

EXPLAINING DUAL-TASK IMPLICIT LEARNING DEFICITS:  
THE EFFECT OF WITHIN STIMULUS PRESENTATION

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EXPLAINING DUAL-TASK IMPLICIT LEARNING DEFICITS:  
THE EFFECT OF WITHIN STIMULUS PRESENTATION

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## SUMMARY

Under typical between stimulus dual-task conditions, implicit sequence learning typically suffers, except under within stimulus conditions, where the stimuli for both tasks are the same. This finding is inconclusive, given that it has not been replicated and the study under which it was obtained was methodologically flawed. The finding also seemed to contradict the psychological refractory period finding that simultaneous presentation of the two task stimuli will result in performance decrements. Two experiments were conducted to test the effect of within stimulus presentation in a dual-task implicit learning task. In Experiment 1, within stimulus presentation resulted in improved sequence learning, relative to between stimulus presentation. The second experiment did not show an effect of response selection load under within stimulus presentation conditions. The findings suggest that implicit learning can occur under attentionally demanding conditions, but that the incidental task structure to be learned should be comprised of stimuli that are already attended during primary task processing.

# CHAPTER 1

## INTRODUCTION

In his recent book *Blink: The power of thinking without thinking*, Malcolm Gladwell (2005) mused about experts and highly trained individuals making decisions and judgments without being able to explain how they know what they seem to know, why they feel a certain way about something, or why they react a certain way. Gladwell asks how we are, at times, able to respond accurately in situations without being able to explain how we arrived at the correct response or behavior. Many of the seemingly fantastic accounts described in his book can be explained in terms of expert performers (i.e., people who have been exposed to certain configurations of stimuli time and again) picking up on incidental features in their environment (i.e., features that are not critical components of a given task). For example, Gladwell describes a tennis pro who is inexplicably able to predict double faults a split second before they happen and is somehow unable to explain his uncanny accuracy. However, as opposed to some magical sixth sense, a more likely explanation is that the tennis pro, after years of carefully observing players serve, picked up on various nearly unnoticeable features of a tennis serve that consistently co-occurred, within a mix of other consistent cues, with a service fault. The man was not intentionally looking for these features and was not consciously aware of their predictive power, yet his performance was greatly supported by his implicit knowledge of these otherwise seemingly random and incidental features.

If we want to understand complex behavior, we must understand those things that go on outside of intention, attentional focus, and even awareness. Any complex behavior

is a combination of control and automatic processes (e.g., Schneider & Chein, 2003), a combination of actions that are consciously carried out under cognitive control and actions that appear to carry on without conscious intent or cognitive control. Within Schneider's model of human information processing (e.g., Schneider & Chein; Shiffrin & Schneider, 1977), control processes involve the activation of a set of neural nodes through attentional control. On the other hand, automatic processes involve the activation of a set of neural nodes by an external stimulus or by a controlled activation by the individual themselves, where the initiation of the automatic process requires attention but the sequence of neural activation occurs and is carried out to completion without any further attentional control by the individual. A subset of these automatic processes is the result of implicit learning, which contributes greatly to the development of complex and skilled behavior. Implicit learning is an unaware learning process in which incidentally encoded associations among stimuli can influence behavior.

There are many ways that information in the environment can be consistently structured such that implicit learning of that structure can occur. For example, stimuli can be spatially arrayed in consistent fashion across various visual environments; two or more stimuli can occur in conjunction with each other across repeated exposures, stimuli can be arranged in a particular sequence, and so forth. The proposed set of studies used an implicit sequence learning paradigm to investigate the effects of multiple, attention demanding tasks on implicit learning.

Although humans can gradually acquire complex relationships amongst sequential stimuli with seemingly minimal effort, this learning appears to be *significantly hindered* by the addition of a second task, even when that task involves simple mental operations

and does not immediately appear to involve the same effectors (e.g., the hands), the same sensors (e.g., the eyes) or attentional resource structure (e.g., spatial) as the primary task (see Shanks & Johnstone, 1998 for a review). The serial response time (SRT) task is used to assess sequence learning without awareness, and the most commonly used secondary task is a tone-counting task, in which one of two tones is randomly presented on each trial, and participants are required to keep a running count of one particular tone.

While many empirical studies have shown changes in the degree of implicit learning under different conditions, no investigation has clearly identified the source of the apparent interference with sequence learning that occurs in the dual-task SRT. The only explicitly stated hypothesis to explain dual-task disruption of implicit sequence learning suggests a disruption-of-organization of the sequence of stimulus locations (Stadler, 1995; also see Schmidtke & Heuer, 1997). The disruption-of-organization hypothesis posits that interference occurs because the secondary task only requires a response on random trials (e.g., when a high-pitched tone occurs, it does not need to be counted and can be ignored). According to this hypothesis, because the secondary task requirement occurs inconsistently, participants are prevented from encoding consistent instances of a given series of spatial locations. However, this hypothesis was undermined by later research using a within stimulus presentation dual-task methodology (Jimenez & Mendez, 1999). The focus of the present study is on within stimulus presentation within this implicit learning methodology and why within stimulus presentation causes a different pattern of dual-task sequence learning.

The goal of this study was to investigate a novel hypothesis for explaining the dual-task deficits, termed the *early encoding hypothesis*, which suggests that dual-task

deficits in implicit learning are driven by the degree of control processing required by the secondary task. Control processes can be reduced when task critical characteristics of relevant stimuli are obligatorily encoded *early* in dual-task processing (Fisk & Schneider, 1984). In two experiments, I investigated how the demands of a secondary counting task in the dual-task SRT task can be reduced by early encoding of stimuli relevant to the secondary task. This will provide an alternative explanation to the source of interference, presenting a means by which the demands of a secondary task can be reduced and implicit learning can progress (relatively) less impeded.

### **Implicit Learning Literature Review**

#### **Dual-Task Implicit Sequence Learning**

Early researchers theorized that implicit learning was an automatic process – that is, individuals would automatically encode consistencies in the relationships between elements in the environment and, over sufficient exposure and incidental conditions, learn the relationships without consciously experiencing the feeling of learning (Reber, 1989). This definition implied that attentional resources were not required for this learning process. According to this viewpoint, the co-occurring stimuli are automatically encoded, and as these instances accrue, learning of the relationship increases. No control processing of the relationship between stimuli is required and thus, a dual-task should not affect the acquisition of the relationship.

A study by Nissen and Bullemer (1987) introduced an influential methodology for studying implicit learning, the serial response time (SRT) task. In this task, participants view four spatial locations that can light up in seeming random fashion. When a location is highlighted, the participant responds with a keypress for the appropriate location.

Unbeknownst to the participants, the sequence in which the locations light up are determined by a repeating pattern (e.g., location 1 – 2 – 4 – 2 – 3 – 1 – 4 – 3). Indirect measures of learning often show that participants become faster and more accurate relative to control groups (who receive a truly random sequence), while direct tests show that participants are unaware of their sequence knowledge that is affecting their behavior. In a direct test of learning, following training, participants may be asked if they noticed any patterns. Participants typically do not notice a pattern, but considering the mismatch between the encoding environment and the retrieval environment in this “direct test,” a more sensitive test is required for assurance of the implicit nature of the learning (Shanks & St. John, 1994).

A crucial finding of Nissen and Bullemer’s (1987) series of experiments was that adding a secondary task to the primary SRT task removed all sequence learning. Several other studies replicated this finding, including a study by Cohen, Ivry and Keele (1990), in which they constructed SRT sequences that either had all unique stimulus transitions (i.e., any given stimulus always followed and preceded the same stimulus; e.g., 31243124), all ambiguous transitions (i.e., any given stimulus could follow and precede more than one stimulus; e.g., 312132), or a hybrid sequence, which included unique and ambiguous stimulus transitions. Dual-task performance was much worse for ambiguous sequences than for unique and hybrid sequences (Experiment 4). In addition, single-task performance for all three sequence groups was still considerably faster than for dual-task. In summary, implicit learning appeared to require attentional resources.

