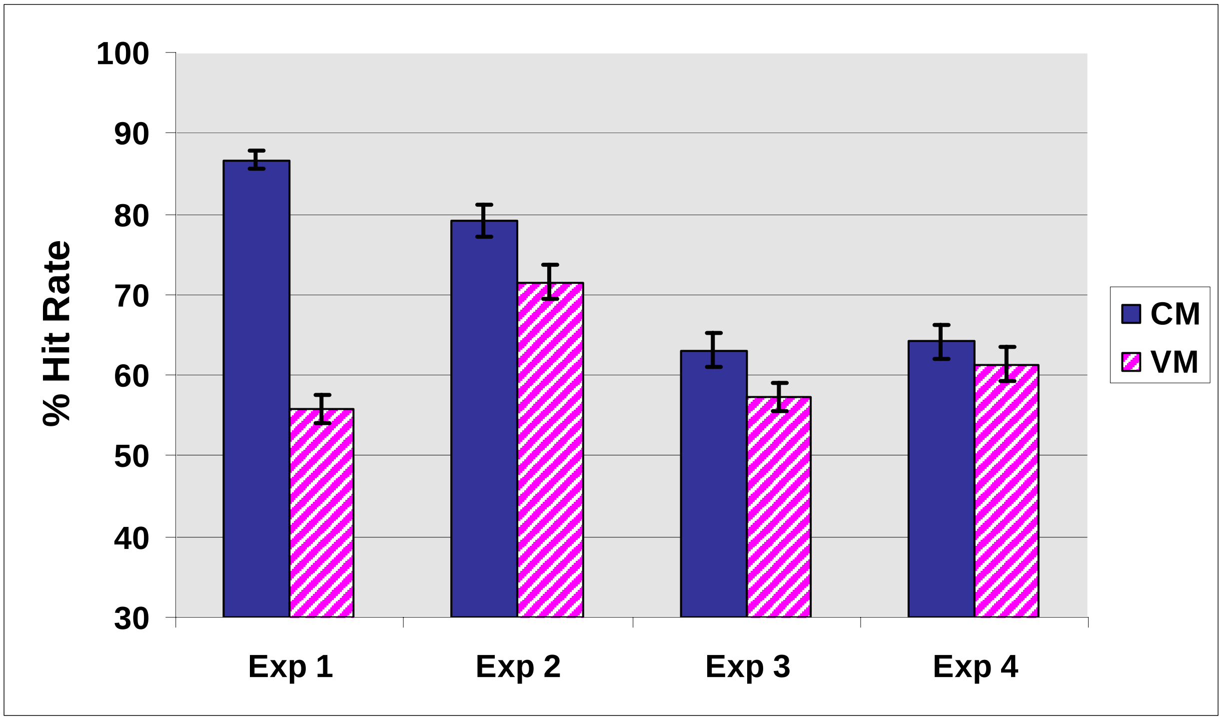


Figure 11. Single-task session one % hit rate scores by experiment

7.0 CONTRASTING EXPERIMENTS

In all experiments there was a significant mapping and session effect in the dual-task deficit scores, see Table 2. Participants were instructed to prioritize the VM task; this required them to attempt to maintain equivalent VM detection levels in the dual-task as compared to the single-task. The participants were clearly able to comply with the emphasis instruction since VM dual-task detection was greater than CM dual-task detection during all sessions. Additionally, the significant session effect indicated that training improved dual-task detection in all experiments. In Experiment 2, participants performed a VMT task that was similar to the pilot studies in which participants were unable to prioritize the VM task or improve VM detection with training, see appendix D. In contrast to the pilot studies participants were able to prioritize the VM task and improve VM detection with training. The different outcomes could in part result from the reduction in search locations or other modifications that were implemented. Given that learning is clearly possible in restricted search with separate CM and VM distractors it is necessary to compare performance across all experiments to see if there are significant differences in dual-task detection.

Table 2. Significant Effects for Experiments 1-4 Repeated Measures MANOVA[16]

	Exp 1	Exp 2	Exp 3	Exp 4
mapping	X	X	X	X
frame rate		X	X	
session (practice)	X	X	X	X
mapping * frame rate		X	B	
mapping * session		X		X
frame rate * session				
mapping*frame rate*session				

7.1 DUAL-TASK DEFICIT SCORES

A repeated measures MANOVA was performed with mapping (CM, VM) and dual-task session (2 – 6) as within subjects factors and experiment (1 - 4) as a between subjects factor. The dependent variable was dual-task deficit scores. In this analysis the data was collapsed across group (CM-number & VM-letter vs. CM-letter & VM-number) and frame rate (slow and fast) due to the fact that these variables where not theoretically important. There is a main effect of mapping Wilk's λ = .542, F(1,92)= 77.84, p<.001, η_p^2= .458. There is a main effect of session Wilk's λ = .266, F(4,89)= 61.44, p<.001, η_p^2= .734.

There is a significant mapping by experiment interaction Wilk's λ = .836, F(3,92)= 6.02, p=.001, η_p^2= .164. There is a significant session by experiment interaction, Wilk's λ = .732, F(12,235.76)= 2.46, p=.005, η_p^2= .099. There is a significant mapping by session interaction, Wilk's λ = .816, F(4,89)= 5.02 p=.001, η_p^2= .184. There a also a significant three way

[16] 'X' indicates a significant effect, a 'B" indicates a borderline effect.

interaction between mapping, session and experiment Wilk's λ = .723, $F(12, 235.76)$= 2.56, p=.003, η_p^2= .103.

Post hoc Bonferroni tests (alpha = .05/6= .008) revealed that Experiment 1 was significantly different than all other experiments (Experiment 2: p<.001, Experiments 4: p<.001, Experiments 4: p=.006) and Experiment 2 was significantly different than all other experiments (Experiments 1: p<.001, Experiments 3: p=.004, Experiments 4: p <.001). The remaining contrast between Experiment 3 and 4 was not significant (p=.992). Experiment 1 had both the smallest deficits (CM:-3.4% to 4.9%; VM: -9.7% to -4.1%) and the smallest improvements post training (CM: 8.3%; VM: 5.6%) for both the CM and VM tasks, see Table 3. Experiment 2, 3 and 4 had similar initial VM deficit scores, respectively -13.6%, -16.4%, and -13.2%; however, both Experiment 3 and 4 improved by 16.7% post training while Experiment 2 only improved by 10.5%. Initial CM deficits were disproportionably large for Experiment 2 (M= -51.0%) compared to Experiment 3 and 4 which had -33.4% and -28.8% deficits respectively. With training CM deficit scores improved by 28.8% for Experiment 2, 25.0% for Experiment 3 and 21.7% for Experiment 4. Although Experiment 2 had the greatest training related CM detection improvement, at the end of training it continued to have the lowest detection score (M= 28.8%) compared to Experiment 3 (M = -8.3%) and 4 (M=-7.1%). To investigate these differences further four oneway ANOVAs were run on a) the CM pre-training detection (session 2), b) the CM post-training detection (session 6), c) the VM pre-training detection and d) the VM post-training detection, each using experiment as a between subjects effect.

Table 3. Experiment 1-4 dual-task deficits scores VM vs. CM

VM	Sess 2	Sess 6	Learning
Exp 1	-3.4%	4.9%	8.3%
Exp 2	-13.6%	-3.2%	10.5%
Exp 3	-16.4%	0.3%	16.7%
Exp 4	-13.2%	3.5%	16.7%

CM	Sess 2	Sess 6	Learning
Exp 1	-9.7%	-4.1%	5.6%
Exp 2	-51.0%	-22.2%	28.8%
Exp 3	-33.4%	-8.3%	25.0%
Exp 4	-28.8%	-7.1%	21.7%

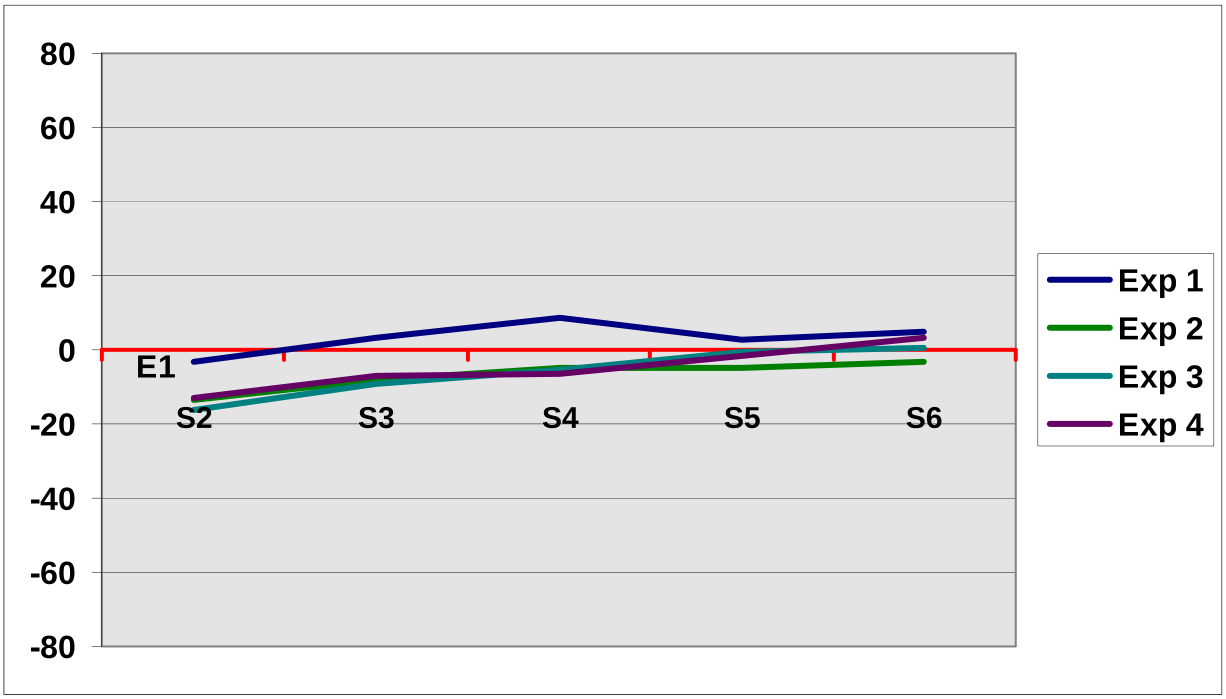


Figure 12. Experiments 1-4 VM dual-task % deficit scores

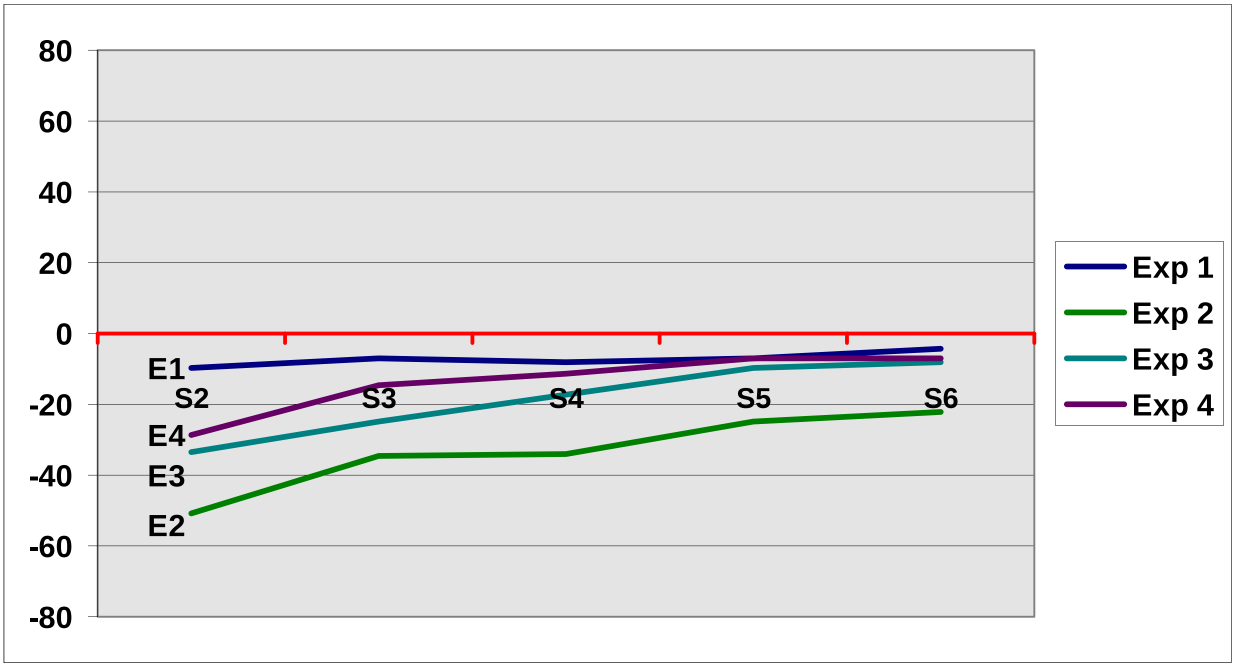


Figure 13. Experiments 1-4 CM dual-task % deficit scores

7.1.1 VM pre- and post-test scores

Due to a violation of Levene's homogeneity of variance test for the VM pre-test ANOVA $F(3,92)= 2.81$, $p=.04$, Welch's F-ratio will be reported. There was a significant effect of experiment on VM pre-test scores, $F(3,50.2)= 5.03$, $p=.004$, $\eta_p^2= .146$. Bonferroni corrected (alpha = .05/6=.008) post-hoc tests revealed one significant comparison between Experiments 1 and 3 ($p=.002$). The effect of experiment was non-significant on the VM post-test scores, $F(3,92)= 2.01$, $p=.118$.