Stadler (1995) proposed a different explanation for the dual-task deficits seen in the SRT task. He suggested that the commonly used tone counting task specifically

interfered with the mental formation of a sequence representation. In this study, one group of participants perform a memory load task (where they retained a list of letters in memory for the extent of the block of trials), one group saw the letters at the beginning of each block but were instructed to ignore them (a single-task control group), one group performed the standard tone counting task, and one group had no secondary task, but the response-to-stimulus interval (RSI) was five times as long on the same proportion of trials that the tone counting group would hear a target tone. Essentially, the memory load group was designed to induce attentional demand without any disruption between each trial (as occurred in the tone counting task), and the extended RSI group was designed to emulate the tone counting group without an attentional demand. Stadler found that the demand on attentional capacity was not the true locus of the dual vs. single-task effect, but instead, that disruption between trials (whether tone counting or variable RSI) negatively affected the ability to create a sequence structure representation. The ignore-letter control condition demonstrated more learning than the memory load group, suggesting that the attentional demand of the memory load secondary task was sufficient to reduce learning. It is unclear from this study that attentional capacity is irrelevant in implicit learning in the SRT task, but Stadler presented clear evidence that organization of stimuli is critical for learning (or at least the expression of learning; *cf.*, Frensch, Wenke, & Runger, 1999).

### **Selective Attention and Implicit Learning**

Researchers have postulated several accounts for this dual-task learning deficit, including a general resources explanation (Cohen et al., 1990; Nissen & Bullemer, 1987) and an explanation that does not rely on a unitary resources account, such as Stadler's

disruption-of-organization (Stadler, 1995). One explanation relevant to understanding the mechanisms of implicit learning was put forth by Jimenez and Mendez (1999) in the SRT paradigm and by Chun and colleagues in the contextual cueing paradigm (Chun & Jiang, 1998; Jiang & Chun, 1999). These researchers argued for the importance of *selective processing* of stimuli in implicit learning. While the attentional debate has otherwise focused on the relative demandingness of implicit learning on attentional resources, these researchers suggested that the degree of implicit learning is moderated by the degree to which stimuli are selectively processed. This attention account of learning is related to accounts of learning in other task domains such as learning frequency of an occurrence of stimuli (Fisk & Schneider, 1984) or as a general explanatory construct for learning (e.g., see Logan, 1988).

Consider a study conducted by Jimenez and Mendez (1999). In this study, they employed the often used dual-task SRT to explore sequence learning. However, their sequence learning task was a probabilistic version of the SRT task (as opposed to deterministic), derived from a noisy finite state grammar tree. Because their sequence was probabilistic, they provided extensive training (31000 trials), considerably more than is typically seen in SRT studies. The location of a stimulus was a predictive cue for the location of the following item (as in all SRT tasks). Their secondary task involved counting the number of times two particular targets appeared (akin to counting the number of high pitched tones typically used to create secondary task SRT studies). Such a manipulation creates a *within stimulus* dual-task. I refer to such a manipulation as within stimulus because participants are required to selectively attend to the relevant stimuli (target shapes), as opposed to divide attention between two stimuli (e.g., the

primary task and irrelevant auditory tones). The latter type of dual-task would be a between stimulus dual-task (the theoretical importance of within versus between stimulus dual-tasks will be discussed below). The “standard” dual-task SRT experiment employs a between stimulus dual-task condition(s).

Jimenez and Mendez (1999) found no evidence of a difference between single task and dual-task performance, indicating that both groups learned and performed similarly. They replicated this finding across three experiments, including an experiment where the two targets to be counted changed during each training session, thereby increasing attentional demands of the overall task. Jimenez and Mendez’s study is suggestive of the need to selectively attend to critical stimuli if implicit learning is to occur.

Jimenez and Mendez’s (1999) data do not seem to fit with the disruption-of-organization hypothesis. That is, in both their study and in Stadler’s study, disruption-of-organization should arise from the unpredictable nature of the secondary task. Participants do not know on any given trial whether a response will be required of them in the secondary task (i.e., on half the trials, an irrelevant stimulus occurs in the secondary task and no response is necessary). The within stimulus manipulation does not negate the unpredictability of the secondary task requirements, and the disruption-of-organization hypothesis does not predict the minimal interference observed by Jimenez and Mendez’s within stimulus dual-task.

However, there is a critical methodological issue in Jimenez and Mendez (1999) study. By creating a within stimulus dual-task condition, Jimenez and Mendez also created dual-task conditions in which the stimuli for the two tasks are presented

concurrently and in which the stimuli for the two tasks are presented in the same modality. Each of these three conditions are departures from the standard dual-task SRT, in which stimuli for the two tasks are presented in separate stimuli, have distinct onset times, and are presented in different modalities (i.e., visual and auditory). In fact, in their study, Jimenez and Mendez never directly compared a standard dual-task condition (a between stimulus dual-task) to the within stimulus dual-task condition they used. Jimenez and Mendez hypothesized that the apparent decrease in dual-task interference was the result of the within stimulus manipulation, but this suggestion is not without challenge. In the present experiments, I will conduct a more direct test of the within stimulus presentation in the dual-task SRT task. I will also discuss why the selective processing afforded to participants in a within stimulus presentation condition results in relatively intact sequence learning.

### **Selective Processing and Obligatory Encoding**

One explanation is that, in a within stimulus presentation task, attention is not divided between two tasks, resulting in greater learning of the SRT sequence (e.g., Naveh-Benjamin, 2002). However, in the only previous within stimulus dual-task SRT task, participants still performed the SRT task and then switched to a retrieval and updating task in the secondary task. A new stimulus was not necessarily attended in the Jimenez and Mendez task, but attention was certainly shifting between tasks. For this explanation, an assumption must be made that the SRT task is (mostly) performed first, followed by the secondary task, even in a simultaneous onset scenario. The rationale for this assumption is that there is a speed demand on the SRT task (participants are asked to respond quickly and accurately to the SRT task) and that an actual external response must

be made on the SRT task. A divided attention explanation does not seem to sufficiently explain the learning differences between a within stimulus and a between stimulus dual-task SRT task.

A plausible alternative explanation is that when a stimulus contains multiple features, attention to that stimulus results in obligatory encoding of other features contained within that stimulus, even if task demands focus attention to only one of the features (Logan & Etherton, 1994). Duncan (1984) proposed a related hypothesis, suggesting that processing a single feature of a stimulus should result in “heightened” access to other features contained within the stimulus. Earlier findings suggested that stimuli could be either *integral* or *separable*, such that the features within an integral stimulus could be encoded simultaneously, whereas features within a separable stimulus could not be (e.g., see Garner, 1974).

For such within-task (or integral) dual-task procedures, the SRT stimulus, which is used to “demonstrate” attention insensitive processing leading to sequence learning, also contained information relevant to the secondary task. Hence, the secondary task-relevant features are also processed in an obligatory fashion. Attention to the secondary task-relevant features results in a heightened activation (or obligatory encoding) of the stimulus features required for the counting task and activation of the stimulus’ place in a sequence. In the standard dual-task SRT (a between stimulus dual-task), obligatory encoding of integral features does not occur as the stimuli for the SRT and secondary tasks are separable such that encoding required for each task performance must be independent.

Presumably, there is some learning advantage gained by quickly and unintentionally processing the stimulus for the secondary task. The locus of this advantage is unresolved. The task switching explanation suggests that the extent and degree to which attention is transferred between tasks may be reduced, allowing the location information in the SRT task to be preserved longer in working memory and, thus, resulting in more efficient sequence learning. In the present set of studies, I intend to first present clearer evidence that the reductions in dual-task interference observed by Jimenez and Mendez were consistent with the early encoding hypothesis, by ruling out the competing hypotheses outlined above. The second experiment will further explore this early encoding hypothesis.

### **Implicit Learning Summary**

Implicit learning was originally thought to be independent of cognitive resources, an automatic learning process that was uncontrolled and unconscious (Reber, 1989). This was thought to be refuted when Nissen and Bullemer (1987) demonstrated significant learning deficits in implicit learning under dual-task conditions in the SRT task. Considerable early effort then went towards testing the resources explanation for dual-task deficits in the SRT task (Cohen et al., 1990; Frensch & Miner, 1994; Nissen & Bullemer, 1987). However, later researchers suggested that the secondary task was not impinging on some resource pool necessary for implicit sequence learning to occur and that implicit sequence learning may not require attentional capacity at all (Jimenez & Mendez, 1999; Stadler, 1995). These researchers focused on the apparent insensitivity of implicit learning to secondary tasks under certain conditions. Several studies suggested that the unpredictable nature of the secondary task resulted in a significantly reduced

capability to form a coherent representation of the SRT sequence in memory (i.e., the disruption-of-organization hypothesis); however, this hypothesis is not corroborated by the within stimulus dual-task data presented by Jimenez and Mendez (1999).

Building from Jimenez and Mendez's selective attention framework, I submit that the response for the counting task was activated early in processing when the features specifically relevant to the secondary task were obligatorily processed in conjunction with the features relevant to the SRT task. Without early activation of the correct response to the secondary task, implicit learning in the dual-task SRT task will be restricted. Consider Stadler's (1995) condition, where participants were required to maintain a set of random digits throughout a block of training. Significantly more implicit learning occurred in this condition, than in conditions where counting task was performed as the secondary task. Certainly this simple digit load task did not result in disruption-of-organization, as defined by Stadler, but it also did not include many potentially critical features of the standard tone counting task. For example, there are several control processes required by the tone counting task, including maintenance of the count, updating of the count, maintenance of the rule for which stimulus is relevant on a given block, and deciding whether a stimulus fulfills the rule of relevance. The processing requirements of these latter two control processes, maintenance of rule and comparison/deciding rule relevance, would be ameliorated by a stimulus that primes the correct response in the secondary task, thereby resulting in reduced interference and enhanced implicit learning. Note that the disruption-of-organization hypothesis would predict that the same degree of interference, whether early encoding and activation

occurred or not, as the secondary task would still demand attentional processing on random trials, thereby disrupting the formation of a sequence representation in memory.

An explicit description of both hypotheses follows. The early encoding hypothesis, as defined in this proposal, runs counter to the disruption-of-organization hypothesis in that the early encoding hypothesis explains dual-task deficits in terms of the multiple control processes that are necessitated by the secondary tone counting task (and other similarly unpredictable secondary tasks). These various control processes (discussed above) result in a division of attention, presumably allowing sequence structure information in working memory to decay and concurrently resulting in reduced implicit learning of the sequence. When these control processes are removed, implicit learning increases, as is the case when a within stimulus dual-task results in intact implicit learning. The disruption-of-organization hypothesis, on the other hand, appears to focus on the unpredictable nature of the attentional requirements for the dual-task. That is, the latter hypothesis does not implicate specific control processes as the source of disruption, but instead, explains disruption as a function of the division of attention that occurs in an inconsistent fashion between SRT trials.

Note that a broader interpretation of the disruption-of-organization hypothesis would point out that this hypothesis *does* implicitly specify a control process (Schneider & Shiffrin, 1977) – selecting and making responses in the secondary task on an inconsistent basis. Although this does not appear to be the precise manner in which this hypothesis (and its variants) is discussed by Stadler, Frensch, and others, it is more in line with the present hypothesis. Taking this interpretation, the early encoding hypothesis is more powerful and broad in its predictive capability, as it states that when some or all of

the control processes necessitated by the secondary task are supported (or primed) during the processing of the first task (i.e., the SRT task), interference should decrease, and implicit learning should approach single task levels.

### **How Does Implicit Sequence Learning Occur?**

The learning process can be described via connectionist mechanisms and by drawing from a hybrid (connectionist and production system) model (Schneider & Chein, 2003; Schneider & Detweiler, 1987). Although the early encoding hypothesis is compatible with this hybrid model (described below), it may run counter to a large body of dual-task literature. This will be described in the following section.

#### *Sequence Learning in a Simple Recurrent Network*

In the dual-task SRT, location information is encoded, and the memory trace is activated briefly in working memory. Depending on whether the task is within stimulus or between stimulus, the trace is differentially activated by the degree of attention given to it (described in more detail shortly). When the subsequent trial occurs, that trial's location memory trace is activated in working memory. Assuming the previous location trace(s) have not fully decayed (removing them from the system), the locations are co-activated, resulting in linkages between the two locations in memory. These linkages are strengthened over repeated occurrences. Using a simple recurrent network (Cleeremans & McClelland, 1990), the previous trials' location information can be stored and activated when a subsequent trial occurs.

The activation pattern for a given trial is stored on a context layer (i.e.,  $T - 1$ , where  $T$  stands for "trial"). These context units serve to store the temporal context of the SRT task. A hidden (or inner) layer in the network receives inputs from both the input

layer (the current trial, or T) and the context layer (T - 1). Thus, two consecutive events are represented on the hidden layer (Figure 1). The hidden layer then feeds back onto the context layer, such that on the subsequent trials, the new context layer pattern of activation (with two consecutive trials represented in the activation pattern) feeds onto the hidden layer along with the current event's inputs. Thus, three consecutive trials are now represented on the hidden layer. This continues on, until the entire sequence is represented.

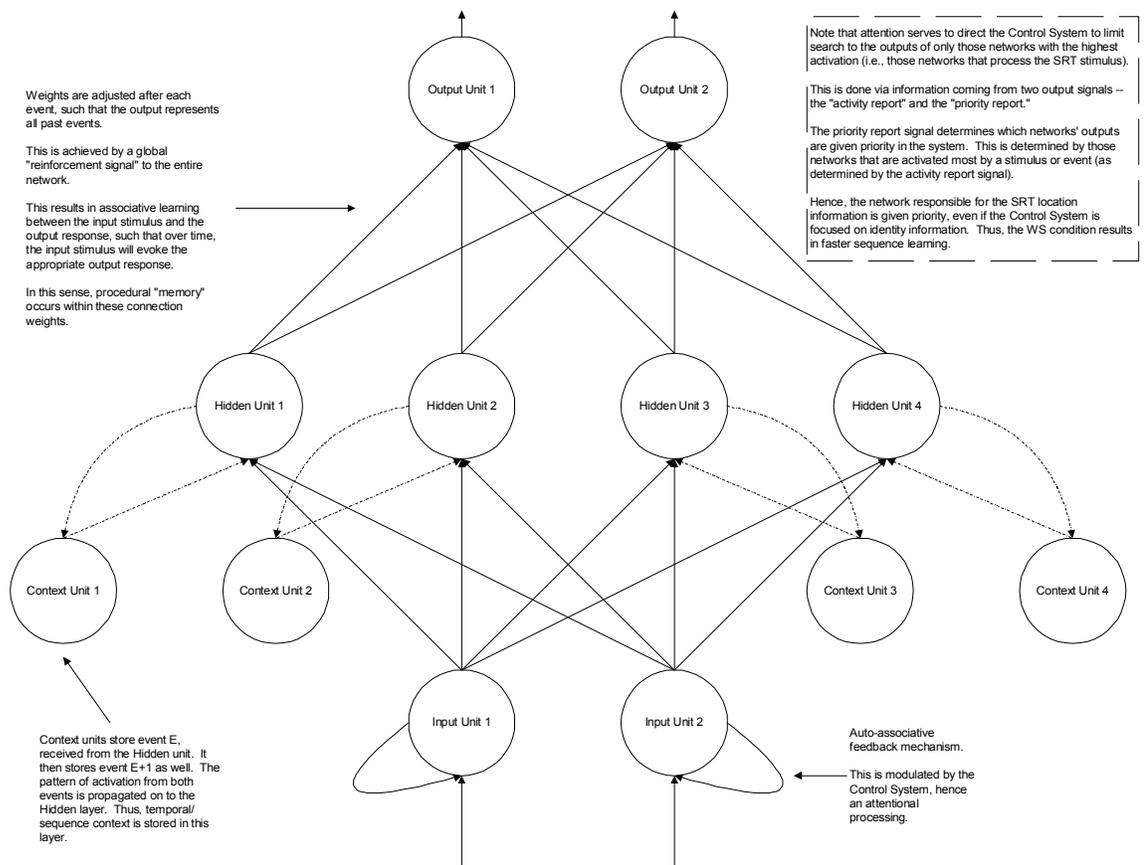


Figure 1. Sequence learning in a simple recurrent network (adapted from Cleeremans & McClelland, 1990).