The pre-test VM ANOVA revealed that the drop in detection that occurred for the untrained VM portion of the dual-task was comparable for Experiment 1 (M=-3.4%), Experiment 2 (M=-13.6%) and Experiment 4 (M=-13.2%); Experiment 3 scores (M=-16.4%) were comparable with experiments 2 & 4 but were significantly lower than Experiment 1. Post-test VM scores (see session 6, Table 3) revealed no significant differences in detection rates between any of the experiments.

7.1.2 CM pre- and post-test scores

Due to violations of Levene's homogeneity of variance test for both the CM pre-test $F(3,92)=4.03$, $p=.01$ and the CM Post-Test $F(3,92)=3.90$, $p=.01$ ANOVAs, Welch's F-ratios will be reported. There was a significant effect of experiment on CM pre-test scores, $F(3,49.6)= 25.9$, $p<.001$, $\eta_p^2= .412$. Bonferroni corrected (alpha = .05/6=.008) post-hoc test revealed significant differences between all pairs except the pairing of Experiments 3 and 4. There was also a significant effect of experiment on CM post-test scores, Welch's $F(3,49.3)= 7.03$, $p<.001$, $\eta_p^2= .268$. Bonferroni corrected (alpha = .05/6=.008) post-hoc test revealed significant differences between Experiment 2 and all other pairs; all pairings that did not include Experiment 2 were non-significant.

The pre-test CM ANOVA revealed that the drop in detection that occurred for the untrained CM portion of the dual-task scores was significantly different between all experiments except Experiment 3 (M=-33.4%) and Experiment 4 (M=-28.8%); together these detection rates are considerably greater than Experiment 1 (M= -9.7%) and less than Experiment 2 (M= -51.0%). Post-training however, there are no differences in CM detection rates between Experiment 1 (M= -4.1%), Experiment 3 (M= -8.3%) and Experiment 4 (M=-7.1%) but all of the experiment's detection rates were significantly greater than the substantial deficit of Experiment 2 (M=-22.2%).

8.0 GENERAL DISCUSSION

Four experiments were conducted to determine why VM prioritization and practice were insufficient for dual-task proficiency in the Visual Multi-Task (VMT) a CM-VM visual search task. Failure in the VMT was unexpected due to the fact that Schneider and Fisk (1982a) were able to train participants on a CM-VM visual search dual-task; in their study learning was only contingent on prioritizing the VM task. There were several differences between the tasks; the goal of this research was to test a subset of these differences. Using a VM-only distractor set and allowing targets to appear in all locations was predicted to facilitate dual-task detection. A VM distractor set would enable pop-out of the CM task which was predicted to enable automatic CM detection. Searching all locations was also predicted to enable detection because it would provide a spatial continuity between the single- and dual-task by ensuring that all locations are relevant to search at all times. Finally, in order to rule out the possibility of a general effect of segregating stimuli with different probabilities of attracting attention, the distractor segregation hypothesis was tested. Separating CM and VM distractors is akin to creating separate spaces for stimuli with different priorities; that is, different probabilities of attracting attention -- moderate and low.

The modified VMT used in this thesis produced superior performance compared to the original VMT in pilot studies; in all experiments both CM and VM detection improved with training. In the VMT pilot studies, VM dual-task deficit scores did not improve with training.

Several modifications were made to the VMT in order to make it more similar to the Schneider and Fisk (1982a) task; these modifications were maintained throughout all of the experiments in this dissertation and are responsible for the improvements relative to the pilot studies. The number of search locations were reduced by half, this facilitated over all performance in both mapping conditions. Some of the other modifications that were implemented that have been established as beneficial in skill acquisition such as providing more specific (VM) feedback (Gopher, 1993), introducing variability (i.e. speed and load) in training (Schneider,1985; Schmidt and Bjork, 1992) and providing financial incentive likely played a role in this improvement. Some or all of the aforementioned modifications were responsible for the VM dual-task improvement that occurred even in Experiment 2, which was the experiment that is most similar to the VMT pilot tasks. However, with regard to the modifications that were empirically tested, pop-out and consistent search appear to facilitate dual-task detection; distractor segregation appeared to have no effect.

Dual-task deficits were the most minimal in Experiment 1 which employed pop-out and free search; this cost was significantly less than Experiment 3 and 4. Experiment 3 and 4 were not significantly different from each other when considering both single-task detection and dual-task deficits. Furthermore, Experiments 1, 3 and 4 were significantly and substantially better than Experiment 2 in terms of CM dual-task deficits.

In Experiment 1, CM target pop-out was perceived because the distractor set consisted entirely of VM items. Low confusability between number and letter stimuli enabled CM pop-out (Shiffrin, 1988). This is evident in session 1 CM single-task detection which was greater in Experiment 1 compared to Experiment 2, even though Experiment 1 participants had to search through twice as many locations. In addition, search was spatially consistent across load because all locations were relevant in both the single- and dual-task without regard to mapping. Experiment 1 participants experienced the smallest dual-task deficit both when dual-tasking was introduced in training and throughout training. However, differences in Experiment 1 VM detection pre- and post training were not significantly different from any of the other experiments with the exception that pre-training VM detection was significantly less than in Experiment 3 (i.e. free search with mixed distractors). In all experiments, the participants successfully complied with the VM priority instruction as evident by lower VM relative to CM deficits; however, performance diverged with respect to CM detection.

Experiment 1 participants had substantially smaller CM detection deficits pre- and post-training. Experiment 3 and 4 were not significantly different from each other in detection despite the fact that pop-out was theoretically possible in Experiment 4 (i.e. CM targets on the VM diagonal and vice versa) and not possible in Experiment 3 (i.e. free search with mixed CM & VM distractors). There was no evidence to suggest that participants were sensitive to partial pop-out; Experiment 4 participants did not have improved single-task detection when compared to Experiment 3 participants. CM deficits in both Experiment 3 and 4 are significantly and substantially less than Experiment 2 (i.e. restricted search with separate CM and VM distractors). Although post-training VM detection was not significantly different across experiments, Experiment 2 was the only experiment still operating with a VM deficit. Furthermore the -3.2% difference between VM single task detection (M=71.5%, SD=13.8%) and VM dual-task detection (M=68.7%, SD=13.8%) was significant.

8.1 EXCLUSIVE CM POP-OUT HYPOTHESIS

The pop-out hypothesis states that tasks that use pop-out should produce less dual-task interference than tasks that do not use pop-out. Furthermore, if pop-out exclusively contributes to the failure that was exhibited in the original VMT than there should be no difference in performance between Experiments 2, 3 and 4 since none use pop-out. CM deficit scores are lower in Experiment 1 compared to all other experiments which is consistent with the pop-out hypothesis. However, the pattern of deficit scores across experiments rules out pop-out as an exclusive source of dual-task deficits. This is because Experiments 3 and 4 had moderate, as opposed to severe, deficits scores. Pop-out facilitates dual-task proficiency giving Experiment 1 participants a clear advantage; CM deficits are both substantially and significantly lower than any other groups.

8.2 EXCLUSIVE CONSISTENT SPATIAL SEARCH HYPOTHESIS

The consistent spatial search hypothesis claims that searching the different locations in the single- and dual-task produces dual-task interference. Furthermore, if consistent spatial search exclusively contributes to the failure that was exhibited in the original VMT than there should be no difference in performance between Experiments 1, 3 and 4 since targets were free to appear in any location across task load in these experiments. Experiments 1, 3, and 4 participants all experienced significantly and substantially less dual-task interference than Experiment 2, as measured by CM deficit scores. However, the fact that deficits where minimal in Experiment 1 and moderate in Experiments 3 and 4, precludes the possibility that consistent spatial search is an exclusive source of the dual-task deficit.

Single-task training in session one appears to result in automating search-location in addition to automating CM target detection. In Experiment 2, only half of the search locations were relevant for each single-task task since CM and VM stimuli occupied separate diagonals and therefore only half of the locations are relevant per task context (i.e. single CM trials vs. single VM trials). If *relevant* search space can be prioritized within task context through consistent practice then both CM and VM locations would begin to develop location-based automaticity resulting from session one training. During session two when dual-task training is introduced, the formerly consistent search space would become varied. As a result, learning to dual-task would require integrating target search across the entire search space; controlled processing would be required for this integration. VM priority would present an additional challenge because although all locations are now relevant for search the participants are also instructed to emphasize the VM diagonal. The additional demands on controlled processing would result in greater dual-task deficits. Furthermore continuing to practice the single-task would exacerbate this interference potentially indefinitely unless multiple overlapping spatial contexts could be automated. In other words, interference would eventually be attenuated if it is possible to divide up the same space and automate different regions based on task context.

An alternative explanation of this interference is that the cost is not due to altering consistency but simply that participants may be unable to perform automatic and controlled search simultaneously over different spaces without cost. This alternative was considered by Schneider and Fisk (1982a) when their participants incurred a CM deficit when diagonal (restricted) search was employed (Experiments 2a, 2c and 3). In the case of their participants, A’ analysis revealed that their participants were equally sensitive to CM targets in the single- and dual-task and therefore the drop in detection was the result of a bias against responding to the CM diagonal (Experiment 3). Based on their results it can be tentatively concluded that simultaneous automatic and controlled detection over separate locations is possible. However, due to the fact that their participants had previously been trained to dual-task without cost, further experiments should be conducted to rule out this alternative interpretation.

8.3 DISTRACTOR SEGREGATION HYPOTHESIS

The distractor segregation hypothesis claims that dual-task interference comes from restricted search; spatially separating distractor sets (i.e. numbers and letters) each of which have distinct priorities (i.e. probabilities of attracting attention) impedes dual-task coordination and integration. As stated above the current data do not support this hypothesis. Experiment 3 and 4 participants had comparable performance during both the single and the dual-task conditions despite the fact that distractors were spatially separated in Experiment 4.

8.4 CM POP-OUT & CONSISTENT SPATIAL SEARCH

In the proceeding sections, all three exclusive source hypotheses have been ruled out. The pattern of pre- and post- training deficit scores are consistent with the predictions that both CM pop-out and consistent spatial search facilitate the development of dual-task proficiency, compare rows '5' and 'Results' in Table 4. Only this combination predicts moderate deficits for Experiment 3 and 4. However, it should be noted, that a similar outcome is predicted if pop-out, consistent spatial search and distractor segregation all contribute to dual-task mastery, see row '7'. In this case, Experiment 4 deficit scores should be at a level intermediate to Experiment 3 and 2 deficit scores; that is consistent search should mitigate the interference produced by distractor segregation. The data does not support this prediction. Although there was a significant difference between Experiment 2 and 4, there was no difference between Experiment 3 and 4 in terms of deficit scores. Furthermore, although this difference is not statistically different, Experiment 4 CM deficits scores are actually less than Experiment 3 which is opposite of the prediction.