Back propagation, a common connectionist model learning mechanism, refers to how the adjustments in the connection weights of the neurons is made. Learning occurs when, via back propagation, the relative weights of the connections between the hidden layer and the output layer are adjusted on the basis of the activation pattern from the context layer. The difference between the outcome of  $T - 1$  (or more specifically, the outcome of the context layer, which holds more than just  $T - 1$ , also  $T - 2, T - 3 \dots n$ ) and  $T$  is recorded and used to make adjustments to the way that the neurons process  $T + 1$ . In the beginning, these adjustments vary widely and do not result in a correct output from the network. But over time, the adjustments are more accurate, the output is corrected, and evidence of learning can be observed. In this way, simple sequence learning can occur. If the sequence is incidentally presented (i.e., participants are not informed about the existence of a sequence) and if the sequence is sufficiently complex to prevent eventual awareness, this sequence learning should be implicit. That is, there is no “special” implicit learning mechanism that qualitatively separates implicit learning from explicit learning.

### **Early Encoding and the CAP2 Model**

While implicit sequence learning itself can be easily modeled, the special case of within stimulus dual-task SRT is less straight forward. My description of the early encoding hypothesis of within stimulus performance and learning borrows from Schneider’s CAP2 hybrid model of cognition (Schneider & Chein, 2003; see also Schneider & Detweiler, 1986). As has already been discussed, focused attention on the SRT stimulus results in an obligatory encoding of the object’s identity (although the participant is intentionally processing the stimulus’s location), thereby resulting in

reduced processing demands when performing the counting task. Because the stimulus's identity has already been encoded previously, this information is already available when the participant must decide whether or not to increase the count in the secondary task. This is a capacity-based approach to understanding dual-task sequence learning, where the reduction in processing requirements in the secondary task results in more attention to the location information memory trace and a higher fidelity signal to be propagated within the sequence learning network. I have already described how a simple recurrent network processes the SRT location information and learns sequences of stimuli, but what differences in processing arise when within stimulus and between stimulus presentation methods are used? The secondary task stimulus's *identity* must be ascertained by the system before a response can be made.

This obligatory encoding of additional features is explained by CAP2 architecture through report signals from perception networks to a control system. In within stimulus processing, as the stimulus's location is being processed, focused attention on the stimulus provides additional processing for identity information, resulting in greater auto-associative feedback on the input units processing that identity information (see Figure 1). According to CAP2, attentional selection is accomplished via two report signals (*activity* and *priority* report signals) sent to the Control System that determine which networks are activated most by a stimulus (e.g., a network that processes location information and a network that processes identity information) and give those networks' outputs priority over others (Figure 2). In this way, multiple features of the same stimulus can be encoded simultaneously (although the priority signals themselves will have different priorities, based on the degree of activation each feature induces). In

effect, this is similar to a process-level description of object-based attentional selection (e.g., Duncan, 1984; Logan & Etherton, 1994).

## Adaptation of CAP2 Macro Level Structure

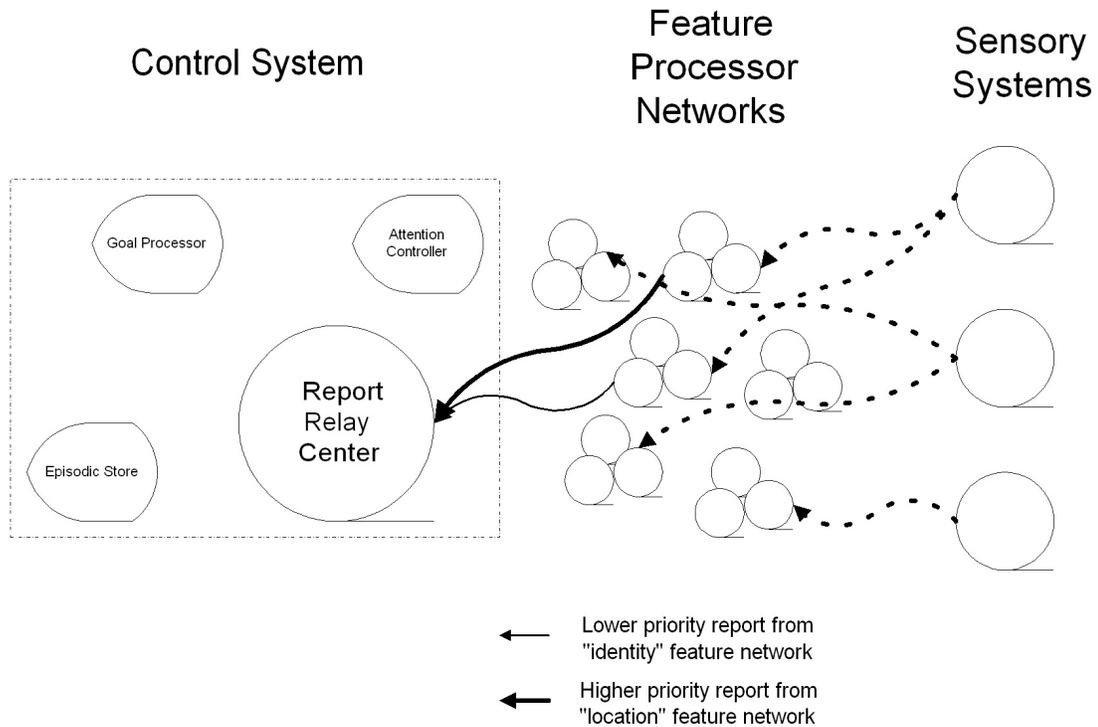


Figure 2. CAP2 macro-level structure (adapted from Schneider & Chein, 2003)

Through activity and report signals, even though additional processing occurs for the stimulus's identity, the strengthening of the input units in the *location* network is also occurring, because of the additional attention to the stimulus. This results in a higher fidelity "location" information signal, and the location signal is strengthened more quickly under fewer exposures. This also allows the signal to be stored in a buffer as opposed to immediately decaying. The actual processing of the identity information

occurs within another network, separate from the network that processes location information in the SRT part of the dual-task. This other network receives input from a different aspect of the stimulus (i.e., the identity of the stimulus), but the additional attention keeps the auto-associative mechanism active, thereby maintaining the location information in the hidden layer buffer. Then, when the next stimulus comes along, the context layer has a stronger context representation. The processing of the identity information probably occurs just slightly asynchronously (i.e., after) the processing of the location information (simply because, by nature of the task, participants probably do the location task first, then the counting task). In summary, the CAP2-based early encoding hypothesis predicts relatively better implicit sequence learning in a within stimulus presentation condition of the dual-task SRT than a between stimulus presentation condition.

### **The Psychological Refractory Period Effect**

Based on the above description of processing in a within stimulus dual-task SRT, participants should learn more sequence information in a within stimulus task than in a between stimulus version. However, the proposed superiority of within stimulus presentation appears to conflict with a large body of existing dual-task research. In the dual-task procedure from this literature, participants are presented with a stimulus for the first task (S1), quickly followed by the stimulus for the second task (S2). Separate responses are then made for S1 (R1) and for S2 (R2). The time gap between the presentation of S1 and S2 is the stimulus onset asynchrony (SOA), and a positive correlation between SOA and RT for R2 is well-documented (Figure 3). The correlation is referred to as the *psychological refractory period* (PRP) effect (e.g., Meyer & Kieras,

1997), given the ostensible inability for R2 to be made in such close temporal proximity to R1. The robust PRP effect would presumably be present in a within stimulus condition, given that the SOA for this dual-task condition is effectively zero. Conversely, in a between stimulus condition, the SOA would be constrained only by the participants' response time to S1 – that is, with no overlap between S1 and S2, there should have been no PRP effect.

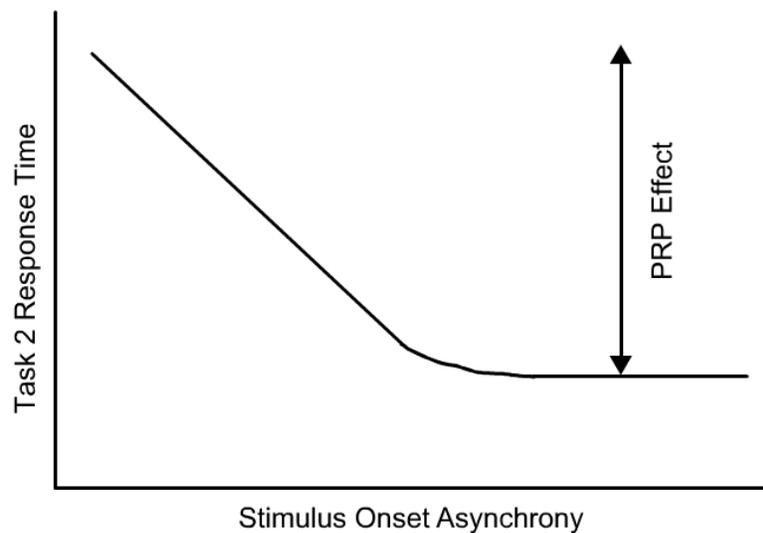


Figure 3. The relationship between Task 2 RT and SOA, resulting in the PRP effect.