Table 4 Deficit score results consistent with predictions (indicated by blue coloration)

Hypotheses	**Exp 1**	**Exp 2**	**Exp 3**	**Exp 4**
1) PO	minimal	severe	severe	severe
2) DS	minimal	severe	minimal	severe
3) CS	minimal	severe	minimal	minimal
4) PO & DS	minimal	severe	moderate	severe
5) PO & CS	**minimal**	**severe**	**moderate**	**moderate**
6) DS & CS	minimal	severe	minimal	moderate
7) All	minimal	severe	moderate	mod-severe
Results	**minimal**	**severe**	**moderate**	**moderate**

8.5 EVIDENCE FOR AUTOMATIC LOCATION SEARCH

The concept of automated location search is supported by existing literature which demonstrates that targets are detected more rapidly in locations that are more likely to contain a target (Miller, 1988; Logan, 1998; Chun and Jiang, 1998; Geng and Behrmann, 2005; Hoffmann and Kunde, 1999; Treisman, Vieira and Hayes, 1992), some of these studies will be reviewed below. Furthermore, this concept is compatible with several accounts of automaticity (Logan 1988; Hasher and Zachs,1979; Schneider, Dumas and Shiffrin, 1984). Although Schneider and colleagues' (Shiffrin, 1988; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) work has focused on the development of automaticity through consistent mapping of stimulus-to-response, they espouse that performance is generally supported by a mixture of controlled and automatic processing in which consistency can effect the development of automaticity on many levels (Schneider, Dumas and Shiffrin, 1984).

Some automaticity models specifically posit that location can be automated (Logan, 1988; Hasher and Zachs, 1979). One such model is Logan's Instanced Based model. According to the model automaticity is a memory phenomenon. Attention to an object or event results in an obligatory encoding in memory. Obligatory encoding extends to all task relevant characteristics (Logan and Etheron, 1994) including spatial location (Logan, 1998). Each event or object is stored separately in an instance representation which can subsequently be retrieved from memory. Separate instance representations or traces are created even when the exact circumstances of an event are replicated, this allows for past solutions to problems to be repeatedly stored. Automaticity is implemented through a horse race model; slow algorithmic solutions race against memory retrieval traces of past successful solutions. A process is automated when the association between the event and the solution is strong enough to enable direct access to a single-step solution. Therefore the fastest trace to be retrieved is the one which is implemented.

Logan (1998) provided support for obligatory spatial encoding and retrieval in a series of experiments involving category search tasks. Participants were required to indicate whether words were members of one of the target or distractor categories. All words consistently appeared in one of 16 locations (Experiments 3) in the test phase. Reaction time decreased over the course of 32 blocks of training during the test phase which indicates the development of automatic processing. Word locations were changed during the transfer phase. Mean RT was15 ms greater for target and distractor words that changed location relative to words that maintained location during the transfer phase; accuracy dropped by 1%. This indicates that participants were sensitive to location change even though the participants were not explicitly require to attend to word location. In a follow-up experiment participants were presented with two words per trial and required to indicate if either word was a target (Experiment 5). Again word location was consistent in the test phase and there were 16 potential locations; reaction time decreased over the test phase. Consistent with the previous result, at transfer mean RT was 31 ms longer for different-location words than same-location words and accuracy dropped by 2%. This experiment also suggests that participants were sensitive to location which was automatically encoded during training. Therefore the speed-up in responses over the test phase reflects both the development of an automatic target detection response and an automatic location detection response.

Treisman, Vieira and Hayes (1992) also found a benefit for location consistency for practiced conjunction targets. According to Treisman’s Feature Integration Theory (Treisman and Gelade, 1980, 2000; Treisman, 1988), sensory features such as line orientation, color and movement are detected automatically and attention is required both for features to be conjoined together into objects and to be located in space. When a target item is distinct from distractors based on a single feature (e.g. color) the target pops-out and detection is insensitive to the number of distractors (i.e. parallel/automatic processing). However if a target (e.g. “R”) is distinct from distractors (“P” and “Q”) based on a conjunction of features (e.g. P-shape + \-shape found in the “Q”) then detection is sensitive to the number of distractors (e.g. serial processing) and therefore target detection is slow because the target does not pop-out. In a series of experiments contrasting *practiced* feature and conjunction targets, conjunction targets were more sensitive to location consistency (Treisman, Vieira and Hayes, 1992). Treisman et al. (1992) trained participants to search for feature and conjunction targets across eight locations (Experiments 2 and 3). Half of the targets were three times more likely to appear in a single location while the remainder of the targets appeared equally in all eight locations (control targets). There was a large effect of position consistency for the conjunction targets which were 465 ms faster (i.e. 38% faster than controls) relative to the feature targets which were only 42 ms faster (9% faster than controls). This benefit also extended to targets that shared a feature with the conjunction target, that is, when shared-feature targets appeared in the conjunction-consistent location they were detected faster. This benefit did not extend to targets that did not share any features with consistent-location conjunction targets.

In other experiments Treisman et al. (1992) contrasted the effects of irrelevant features versus irrelevant locations (Experiment 4). Participants were instructed to look for targets that were *defined by the conjunction of two features*; however, all stimuli were composed of three features. The third feature which was irrelevant (i.e. not included in the definition of the target) but was correlated with one of the two targets. The other target was more likely to appear in one of the locations. Responses were faster when the conjunction target appeared with its high frequency irrelevant feature or in its high frequency irrelevant location relative to random controls. However the benefit was greater for the frequent location (13.0% decrease in RT) versus the frequent feature (7.8% decrease in RT). This is further evidence that consistency in location over training produces an automatic location-specific target detection response.

Similar to the work of Treisman, Vieira and Hayes (1992), Geng and Behrmann (2005) found a benefit for targets that appear in high probability locations as compared to low probability and random locations. In the Treisman et al. study the benefit was highly specific, that is a specific conjunction target was prioritized (i.e. detected faster) when it appeared in its high consistency location; this benefit did not extend to all targets that appeared in that location but it did extend to targets that shared one feature with the prioritized conjunction target. In the Geng and Behrmann study, on the other hand, the benefit was location specific because some locations were more likely to contain targets. In 75% of trials, the target appeared in a single (high probability) location, on the remaining 25% of the trials, targets were equally likely to appear in each of the other (low probability) locations. Detection was compared to even probability blocks in which targets were equally likely to appear in all locations. The participants were required to detect a rotated "T" and indicate if it was pointing to the left or the right.   Targets were detected faster in high probability locations; furthermore, this effect was distinct from repetition priming. Detection was faster when consecutive tasks appear in the same location (i.e. repetition priming) but there was an additional RT decrease associated with high probability locations.

In another visual search task, Chun and Jiang (1998) demonstrated a benefit for targets that appear in learned configurations, they have termed this effect "Contextual Cueing".

According to Chun and Jiang human visual processing is sensitive to covariations in the environment and therefore can use this sensitivity to constrain visual processing. They claim that, “global properties of an image can prioritize objects and regions in complex scenes for selection, recognition, and control of action.” (Chun and Jiang , 1988, p. 30). They trained participants to detect a rotated “T” in an array of “L”s that were randomly rotated; all stimuli were randomly positioned and colored. The participants had to indicate if the rotated “T” was pointing left or right. The participants assessed 300-372 array configurations, 12 of which were repeated per block (position, rotation and color of all items were replicated). The target was identified quicker when it appeared in the repeated context (i.e. one of the 12 repeated arrays). When new configurations were introduced, target detection increase when a target appeared in the repeat configuration target location. According to Chun and Jiang, contextual cueing occurs because there is a consistent mapping between target location and visual context (i.e. targets can not appear in that location while being embedded in different distractor configurations). Once the mapping is varied (i.e. targets can appear in the same location while embedded in different distractor configurations), reaction times increase. They also demonstrated that contextual cueing can generalize to two locations (i.e. more than one location can be prioritized by a specific repeated context). Finally, their participants were generally unaware of that repeats occurred.

In the aforementioned research, attention is biased to specific locations to facilitate target detection. Targets that appear in consistent locations are prioritized and as a result are detected faster. When location consistency is varied response time increases. This is consistent with automaticity accounts; additionally, selection based on location is supported by the biased competition model (Desimone & Duncan, 1995) which is a model of neuronal visual processing. According to the model, visual objects compete for representation, analysis and the control of behavior. In the model, an attentional template specifies the properties used for selection. In visual search, if distractors are a poor match to the template, they receive a weak competitive bias. In that circumstance target detection will be fast and may be independent of the number of distractors. On the other hand, if distractors are a good fit for the attentional template then targets have less of a competitive advantage because non-targets also receive bias for selection. In this case distractors interfere with target detection and search is dependent on the number of distractors. According to Desimone and Duncan, “Prior knowledge of the target’s spatial location is just another type of attentional template that can be used to bias competition in favor of the targets”, (Desimone and Duncan, 1995, p. 200).

In the model, stimuli compete for neuronal processing; one area of competition is the receptive fields in the ventral stream. Spatial selection enhances target processing at the attended location; in addition, the ventral stream also resolves competition with other stimuli in the receptive field. When targets and distractors both occur in a receptive field, cells respond only to the target as if the receptive field has shrunk around the target. Responses to a neighboring distractor are suppressed.

In the case of the reviewed and the current research, prior context specific training produces a location biased template that can facilitate target detection both through enhancing targets and suppression of neighboring distractors. In the case of the Visual Multi-Task when the number and letter task appear on separate diagonals (Experiment 2), this would suggest that single-task training produces a spatial-based attentional template that enhances context specific locations and suppresses non-relevant locations. For example, training the number single-task would enhance the number task diagonal where target items may occur while suppressing all items in the letter task diagonal where only distractors will occur. When dual-task training is introduced, these spatial-based attentional templates would be incompatible and any suppression of "distractor areas" would result in suppression of the other component task. The VM prioritization instruction appears to have shielded VM detection since it was comparable to VM detection in the other experiments; however CM detection experienced a substantially large co-occurrence cost. The large post-training CM deficit and drop in sensitivity may reflect ongoing suppression of the CM task as a result of a VM-based location template.

8.6 LIMITATIONS OF THE CURRENT RESEARCH AND FUTURE DIRECTIONS

The current research demonstrates that pop-out and consistent spatial search facilitate cost-free detection when a dual-task contains an attention consuming (varied-mapped) task. Dual-task interference was reduced in three separate experiments when the same areas were searched across task load. The distractor segregation hypothesis was rejected based on comparisons between Experiment 3 and Experiment 4 participants which required assumptions regarding task equivalency. Critical to this interpretation is the assumption that Experiment 4 participants could not capitalize on CM/VM pop-out. Additional research should be conducted to verify the results. For instance, if inconsistent spatial context is the source of Experiment 2 interference then comparable levels of interference should occur if restricted search is implemented with a mixed CM-VM distractor set. Furthermore, restricted search with a VM-only distractor set should also produce substantial interference; however it should be less than Experiment 2 as a result of CM pop-out.

The component tasks in the current work involved text-based search. Number and letter stimuli share overlapping processing resources which likely contribute to dual-task interference

(Wickens, 1980; 1984; 2002; Lintern and Wickens, 1991). If inconsistent spatial context generally contributes to dual-task interference then spatial inconsistency should also produce interference in visual search tasks that share *relatively* less processing resources (e.g. number and color search).

Future research should also verify the role spatial inconsistency in CM-CM dual-task deficits. Consistent spatial search may substantially reduce the amount of dual-task practice necessary to develop proficiency when component tasks are automatic. Extensive single-task training typically does not eliminate dual-task deficits (Detweiler and Lundy, 1995; Hill and Schneider, 2007, Schneider and Fisk, 1984), and therefore single-task training has been regarded as insufficient; however like CM-VM dual-tasks, CM-CM tasks typically involve spatial location inconsistency. Schneider and Detweiler (1988) posit that dual-task practice is necessary to produce timesharing skills that can not be developed from isolated practice. Researchers have debated the relative value of part-task versus whole-task training for many decades (Schneider, 1985; Stammers, 1980, Detweiler and Lundy, 1995; Mané, Adams, Donchin, 1989; Naylor and Briggs, 1963; Rieck, Ogden, Anderson, 1980; Wightman and Lintern, 1985), in a review by Stammers (1982) he concluded with a *cautious* recommendation that it is more preferable to train the whole task.

Dual-task practice is clearly important and necessary; however, the current work demonstrates that training time may be effectively reduced and performance increased through considerations of internal task consistency. The participants in Experiments 1, 3 and 4 likely received dual-task detection benefits from both single- and dual-task training because the single-task search was not inconsistent with the dual-task search.

Consistency is easily controlled in a search task, although minimizing inconsistency is challenging in the real-world, there are clear substantial benefits for performance. A recent study by Gonzalez and Thomas (2008) demonstrated that consistent-mapping of visual and memory search components of a Radar task facilitated decision making even though the decision making components of the task were variable. Varied-mapping is resource intensive, the work of Gonzalez and Thomas and the current work highlight the importance of eliminating unnecessary inconsistency which can be particularly detrimental in high workload situations.