Note that the PRP effect is demonstrated in terms of a performance decrement as SOAs decrease. The negative correlation between SOA and the time to respond to R2 (i.e., performance deficits) have been well-documented through PRP curves (Meyer & Kieras, 1997). However, it is less clear whether performance deficits would translate to

*learning deficits* as well, in a dual-task SRT task. To explain this effect in the SRT methodology, the PRP finding must be further explained. Several models have been proposed that implicate a processing bottleneck as the cause of the response interference in the second task (e.g., Fagot & Pashler, 1992); however, the *strategic response deferment (SRD) hypothesis* (derived from the EPIC architecture of human information processing, Meyer & Kieras, 1997) eschews the notions of bottlenecks altogether. In the SRD explanation of the effect, at shorter SOAs, R2 is briefly stored in working memory, so that the response is not made potentially *too* close in conjunction with R1 (which could lead to motor crosstalk or simply physical interference between the two responses; cf. Allport, 1989; Neumann, 1987; see Figure 4).

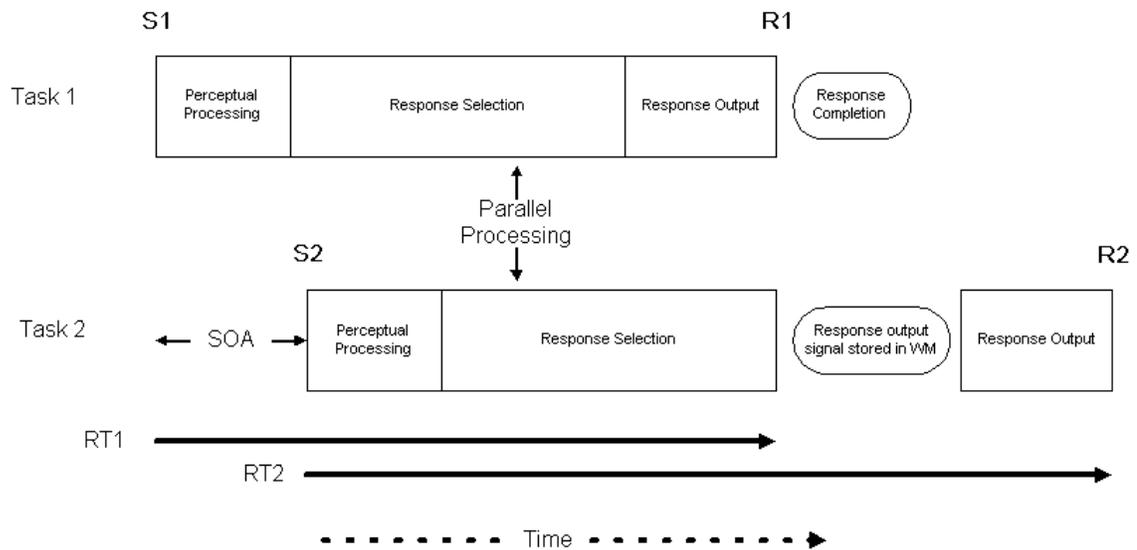


Figure 4. Dual-task timeline depicting the storage of responses in working memory to prevent cross-talk, from the SRD model.

That is, there is no limiter or bottleneck in the system, and, in the PRP procedure, a response may be selected, but the output of the response will likely be interfered with by

some other process. Thus, a central processor controls processes like response selection and production, employing strategies to minimize such interference by utilizing available attentional resources (i.e., working memory storage) and by outputting the responses at a strategically optimal time.

Firstly, the SRD hypothesis clearly states that a dual-task condition in which the stimuli for two tasks are presented close together in time will result in poorer performance than a dual-task condition in which the two stimuli have a long SOA. In the within stimulus version of the dual-task SRT, the stimuli for the two tasks, being combined into a single stimulus, is essentially a zero second SOA condition. Thus, the SRD hypothesis would predict poorer performance in a within stimulus condition than in a between stimulus condition. Turning to actual implicit sequence learning, with the invocation of working memory demands, the SRD hypothesis predicts that the amount of sequence learning in a between stimulus presentation will be greater than that in a within stimulus presentation. In a within stimulus presentation condition, where a PRP effect would presumably occur (given the functional zero second SOA between the two tasks), the working memory load of the response to Task 2 should result in reduced attentional processing of the sequence information also stored in working memory (recall the simple recurrent network model of sequence learning and the role of working memory storage for previous trials' location information). In a between stimulus presentation condition, the PRP effect should not occur (or be significantly reduced, depending on the exact SOA), and working memory demands will be reduced, allowing for better sequence learning in addition to overall better task performance.

In summary, the different predictions made by the early encoding hypothesis and the SRD hypothesis provide the starting point for this study. The early encoding hypothesis predicts that within stimulus methodology will allow for greater implicit sequence learning than between stimulus versions of the dual-task SRT (i.e., discounting other previously confounded explanations). However, the SRD hypothesis, derived from dual-task findings using the PRP procedure, predicts less sequence learning in the within stimulus group and poorer overall performance. Experiment 1 will directly test the hypothesized learning advantage of the within stimulus version (and the proposed early encoding hypothesis), and Experiment 2 will investigate the locus of the hypothesized within stimulus learning advantage.

## **CHAPTER 2**

### **EXPERIMENT 1**

Previous research has demonstrated that within-stimulus presentation in the dual task version of the SRT task resulted in implicit learning close to that of single task SRT. However, because Jimenez and Mendez (1999) did not include a standard (between-stimulus) version of the dual-task SRT for comparison to their within-stimulus condition there are several plausible alternative explanations for their findings.

The confounds in the original within-stimulus presentation condition have already been discussed, and the same-presentation onset and same-modality accounts currently remain plausible explanations for these findings. Presently, however, these other explanations have not been evaluated such that the locus of the learning can emerge. To evaluate the locus of the learning, four dual task conditions were constructed (and one single task control condition) to control for the confounds in the within-stimulus presentation methodology: a within-stimulus presentation condition (WS-DT), a standard between-stimulus presentation condition (standard-DT), a zero second SOA condition (0SOA-DT), and a visual modality condition (visual-DT).

The first alternative explanation for Jimenez and Mendez's within stimulus findings (accounted for here by the visual-DT condition) is that the switch from different modalities (in the standard dual-task SRT) to the same modality resulted in reduced dual-task interference. This is less plausible than the within stimulus explanation, because processing two visual stimuli often results in crosstalk in the visual pathway (Allport, 1989). Even though one stimulus would result in a "where" response (i.e., the SRT task

stimulus) and the other would result in a “what” response (i.e., the secondary counting task), more interference is theoretically plausible versus a condition in which a visual stimulus and an auditory stimulus are presented (e.g., Wickens, 1984).

The other possible explanation is that the simultaneous presentation resulted in increased implicit learning (accounted for here by the 0SOA-DT condition). This is plausible given models of working memory that propose separate auditory and visuo-spatial stores (e.g., Baddeley, 1986), such that performing two tasks that load the two stores separately would be less demanding than performing two tasks that load the same working memory store (as in a condition where both tasks require storage of visual stimuli). This would suggest a benefit for the 0SOA-DT and standard-DT conditions. However, the 0SOA-DT condition would very closely replicate PRP tasks in which interference greatly increases as the time between the onsets of the stimuli for two separate tasks decreases. So it is unclear whether such a condition would result in *more* implicit learning than the standard-DT condition.

Thus, the 0SOA-DT and visual-DT conditions account for the potential confounds in the original within stimulus presentation condition. Also, the four conditions provide a test of the SRD hypothesis. The WS-DT and 0SOA-DT conditions are minimal SOA conditions, which should result in poorer overall performance and sequence learning, while the standard-DT and visual-DT conditions are long SOA conditions, which should result in greater overall performance and sequence learning, as predicted by the SRD hypothesis.

The following predictions are made for Experiment 1:

- 1) The early encoding hypothesis will be supported over the SRD hypothesis. The WS-DT condition will result in greater implicit sequence learning than the other dual-task conditions.
- 2) The PRP effect will be demonstrated by faster overall performance in the two long SOA conditions. The standard-DT and visual-DT conditions will have faster overall performance.

## **Method**

### **Participants**

One hundred participants were recruited from the Georgia Institute of Technology School of Psychology participant pool. Participants were between the ages of 18 – 26 ( $M = 20.36$ ,  $SD = 1.41$ ), with 51 females. They received psychology course credit for their participation.

### **Stimuli & Design**

The visual stimulus set consisted of two shapes (a red triangle and a yellow oval) (Figure 5), and the auditory stimulus set consisted of an 800Hz tone and 1200Hz tone. The stimuli were created in Adobe Photoshop, and the experiment was created using the E-Prime© (2000) programming package. Participants completed the experiment on Pentium 4 systems. There were 5 between group conditions (described below): single task (ST), standard dual-task (standard-DT), within stimulus (WS-DT), zero second stimulus onset asynchrony (0SOA-DT), and visual modality (visual-DT). There were 20 participants in each condition.

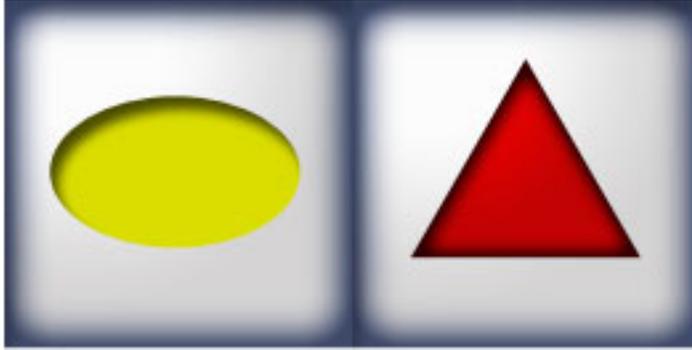


Figure 5. Target shape stimuli for Experiment 1.

### Sequence Information

Two different 12-item sequences were used for the 12 sequenced blocks, both randomly assigned to half of the participants (S1: 1-2-1-3-4-2-3-1-4-3-2-4 and S2: 3-2-3-1-4-2-1-3-4-1-2-4). These sequences were designed to follow the statistical rules laid out by Reed and Johnson (1994). All blocks began at a random point within the sequence to reduce explicit learning of the sequences. Half of the participants trained on S1, where S2 was used in a transfer task (described below); the other half did the opposite.

### **Procedure**

#### Condition-Specific Procedure

In the ST condition, a random shape appeared in one of the four locations according to the deterministic sequence. Participants made a location key press response, the SRT stimulus disappeared, and 100ms after, a random auditory tone was presented. The tone lasted for 200ms, followed by a 100ms pause, and then the next trial began with the onset of the next SRT location. ST participants were informed that the tones were designed to distract them from the SRT task and were instructed to ignore these tones. The standard-DT condition received the same procedure, except they were instructed to

attend to the tones and keep a running count of a particular tone. Participants were instructed which tone was relevant at the beginning of each block, and the relevance consistently shifted between the high- and low-pitched tones between blocks.

The WS-DT condition received the same procedure, except they were instructed to maintain a running count of one of the two shapes. Just as the relevant tone shifted in the standard DT condition, the relevant shape changed between blocks. The auditory tones were presented between SRT trials, but as in the ST condition, participants were instructed to ignore them. Thus, the trial procedure for the ST, standard-DT, and WS-DT conditions were identical, but with differing instructions.

In the 0SOA-DT condition, a random shape appeared in the SRT task (just as in the above conditions) and, simultaneously, a random auditory stimulus was presented. Participants were instructed to respond to the location of the SRT stimulus and then to perform the counting task. To maintain the same time course between conditions, after a response was made to the SRT stimulus, there was a 400ms pause before the onset of the next trial.

In the visual-DT condition, a black dot was employed as the SRT stimulus. After a response, the target dot disappeared, and a random shape from the shape set was presented in the middle of the display for 200ms (thus maintaining a consistent time course across conditions).

### Training Phase

All groups performed 20 blocks of training trials, comprised of 96 trials each. Each trial consisted of the presentation of the four SRT locations, with a single location containing the target for that trial (see Figure 6). Participants made a key press response

to the location of that target to complete the SRT task. The response keys were the “z,” “x,” “n,” and “m” keys, where the spatial position of the keys corresponded to the spatial arrangement of the locations in the SRT task. Participants were required to respond with the index and middle fingers of their right and left hands.

Participants initially performed 24 orientation trials, after which they were able to ask questions if necessary. Following the orientation block, participants performed 20 blocks of training. Participants were required to take a five minute break after the 18<sup>th</sup> block to provide a rest from the task before the final two training blocks and the following transfer conditions.

After the 96<sup>th</sup> trial in each block, a text box appeared, asking participants to enter the count for the secondary counting task. If participants were within 5% of the correct number, they were congratulated and encouraged to continue this level of performance.

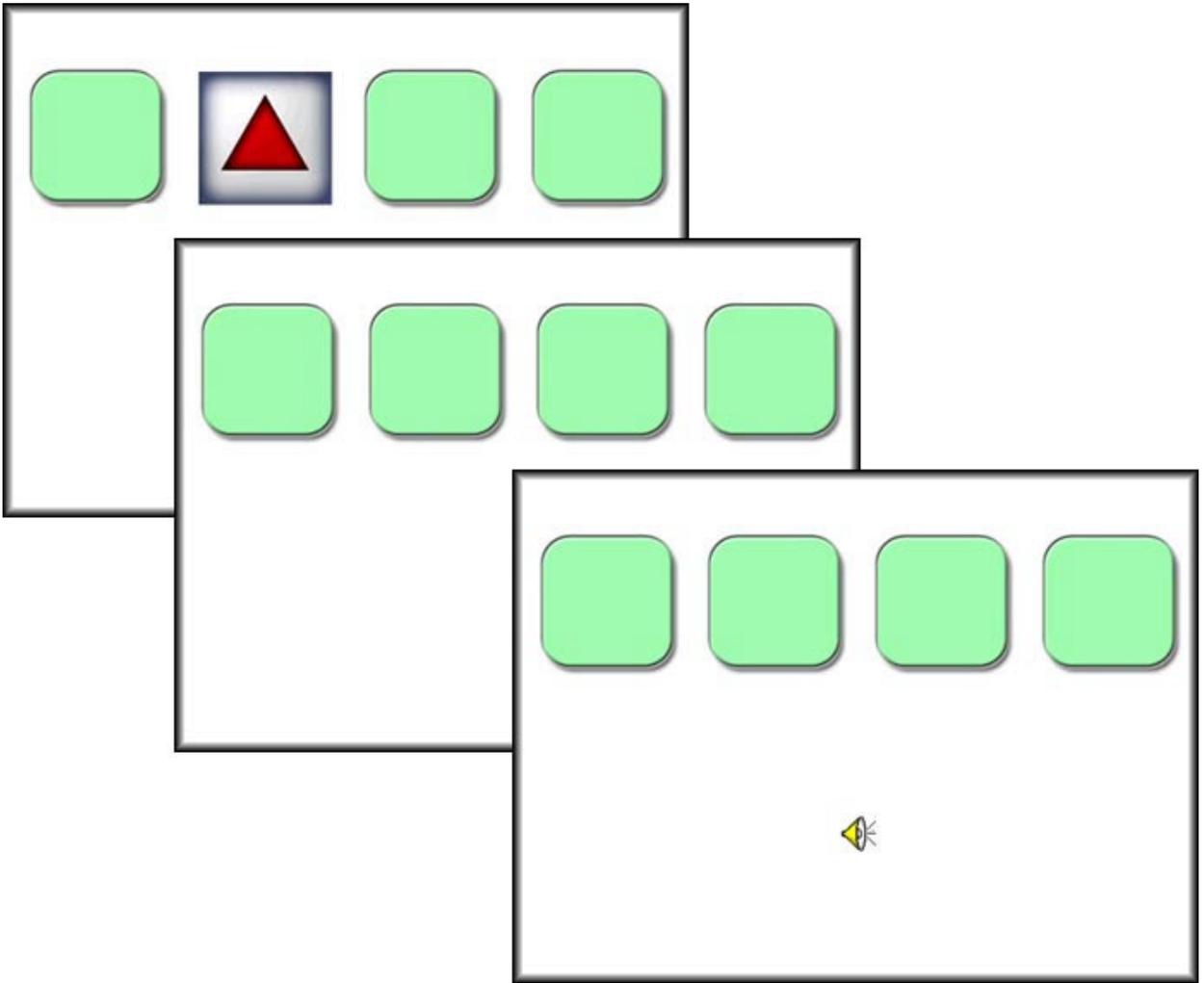


Figure 6. Task progression for the standard DT, WS-DT, and ST conditions in Experiment 1.