Technology utilization is becoming increasingly prevalent for laypeople (e.g. personal computers, GPS, smart phones, vehicle computer systems, etc.) and therefore considerations of usability is no longer relegated to technical professions (e.g. piloting and air traffic control); as a result, consistency in graphic user interfaces (GUIs) is important to minimize error and risk as well as increase productivity. The human factors/human-computer interface (HCI) literature also highlights the importance of consistency in technology and technical training (Pirolli, 1999; Polson, 1988; Howes and Young, 1996; Ozok & Salvendy, 2000; 2001; Tanaka, Eberts & Salvendy, 1991; Rogers, Rousseau & Fisk, 1999). The HCI literature has examined the effects of multiple levels of consistency such as the effects of syntactic and mnemonic consistency (Payne and Green, 1986; 1989) as well as the consistency of task-action mappings (Howes and Young, 1996) on user performance. This work provides evidence that consistent interfaces benefit application learning and performance. The consistency benefit is not limited to the ease of operating devices. A study by Ozok and Salvendy (2000) found that comprehension of web page content is decrease by physical inconsistency -- label, text and pictorial locations and spacing. Therefore location consistency is important for knowledge acquisition as web- and software- based learning is becoming more prevalent in formal and informal education.

Consistency between technical applications (e.g. Macintosh and Windows operating systems) and across application versions is the exception (Polson, 1988); therefore, product design can benefit from cognitive research (Pirolli, 1999; Rogers, Rousseau & Fisk, 1999). An appreciation of the importance of interface consistency has led to the development of UNIFORM, a remote control device that generates user-specific controls based on prior interface experience (Nichols, Myers & Rothrock, 2006). The current work suggests that tools such as UNIFORM, and applications that allow the user to influence design in order to generate experience-based consistent interfaces will be beneficial to skill acquisition involving technology.

8.7 NOVEL FINDINGS

When attempting to timeshare an attention-consuming task, participants must be instructed to prioritize that task (i.e. the VM task, Schneider and Fisk, 1982a). The current work clearly demonstrates VM priority training is not sufficient for dual-task mastery. Reducing target/distractor confusability clearly played an important role in dual-task ability. Participants who trained under free search with VM-only distractors experienced considerably less interference than those who trained under free search alone. The benefit of reducing confusability in task design is not surprising. Shiffrin (1988) already posited that extremely low confusability could potentially eliminate load effects. However, it is important nonetheless to highlight that reducing confusability should be an explicit design goal. Previous work in which participants successfully learned a highly-confusable CM-CM VMT (Hill and Schneider (2007) resulted in overlooking the importance of confusability when a VM-CM design was implemented in the VMT. Both confusability and task load impose demands on cognitive control.

This work demonstrates that in order to effectively timeshare a controlled processed task it is important not to introduce other task elements that require attentive control such as introducing spatial inconsistency when attempting to simultaneously perform two tasks. Spatially inconsistent single-task training produces substantial, prolonged CM dual-task detection deficits. Given sufficiently high workload (VMT pilot studies, see appendix D) participants may be unable to prioritize the VM task despite extensive training.   Participants in Experiment 2 were able to prioritize the VM task and benefit from practice, due to reduction in the number of search spaces; however, they clearly required considerably more training to develop competency. Maintaining spatially consistent search across task loads was beneficial under various distractor configurations. This affirms the importance of consistency, in addition to minimizing confusability, in the development of automaticity. This dissertation demonstrates that consistency effects are not restricted to stimulus-to-response mappings. Automaticity can be developed at multiple levels simultaneously (Logan 1988; Schneider, Dumas and Shiffrin, 1984) therefore in order to bolster performance, it is important to identify and rectify potential sources of inconsistency.

APPENDIX A

DETECTION CALCULATION EQUATIONS

The accuracy data will be reported in terms of % deficit. First % hit rate reflects detection accuracy, see below, and is calculated independently for the single- and dual-task. The dual-task hit rate is not a combined score from both tasks, rather it reflects the detection rate for each component task in the dual-task condition. Therefore, four scores are calculated-- single-number, single-letter, dual-number and dual-letter.

<u>% Hit Rate Formula</u>
This value uses the false alarm rate to scale the number of observed hits. This scaling is deemed necessary due to the pace of the task, the display changes every 150 or 200 msec, and the high workload nature, either 600 or 800 stimuli are presented per trial.

% hit rate = (estimated hits * 100)/(observed hits + observed misses)

estimated hits = observed hits – (hit time * FA rate)
FA rate = observed false alarms / FA time
FA time = total time – miss time – hit time
miss time = observed misses * maximum response time
hit time = (observed hits * observed hit RT) – minimum response time
total time= 30000 msec
maximum response time = 1000 msecs
minimum response time = 200 msec

<u>Dual-Task Deficit Formulas</u>
% Dual-number hit rate = (dual-number hit rate – single-number hit rate) / single-number hit rate
% Dual-letter hit rate = (dual-letter hit rate – single-letter hit rate) / single-letter hit rate

APPENDIX B

SESSION 2 DUAL-TASK INSTRUCTIONS

B.1 GROUP 1 PARTICIPANTS: CM-NUMBER & VM-LETTER

For the remaining sessions your goal is to learn to perform both tasks as a dual-task. You will continue to perform the number and letter single-tasks. And you will also perform both tasks together as a dual-task.

From this point on you have to remember that your number targets are "1" and "8". When you perform the number single-task or the number-letter dual task, you will notice that 2 dots will appear on the screen. These dots are to remind you that you are looking for the two number targets, "1" and "8". Since your letter target will continue to change on each trial, you will still be told which letter is your current target.

When performing the dual-task prioritize the letter task. This means that you will put your efforts towards finding the letter target. When you happen to notice a number target, please respond to it.

You will be able to earn bonuses during the dual-task trials. The computer will evaluate your letter performance during these trials. You will be paid $.25 for each dual-task trial when you perform well on the letter task.

Do you have any questions?

B.2 GROUP 2 PARTICIPANTS: CM-LETTER & VM-NUMBER

For the remaining sessions your goal is to learn to perform both tasks as a dual-task. You will continue to perform the number and letter single-tasks. And you will also perform both tasks together as a dual-task.

From this point on you have to remember that your letter targets are “A” and “C”. When you perform the letter single-task or the letter-number dual task, you will notice that 2 dots will appear on the screen. These dots are to remind you that you are looking for the two letter targets, “A” and “C”. Since your number target will continue to change on each trial, you will still be told which number is your current target.

When performing the dual-task prioritize the number task. This means that you will put your efforts towards finding the number target. When you happen to notice a letter target, please respond to it.

You will be able to earn bonuses during the dual-task trials. The computer will evaluate your number performance during these trials. You will be paid $.25 for each dual-task trial when you perform well on the number task.

Do you have any questions?

APPENDIX C

TRIAL SCHEMATICS

C.1 THE VMT TRIAL STRUCTURE

Next is an example of a consistently mapped single-task letter trial. The instruction screen indicates that the current targets are “A” and “C” during session one. Two dots would appear in place of the “A” and “C” on all subsequent sessions; the participants would have to remember that “A” and “C” are the letter targets. The trial automatically begins and the participant is required to respond with the letter key whenever either letter target appears. Feedback is presented at the end of the trial.

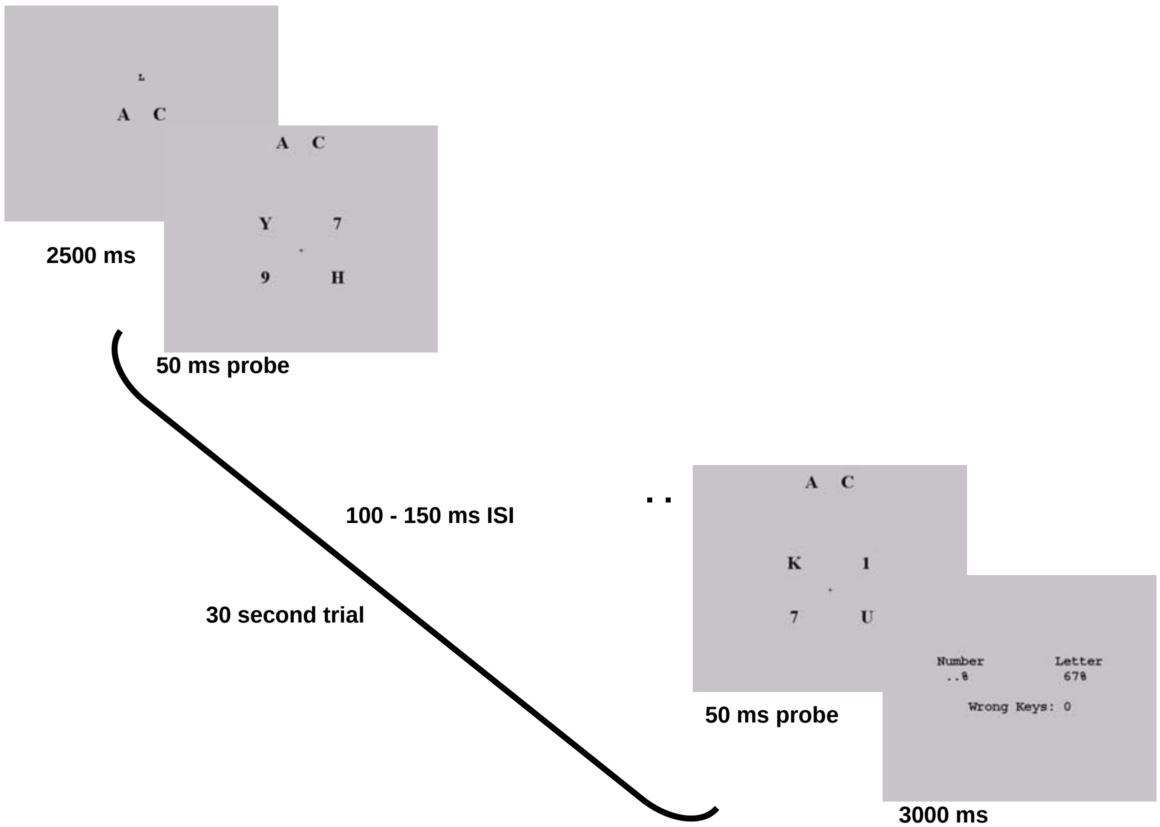


Figure 14. Schematic of a Visual Multi-Task trial

C.2 EXPERIMENT 1 PROBE SCREENS

Group 1 is assigned to number-CM and letter-VM (top boxes) while group 2 is assigned to letter-CM and number-VM (bottom boxes). The current target(s) appears on the top of the screen, the search locations are below. CM/VM targets are free to appear in all four locations. Distractors are populated from the VM set.

Group 1

Group 2

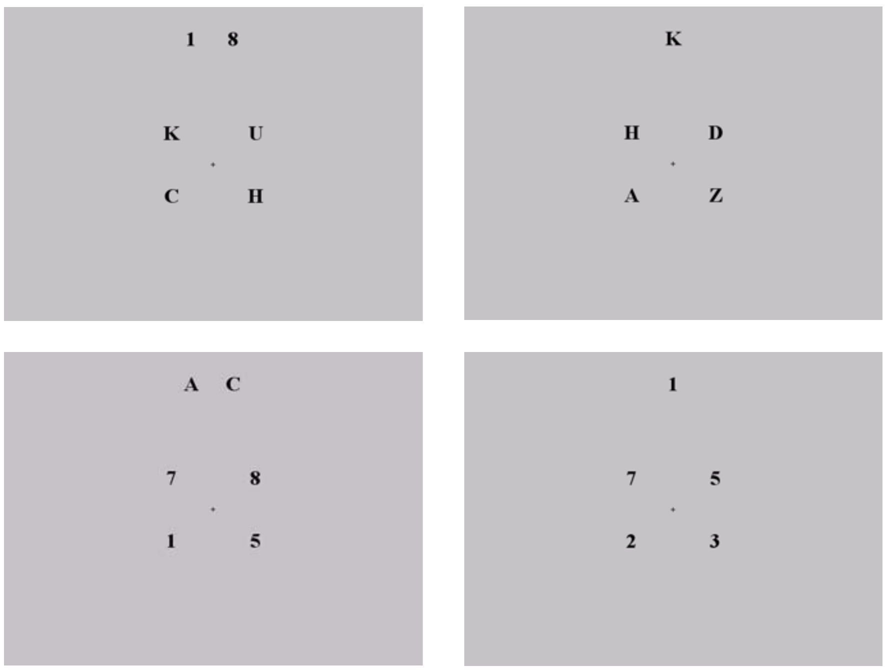


Figure 15. Experiment 1 probe screens for CM and VM trials, left to right respectively

C.3 EXPERIMENT 2 PROBE SCREENS

Group 1 is assigned to number-CM and letter-VM (top boxes) while group 2 is assigned to letter-CM and number-VM (bottom boxes). The current target(s) appears on the top of the screen, the search locations are below. Targets and distractors are restricted to separate CM and VM diagonals. Letter search appears one diagonal, upper-left corner to lower-right corner, and number search appears on the other diagonal, upper-right corner to lower-left corner.

Group 1

Group 2

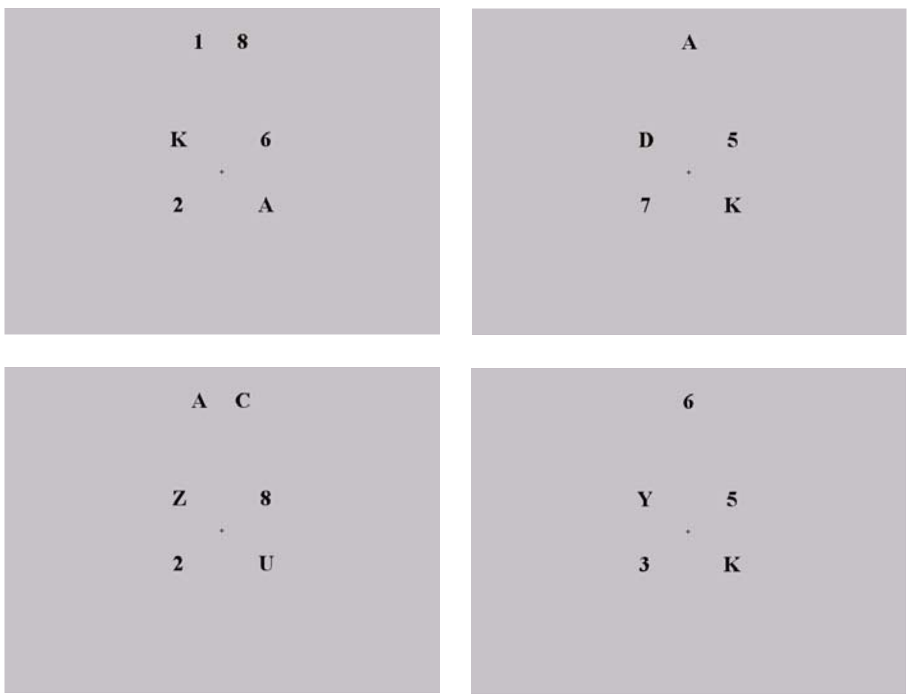


Figure 16. Experiment 2 probe screens for CM and VM trials, left to right respectively

C.4 EXPERIMENT 3 PROBE SCREENS

Group 1 is assigned to number-CM and letter-VM (top boxes) while group 2 is assigned to letter-CM and number-VM (bottom boxes). The current target(s) appears on the top of the screen, the search locations are below. CM/VM targets are free to appear in all four locations. Distractors are populated from a mixture of the CM and VM set.

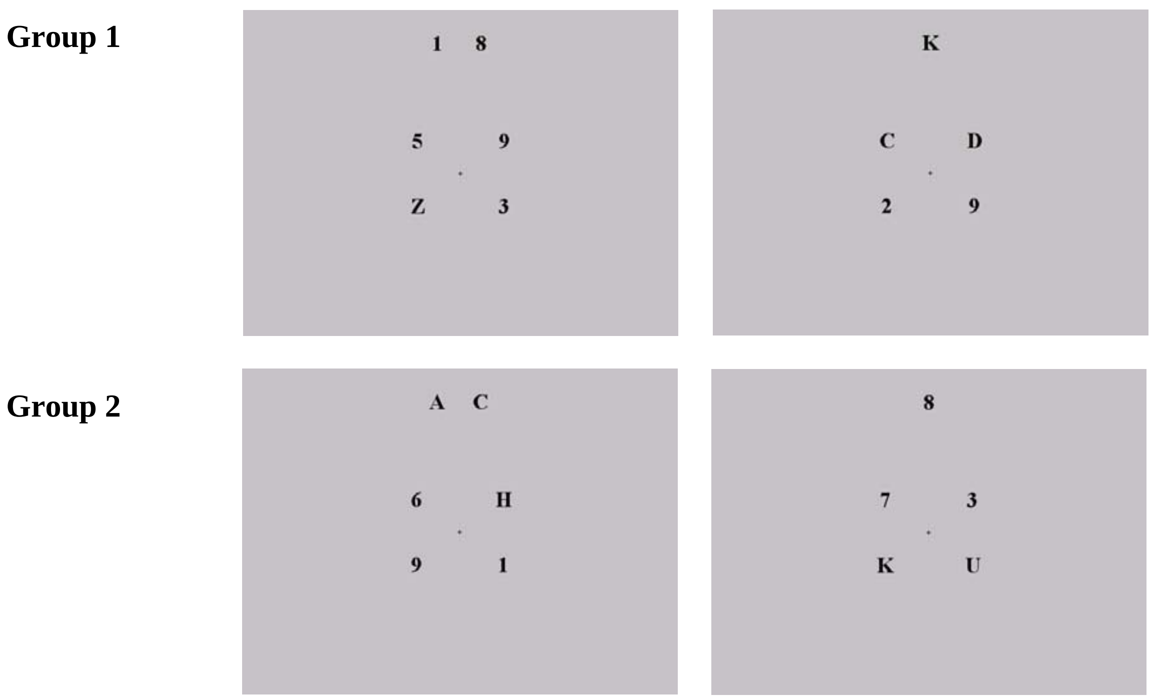


Figure 17. Experiment 3 probe screens for CM and VM trials, left to right respectively

C.5 EXPERIMENT 4 PROBE SCREENS

Group 1 is assigned to number-CM and letter-VM (top boxes) while group 2 is assigned to letter-CM and number-VM (bottom boxes). The current target(s) appears on the top of the screen, the search locations are below. CM/VM targets are free to appear in all locations. Letter distractor appears one diagonal, upper-left corner to lower-right corner, and number distractors appears on the other diagonal, upper-right corner to lower-left corner.

Group 1

Group 2

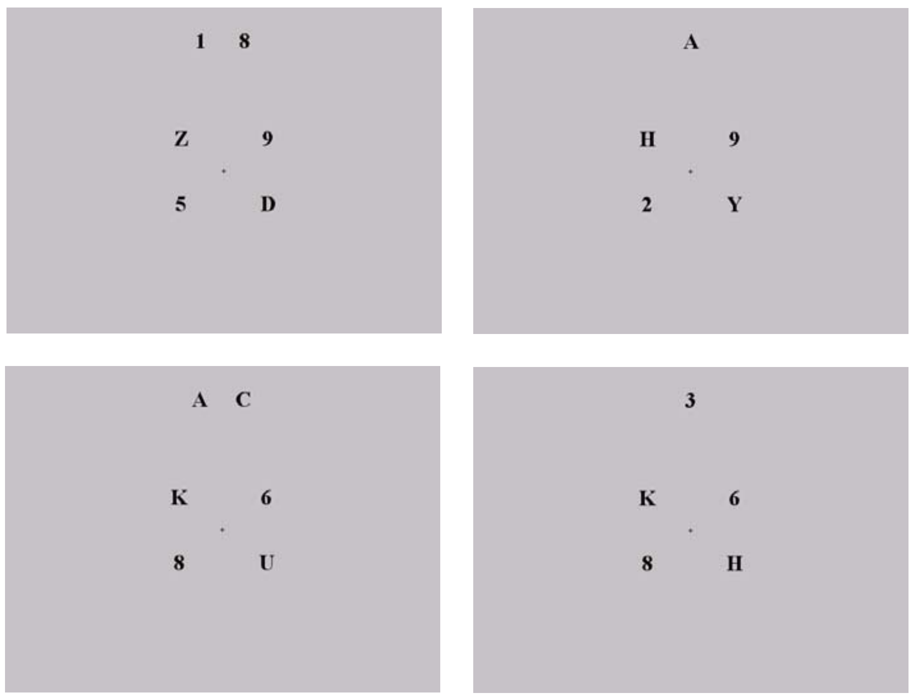


Figure 18. Experiment 4 probe screens for CM and VM trials, left to right respectively

APPENDIX D

VMT PILOT STUDIES

D.1 GENERAL METHODS

D.1.1 Participants

All participants were University of Pittsburgh Introduction to Psychology students. They participated in four 1-hour long sessions of testing for class credit.

D.1.2 Task Design and Procedures

In the original VMT the number- and letter-search tasks either had eight total search locations (pilot 1) or six total search locations (pilot 2). During the first training session the participants practiced the number and letter single-tasks separately, one task was assigned to the CM condition and the other task was assigned to the VM condition.

Session one training was adaptive, that is the task could be performed at three speeds and it accelerated as performance increased. The three speeds were 1) fast= 100 ms probe + 100 ms ISI, 2) moderate = 150 probe + 150 ISI, and 3) slow = 200 probe + 200 ISI. Training began with the moderate speed and speed could be adjusted during every block— if average block detection was 85% or greater the task increased speed by one level (up to the maximum speed) and if average block detection was less than 70% the task speed decreased by one level (down to the minimum speed). The speed was adjusted for each task separately; for example, number detection could have the fast timing while letter detection could have the slow timing. However, during a single-number trial, the entire display, number and letter stimuli alike, would have the fast number timing, and likewise for the letter single-trial. The timing for the remaining sessions was determined by the final block of session 1 timing for each task. Again, if the last average block detection was 85% or greater the task increased speed by one level (up to the maximum speed) and if average block detection was less than 70% the task speed decreased by one level (down to the minimum speed). As a result of adaptive training, during the dual-task trials the two tasks could have asynchronous timing. This was done in an attempt to coarsely equate difficulty across tasks and performers.

During the remaining three sessions the participants trained entirely on dual-task trials. During the beginning of the second session; however, the participants were administered one block of CM and VM trials in order to have a baseline measurement of single-task performance. This measure was used to calculate dual-task deficit scores, see Appendix A.

D.1.3 Results

In pilot study 1 both the CM and VM tasks had four search locations. Participants were instructed to prioritize the VM tasks which required them to concentrate on maintaining VM performance even at the expense of CM performance. VM priority training is necessary in order to learn to dual-task a CM-VM task without cost (Schneider and Fisk, 1982a). Participants were unable to learn to prioritize the VM task, in fact, performance declined over the course of three sessions of training as evident by the negative dual-task detection scores, see Figures 20 and 21. Negative scores indicate that single-task detection is greater than dual-task detection. It appears that the participants attempted to prioritize the VM task because initial detection was lower for the CM task. CM detection; however did improve with practice, but there was a substantial post-training cost. The participant's performance appeared more consistent with dual-task performance when the CM task is prioritized (Schneider and Fisk, 1982a; Experiment 2b). Unwillingness or inability to prioritize the VM task produces dual-task interference that can not be attenuated by practice (Schneider and Fisk, 1982a Experiments 2b and 4). Therefore the task in pilot study 1 appears unable to be learned.

The number of search locations was predicted to be problematic for dual-task search. The VM search locations were reduced to two. CM search is less capacity limited and therefore the number of CM search locations was unchanged. A total of six search locations were employed in pilot study 2. The result, however, was consistent with pilot study 1. VM dual-task detection was unaffected by practice while CM detection improved, again resembling CM priority. This time, there was a CM detection plateau between sessions two and three; however this did not reflect an opportunity for VM improvement which remained unchanged. Again it appears that participants attempted unsuccessfully to prioritize the VM task since initial CM performance had a greater deficit than initial VM performance.