If their count was more than 5% off, they were instructed to pay more attention to the secondary task. Thus, if the correct count in a given block was 48, participants would receive positive feedback if their response was between 46 and 50.

At the beginning of the experiment and at the beginning of each block, all participants were strongly encouraged to perform the secondary task to the highest level possible. After the count report, participants were shown their average SRT response time and accuracy. If they missed more than nine SRT trials (i.e., below 90% accuracy), they were instructed to respond more carefully. If they missed one or zero SRT trials (i.e., above 98% accuracy), they were instructed to respond more quickly. At the beginning of the experiment, they were told that the target accuracy range for the SRT task is between 90% and 98%. They were able to continue on to the next block of trials at their own pace; however, they were asked to not take extended breaks during the experiment.

Table 1

*Blocks in Each Training and Transfer Condition in Experiments 1*

	Block Conditions				
	Training	Single-Task Transfer	Sequence Transfer	Single-Task	Generation Task
Single-Task	<b>22</b>	<b>N/A</b>	<b>1</b>	<b>2</b>	<b>1</b>
Dual-Task	<b>20</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>1</b>

### Transfer phase.

The design of the transfer blocks was taken from Shanks and Channon (2002) (Table 1). After the 20 training blocks, participants performed several additional blocks designed to test learning over the training blocks. The 21<sup>st</sup> and 22<sup>nd</sup> blocks were a single-task transfer, in which all participants were instructed to discontinue the secondary counting task but to continue to respond to the location of the SRT stimulus as quickly and accurately as possible (nothing changed for the ST condition). In the 23<sup>rd</sup> block, participants continued single-task but were transferred to the non-training sequence. In blocks 24 and 25, participants continued single-task but switched back to the training sequence.

### Generation Task

After the 25 blocks, participants performed a test of their explicit knowledge of the sequence. No tones or shapes were presented. Participants were instructed to press the key that they thought corresponded with the *subsequent* sequence location. The dot would then move to the selected location, and participants were instructed make a key response corresponding to the subsequent location. Thus, participants were reconstructing the sequence from training, although they were not explicitly told to remember the sequence from training and recreate it. The free generation test lasted for 96 trials.

In the sequences used in this task, locations were completely random at the “doublet” level. That is, all possible sequences of two locations occurred with equal probability. However, at the “triplet” level, the sequence was completely consistent and learnable. That is, during the training portion of the task, if the target appeared in

Table 2

*Correct and All Alternative Chunks of the Training Sequence (Full Sequence: 1-2-1-3-4-2-3-1-4-3-2-4)*

<b>Correct chunk</b>	Alternative 1	Alternative 2	Alternative 3
<b>1-2-1</b>	1-2-2	1-2-3	1-2-4
<b>2-1-3</b>	2-1-1	2-1-2	2-1-4
<b>1-3-4</b>	1-3-1	1-3-2	1-3-3
<b>3-4-2</b>	3-4-1	3-4-3	3-4-4
<b>4-2-3</b>	4-2-1	4-2-2	4-2-4
<b>2-3-1</b>	2-3-2	2-3-3	2-3-4
<b>3-1-4</b>	3-1-1	3-1-2	3-1-3
<b>1-4-3</b>	1-4-1	1-4-2	1-4-4
<b>4-3-2</b>	4-3-1	4-3-3	4-3-4
<b>3-2-4</b>	3-2-1	3-2-2	3-2-3
<b>2-4-1</b>	2-4-2	2-4-3	2-4-4
<b>4-1-2</b>	4-1-1	4-1-3	4-1-4

location 1, there was an equal probability of location 2, 3, or 4 containing the target on the subsequent trial (there were no runs of the same consecutive location). However, if the target on the next trial was in location 2, the target location on the *subsequent* trial was always location 1, as defined by the fully deterministic sequence (see Table 2 for all possible triplets from sequence S1).

In the generation task, after a participant made two location responses, their next response would be either the location that correctly completed the triplet (as defined by the training sequence) or one of three alternative third responses. For example, if the participant responded with locations 1 and 2 in the first two trials, a response of location 1 again would complete a correct triplet, while a response of locations 2, 3, or 4 would complete incorrect triplets. Generation task scores were computed for each participant based on the proportion of correctly constructed triplets.

Chance level responding is difficult to calculate for this task because although there are four possible ways to complete a triplet (i.e., 3-2-x may be completed with a 1, 2, 3, or 4; thus setting chance responding at 25%), it is very likely that nearly all participants were explicitly aware that no location occurred twice in a row (setting chance responding closer to 33%). Furthermore, contrary to the way this task has been discussed in the literature, performance on the generation task is likely a combination of implicit and explicit knowledge. Prompted by the strenuous tests of implicit knowledge recommended by Shanks and St. John (1994), most implicit sequence learning researchers have taken the generation task as a measure solely of explicit knowledge. Based on exit interviews, over half of the participants in both experiments reported

responding randomly or without any strategy in the generation task, suggesting that many participants were not even performing the generation task as a test of explicit knowledge.

Following the free generation test, participants were debriefed. Participants were asked if they felt they had detected a sequence during training, what the sequence was, and if they tried to use this knowledge on the free generation task.

## **Results**

### **Secondary Counting Task Data**

Poor counting task performance indicated that the experiment was not being treated by participants as a true dual-task. Participants who performed below 85% accuracy on average in the counting task were removed from the analyses. Three participants in the standard-DT condition fell under this constraint, and all analyses are based on the remaining participants. There was an overall main effect of group on counting task performance (Figure 7), with the effect driven by the significantly better counting performance of the WS-DT condition (see Table 3).

Table 3

*Analysis of Variance of Group on for Counting Task Performance for Training Blocks 1 – 20*

Source	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
WS-DT v. 0SOA-DT	1	12.38	.25	<.005
WS-DT v. visual-DT	1	4.95	.12	<.05
WS-DT v. standard-DT	1	17.33	.33	<.001
0SOA-DT v. visual-DT	1	1.50	.04	.23
0SOA-DT v. standard-DT	1	0.13	.00	.72
Visual-DT v. standard-DT	1	2.63	.07	.11
Between-group error	35			