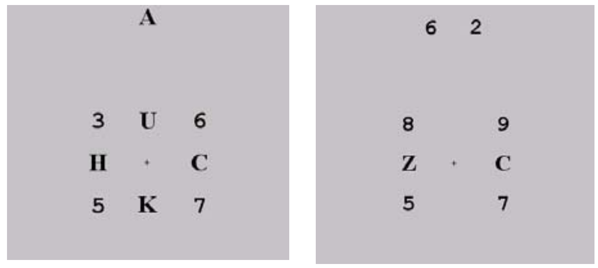


Figure 19. Task layouts for pilot study 1 (left) and pilot study 2 (right)

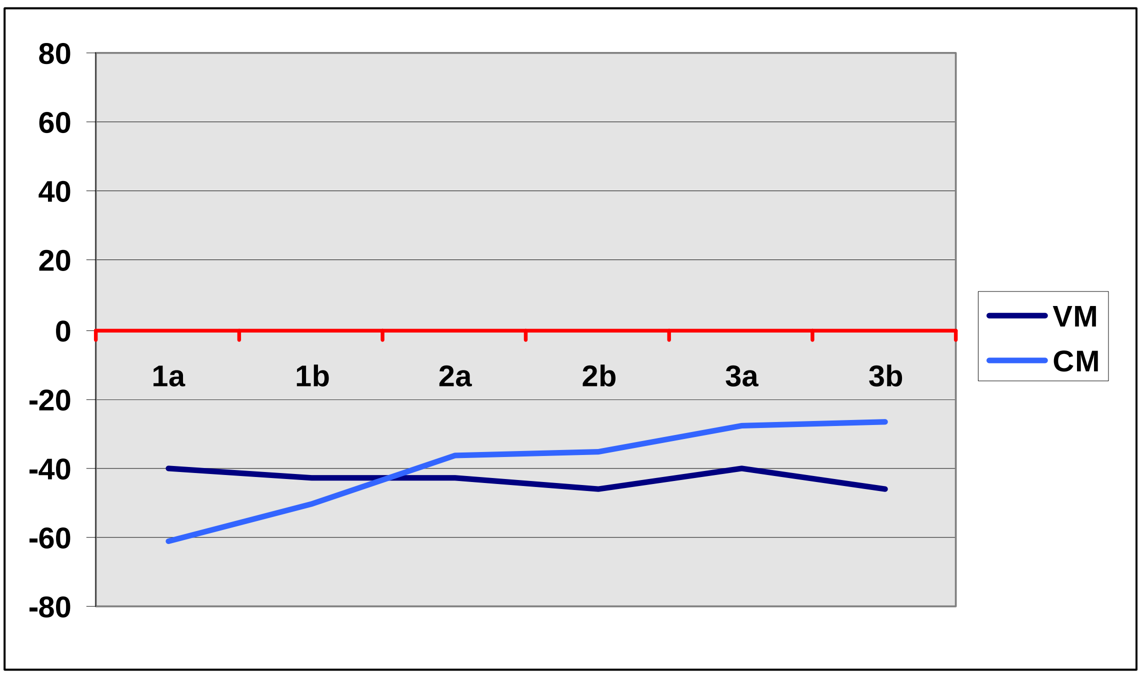


Figure 20. Pilot Study 1 dual-task % deficit scores over 3 (half) sessions

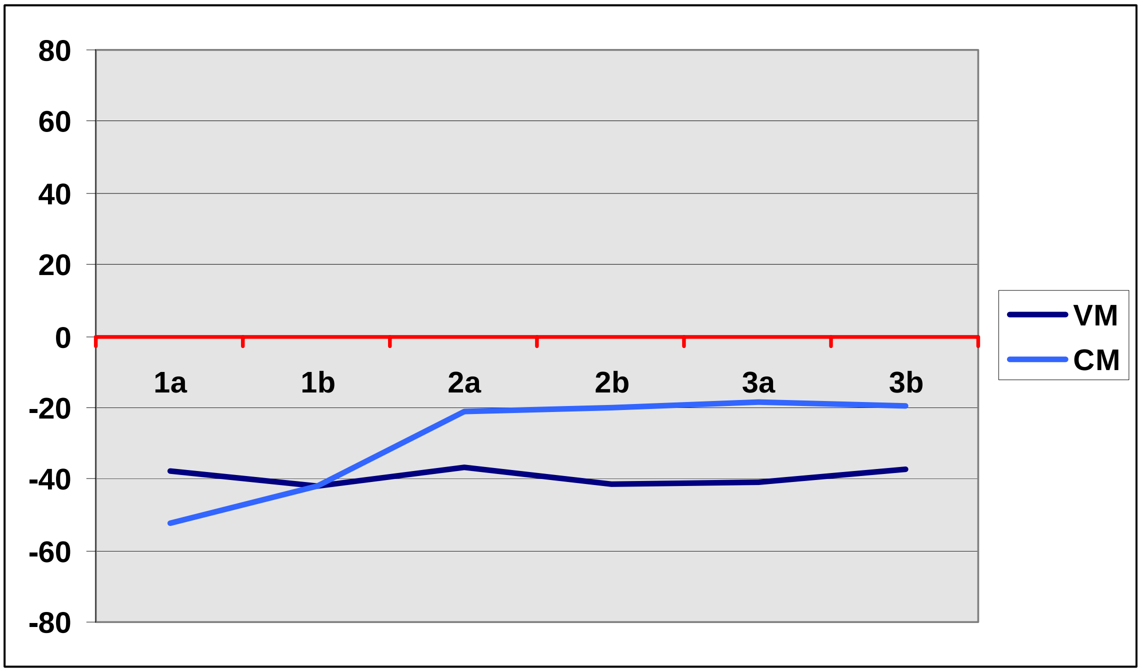


Figure 21. Pilot Study 2 dual-task % deficit scores over 3 (half) sessions

APPENDIX E

VMT % HIT RATE DATA

This appendix contains single- and dual-task detection data. All scores are % hit rate, see appendix A for formulas.

E.1 APPENDIX SECTION

The figures below depict the single-task detection data for session 1, broken down by mapping (CM, VM) and task speed (i.e., frame rate: fast/slow).

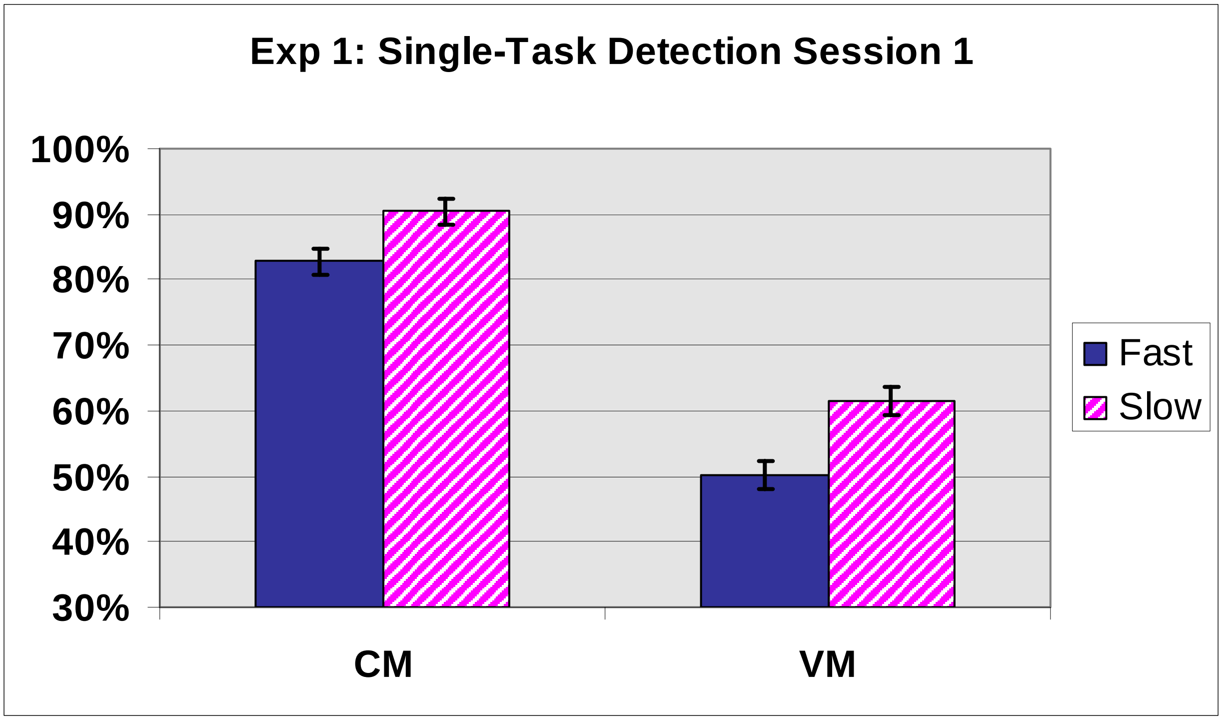


Figure 22. Experiment 1 session 1 single-task data

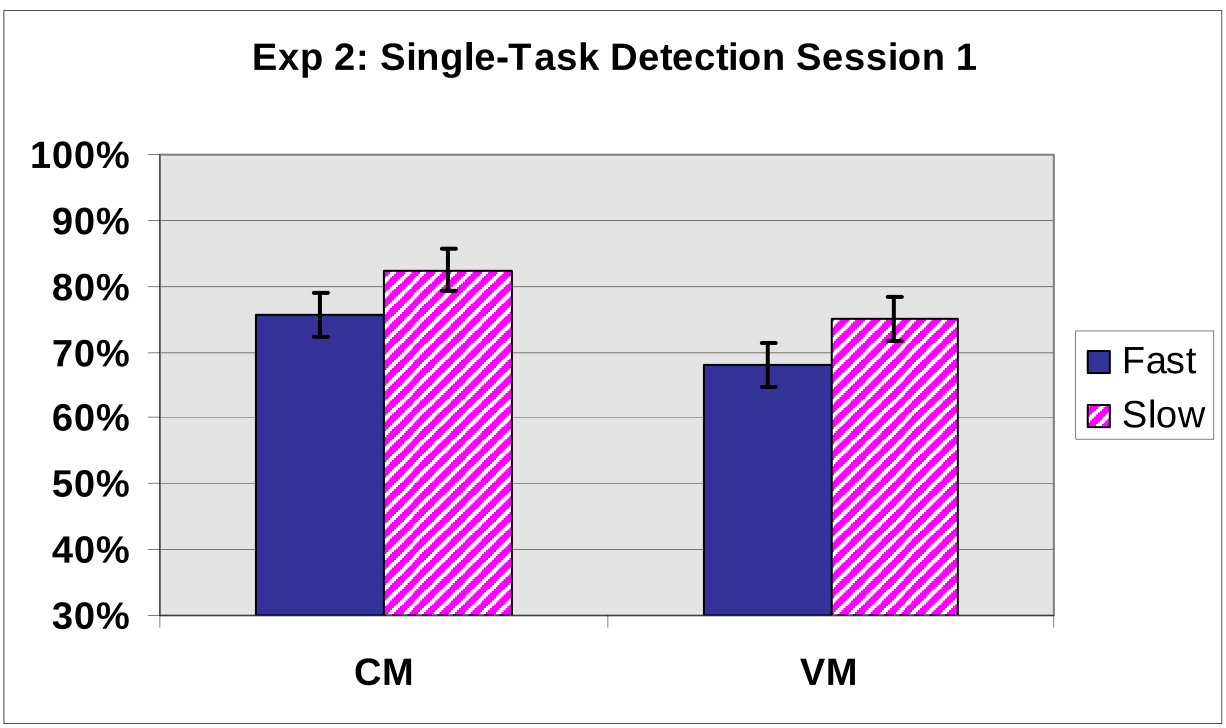


Figure 23. Experiment 2 session 1 single-task data

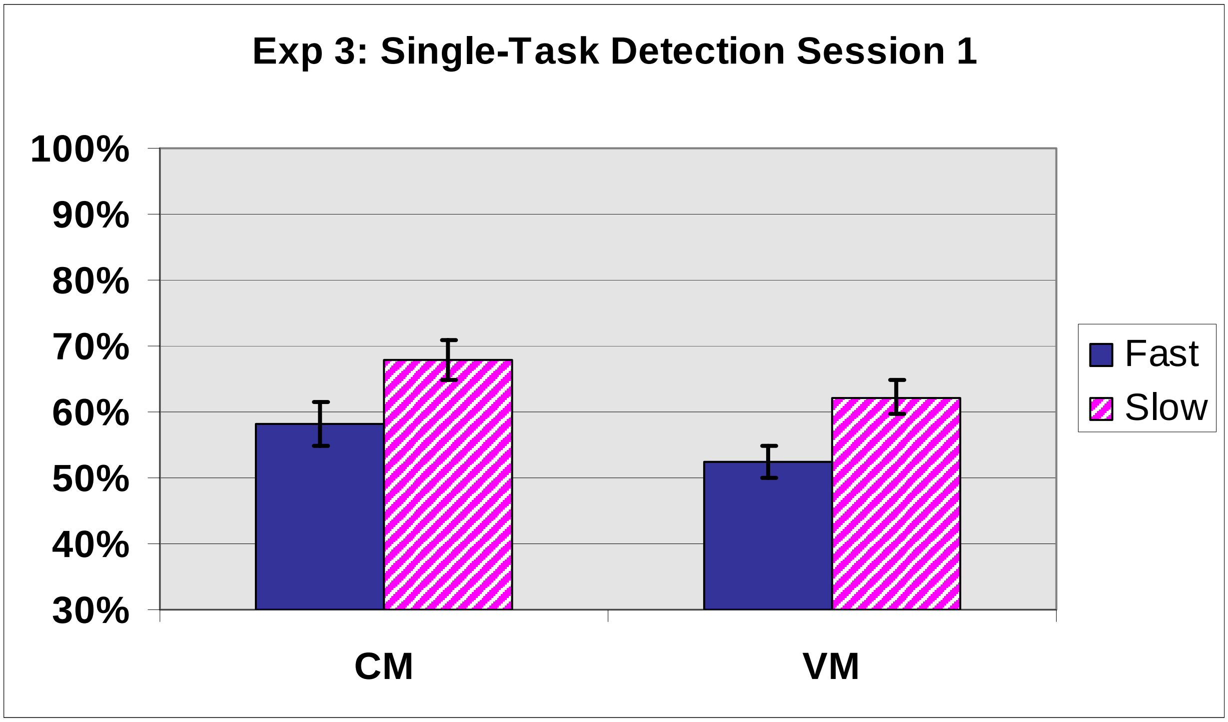


Figure 24. Experiment 3 session 1 single-task data

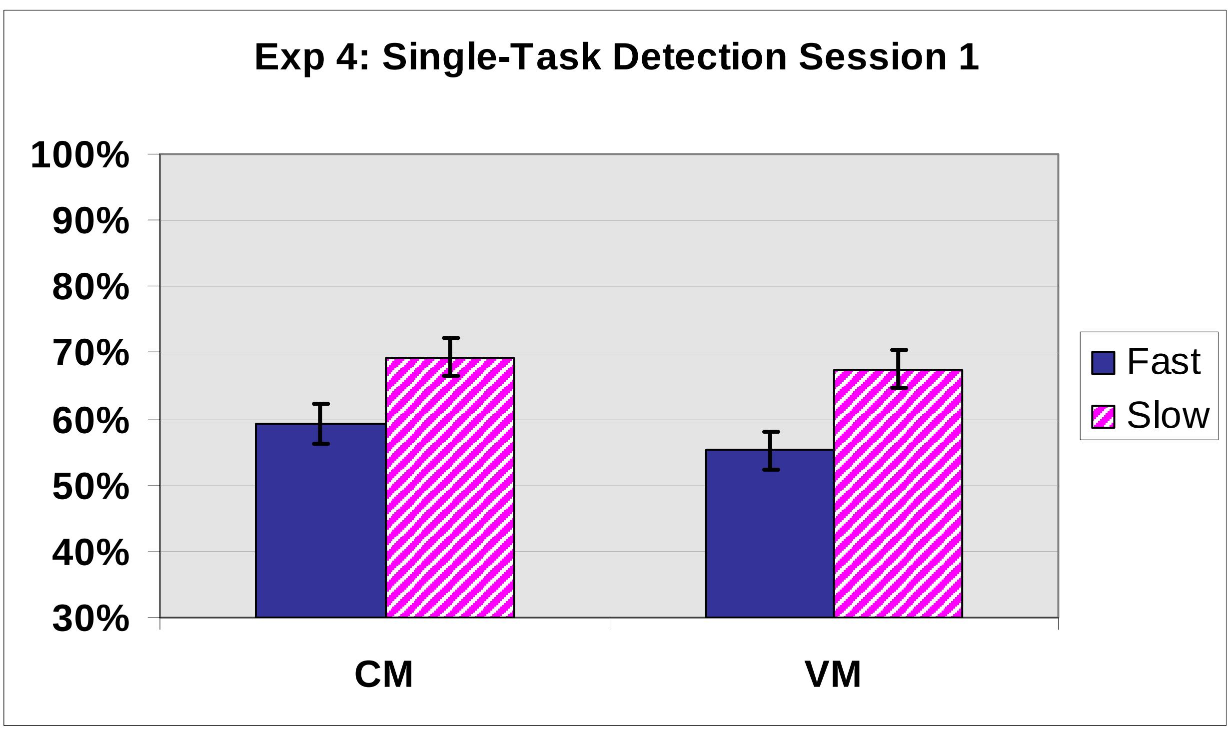


Figure 25. Experiment 4 session 1 single-task data

E.2 APPENDIX SECTION

The figures on the following pages depict the single-task and dual-task detection data for sessions 2 - 6, broken down by task load (single: S, dual: D) and task speed (i.e., frame rate: fast/slow).

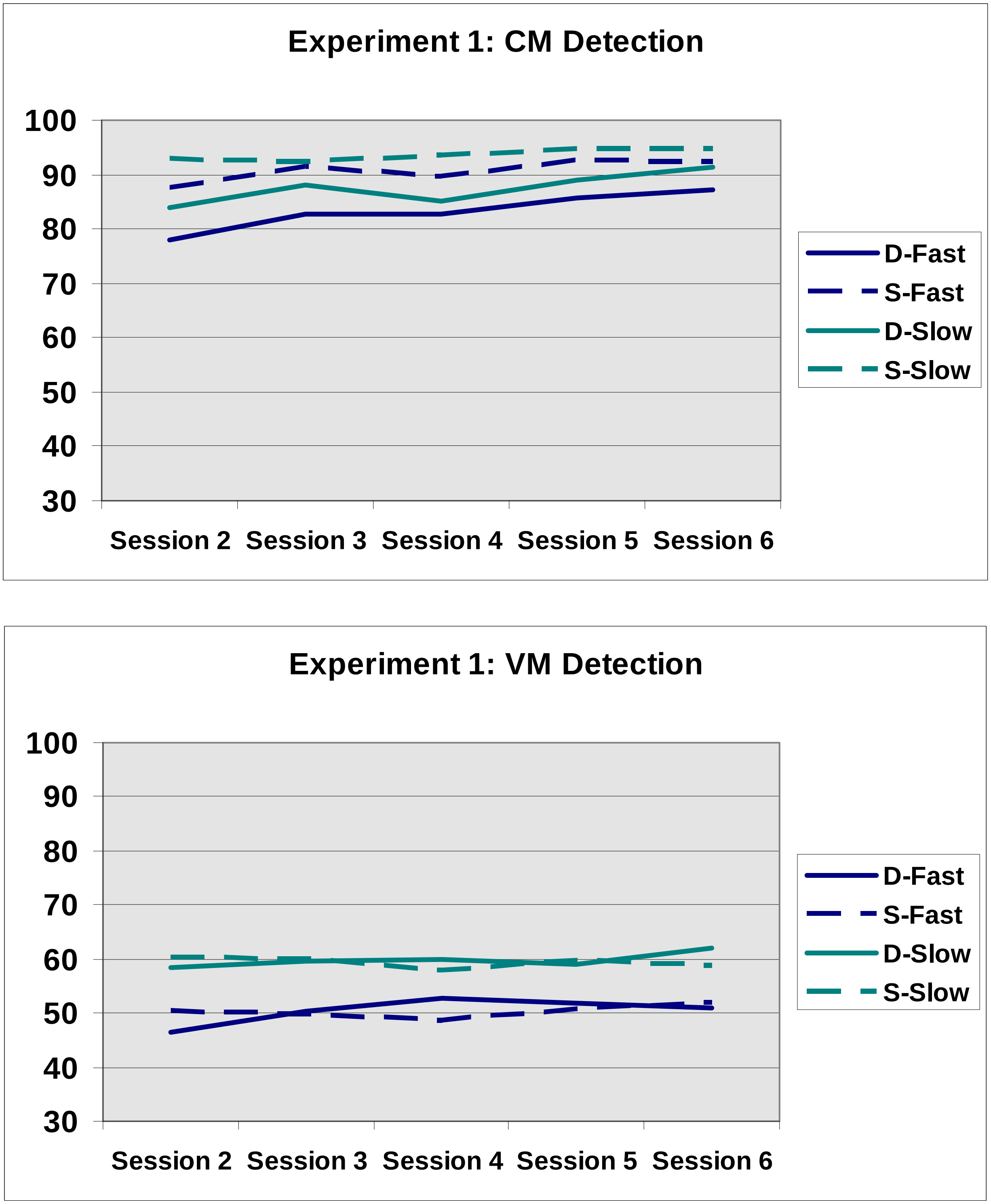
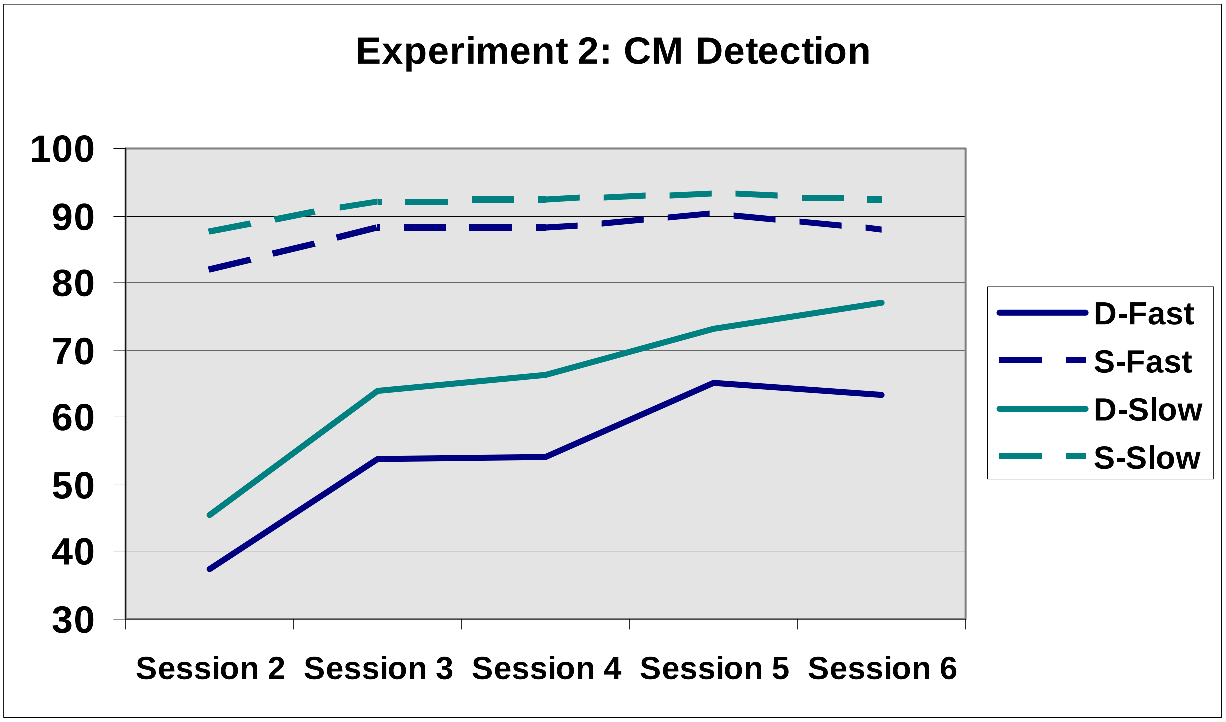


Figure 26. Experiment 1 CM and VM detection



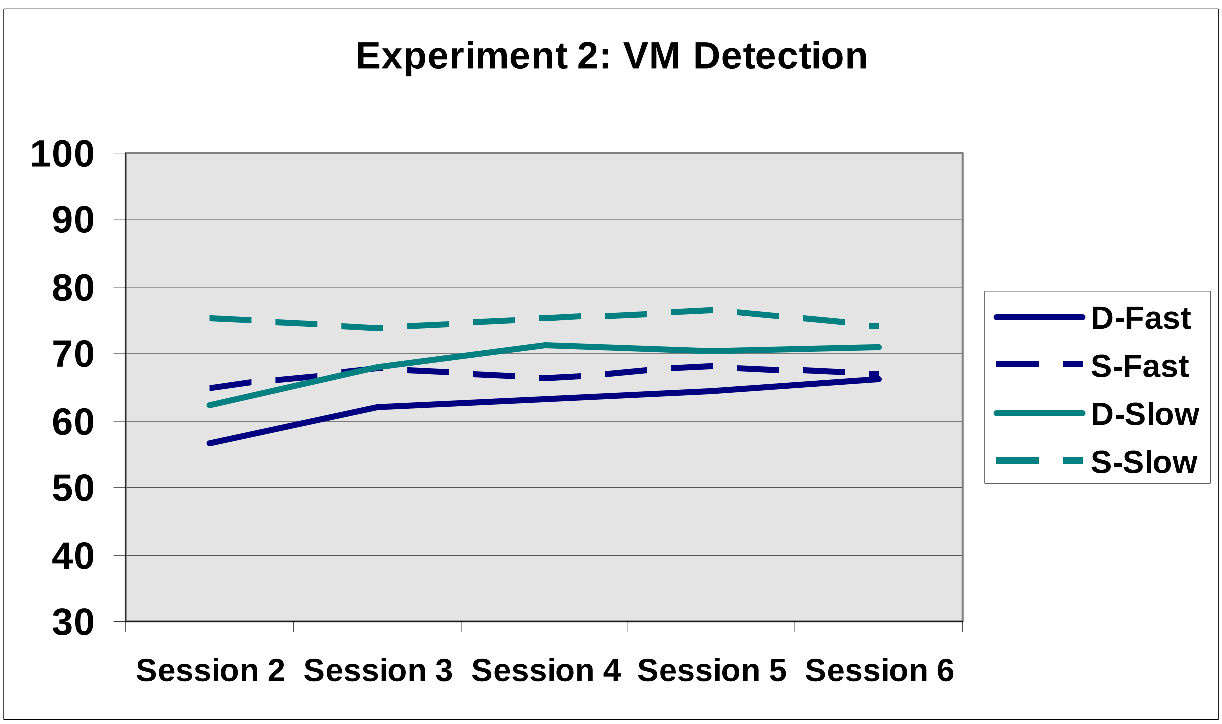
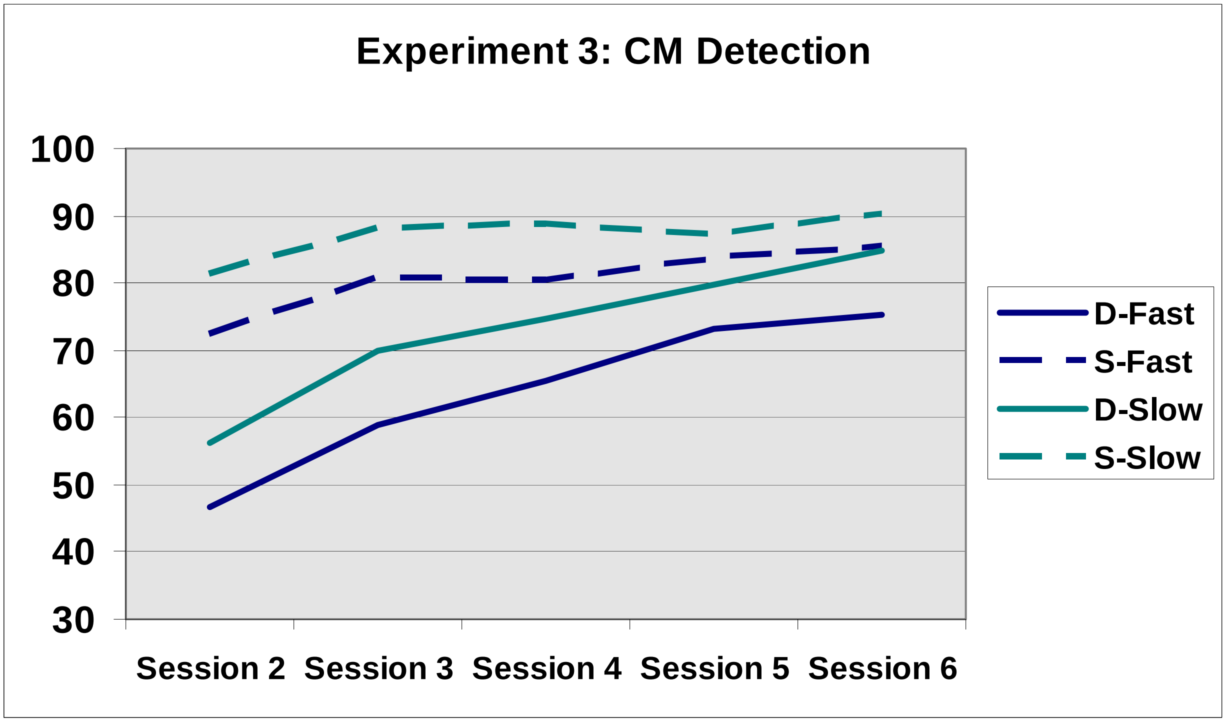


Figure 27. Experiment 2 CM and VM detection



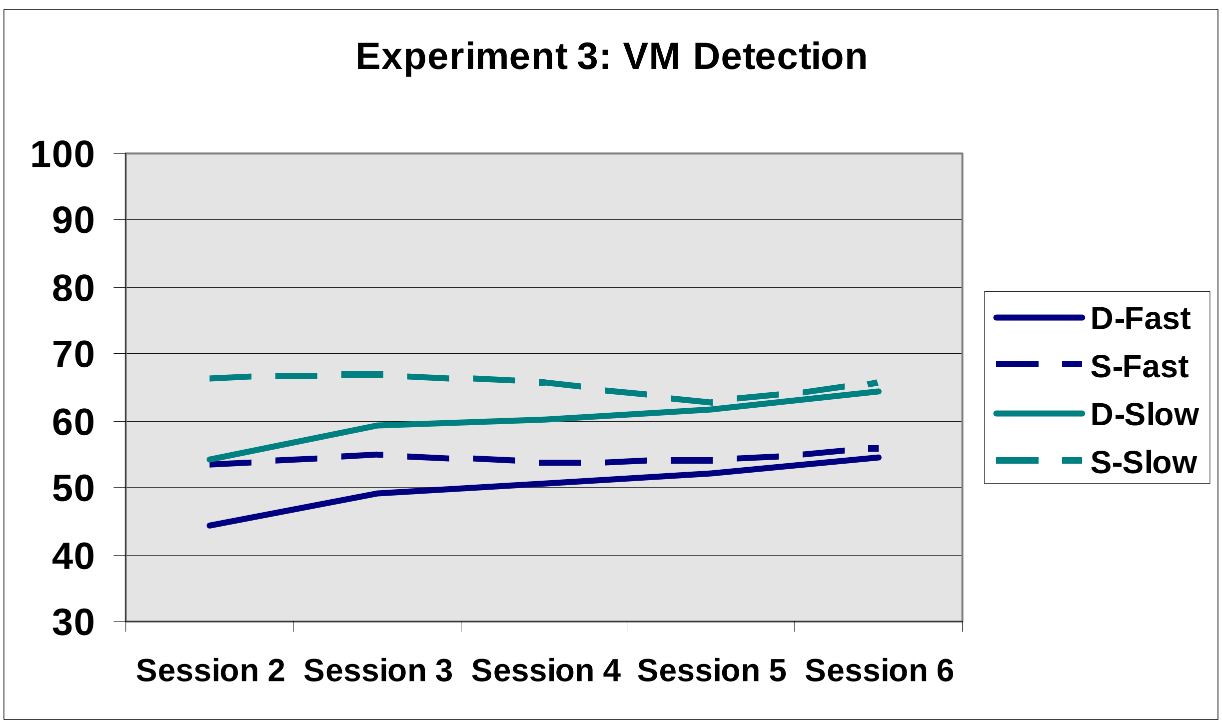
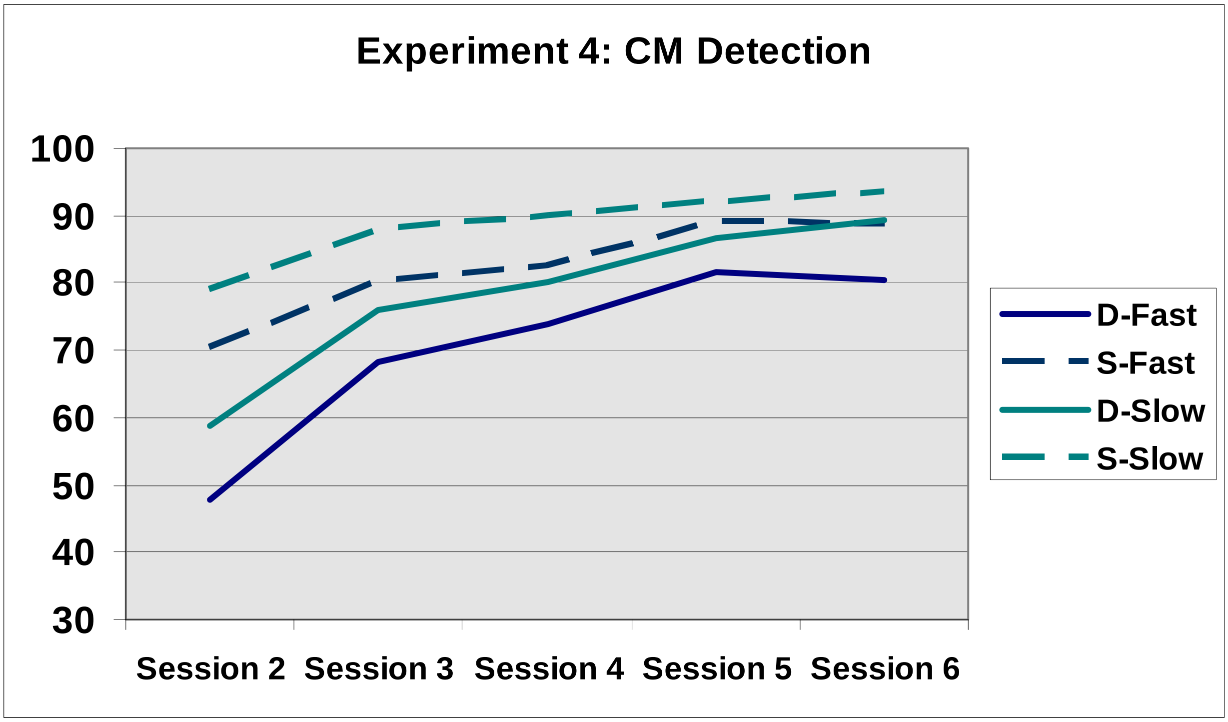


Figure 28. Experiment 3 CM and VM detection



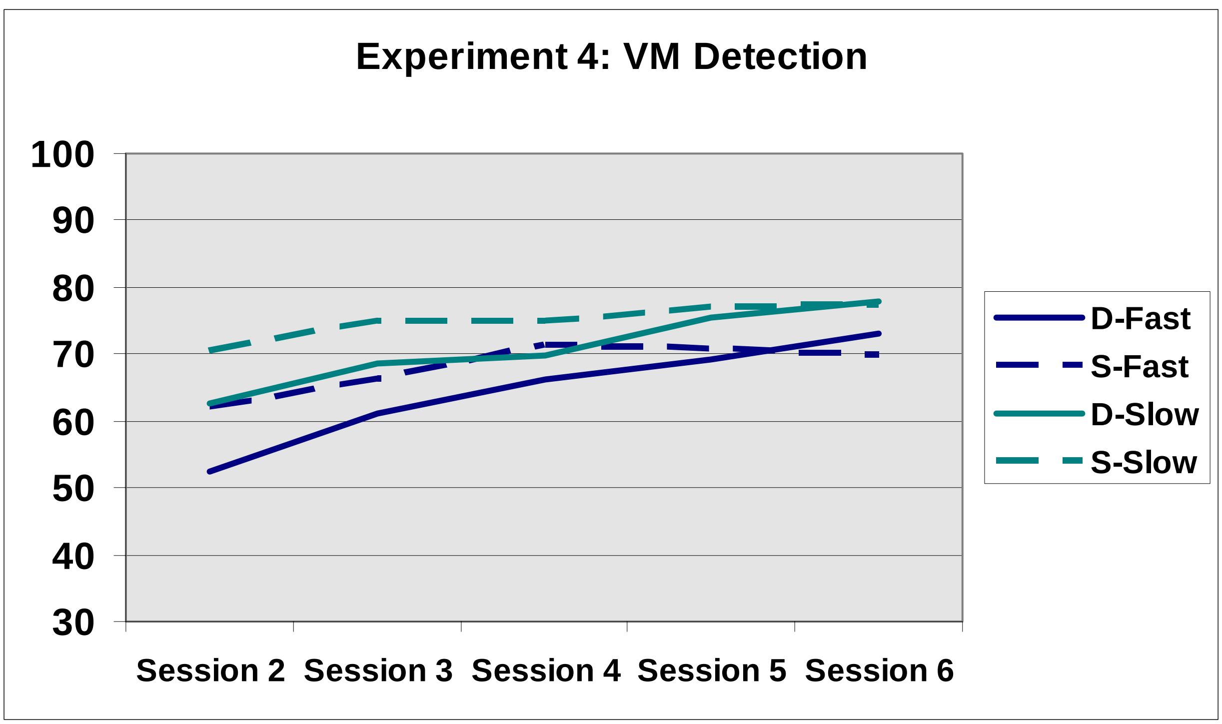


Figure 29. Experiment 4 CM and VM detection

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