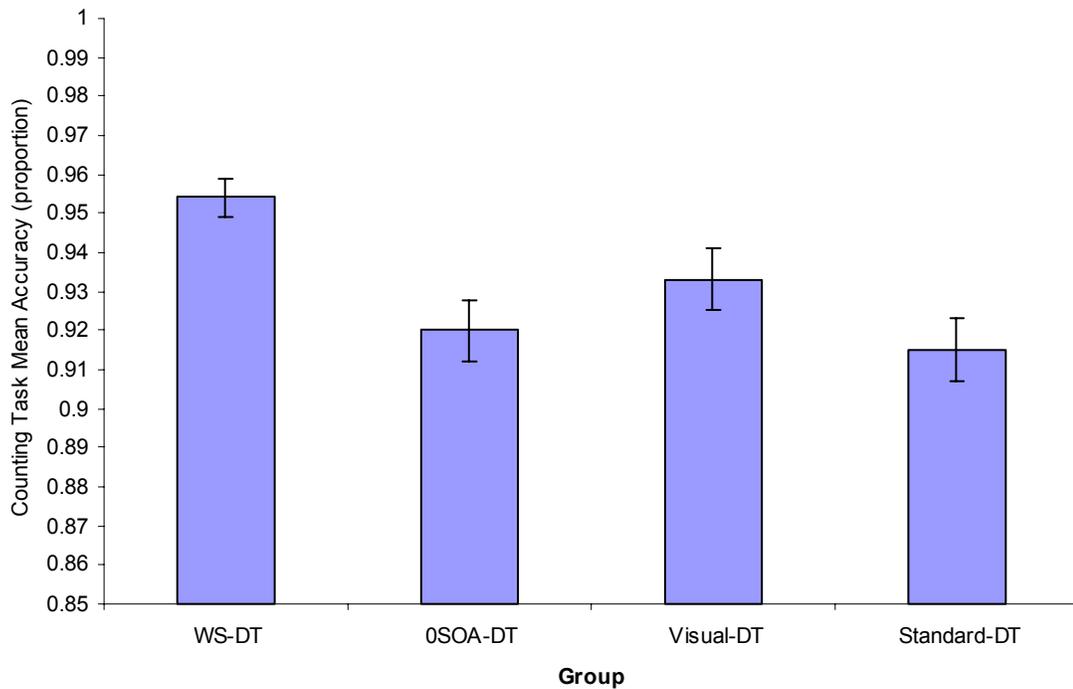


Figure 7. Mean accuracy (proportion correct) for the secondary counting task in Experiment 1 (with standard error bars).

## Training Data

### Response Time

There was no effect of sequence type ( $p = .97$ ), and the remaining analyses are collapsed across this variable. All groups demonstrated an increase in speed across the first 20 training blocks, and this block effect interacted with group (Table 4). This interaction suggested that the five groups' performances changed differentially across the training blocks. The response times of each group significantly improved over training ("Simple Effects" in Table 4; Figure 8), but paired comparisons of the effect of training block on groups suggested that the ST and WS-DT group exhibited the most reliable improvements in response time performance (see the Planned Comparisons panel in

Table 5). The ST group showed greater response time improvements than each of the dual-task groups, and the WS-DT group showed greater response time improvements than the visual-DT and the standard-DT groups.

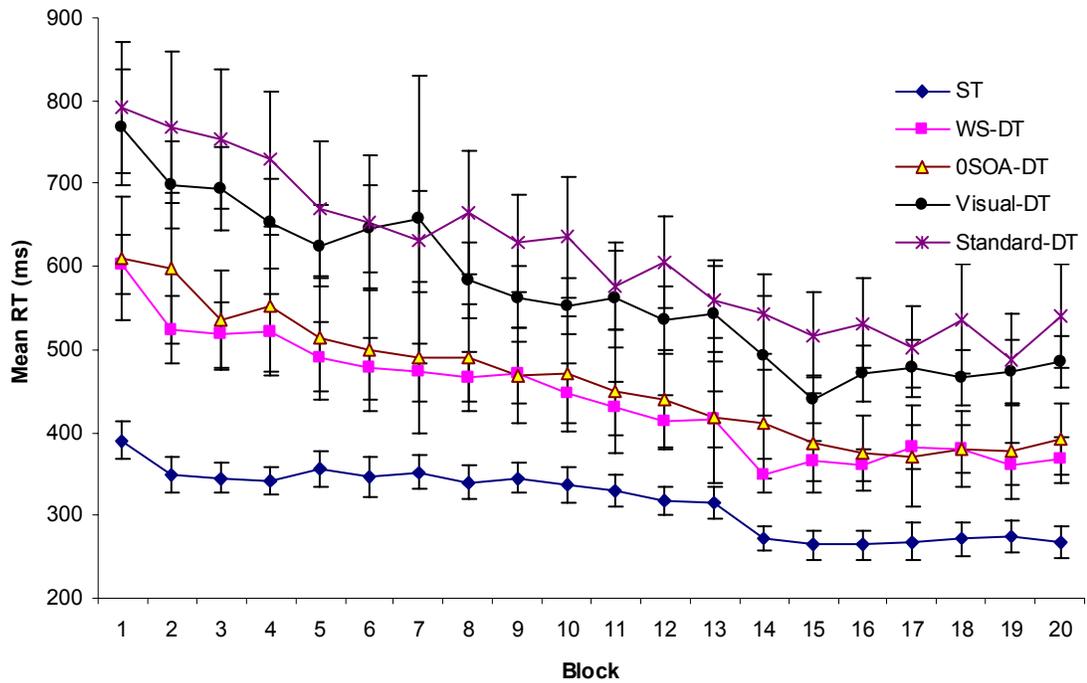


Figure 8. Mean RT (ms) for the five groups across training block in Experiment 1. 95% confidence intervals depicted for block means within each group.

The other three dual-task groups did not differentiate based on their response time performance. The groups also differed in overall RT performance across training, with the two groups with zero second SOAs (WS-DT and 0SOA-DT) responding faster than the two groups with long SOAs (visual-DT and standard-DT) (Table 6). These data indicate that, in the dual-task SRT, simultaneous presentation of the two tasks' stimuli

results in overall faster performance, which seemingly contradicts the overall performance predictions made by the SRD hypothesis. This will be discussed further.

Table 4

*Analysis of Variance of Group on Training Blocks 1 – 20*

Source	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
Main Effect of Group on Block				
<i>Group (G)</i>	4	20.64	.49	<.001
<i>Block (B)</i>	19	85.13	.50	<.001
<i>G X B</i>	76	2.42	.10	<.001
<i>B</i> within-group error	1653			
<i>G</i> between-group error	87			
Simple Effect of Training Blocks 1 – 20, by Group				
ST	19	40.80	.68	<.001
WS-DT	19	34.74	.65	<.001
0SOA-DT	19	17.12	.47	<.001
Visual-DT	19	22.17	.54	<.001
Standard-DT	19	11.26	.43	<.001
Within-group error	361 <sup>a</sup>			

<sup>a</sup>The within-group error for the standard-DT condition was 285, due to the removal of three participants from this condition.

Table 5

*Interaction Effects for Pairwise Group Comparisons vs. Training Block 1 – 20*

Source	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
ST v. WS-DT	19	6.58	.15	<.001
ST v. 0SOA-DT	19	4.86	.11	<.001
ST v. visual-DT	19	8.20	.18	<.001
ST v. standard-DT	19	5.52	.14	<.001
WS-DT v. 0SOA-DT	19	0.84	.02	.66
WS-DT v. visual-DT	19	1.99	.05	<.01
WS-DT v. standard-DT	19	1.43	.04	.11
0SOA-DT v. visual-DT	19	1.15	.03	.29
0SOA-DT v. standard-DT	19	0.57	.02	.93
visual-DT v. standard-DT	19	0.69	.02	.83
Within-group error	722 <sup>a</sup>			

<sup>a</sup>The within-group error term for the analyses involving the standard-DT condition was 665, due to the removal of three participants from this condition.

Table 6

*Pairwise Group Comparisons Collapsed Across Training Blocks 1 – 20*

Source	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
ST v. WS-DT	1	42.62	.53	<.001
ST v. 0SOA-DT	1	13.53	.26	<.005
ST v. visual-DT	1	103.10	.73	<.001
ST v. standard-DT	1	96.10	.73	<.001
WS-DT v. 0SOA-DT	1	0.15	.01	.70
WS-DT v. visual-DT	1	21.91	.37	<.001
WS-DT v. standard-DT	1	25.42	.42	<.001
0SOA-DT v. visual-DT	1	7.40	.16	<.05
0SOA-DT v. standard-DT	1	9.57	.22	<.005
Visual-DT v. standard-DT	1	0.70	.02	.41
Error	38 <sup>a</sup>			

<sup>a</sup>The between-group error term for the analyses involving the standard-DT condition was 35, due to the removal of three participants from this condition.

## Accuracy

As with RT, there was no effect of sequence ( $p = .09$ ), and the remaining analyses are collapsed across this variable. Overall, participants across conditions decreased slightly in accuracy across the twenty training blocks, from an overall high average of 98% in Block 1 to a low average of 95% over the last five blocks,  $F(19,1653) = 8.62, p < .001, \eta_p^2 = .09$ . The five groups also differed in their accuracy, averaged across training block,  $F(4,95) = 10.90, p < .001, \eta_p^2 = .33$  (Figure 9).

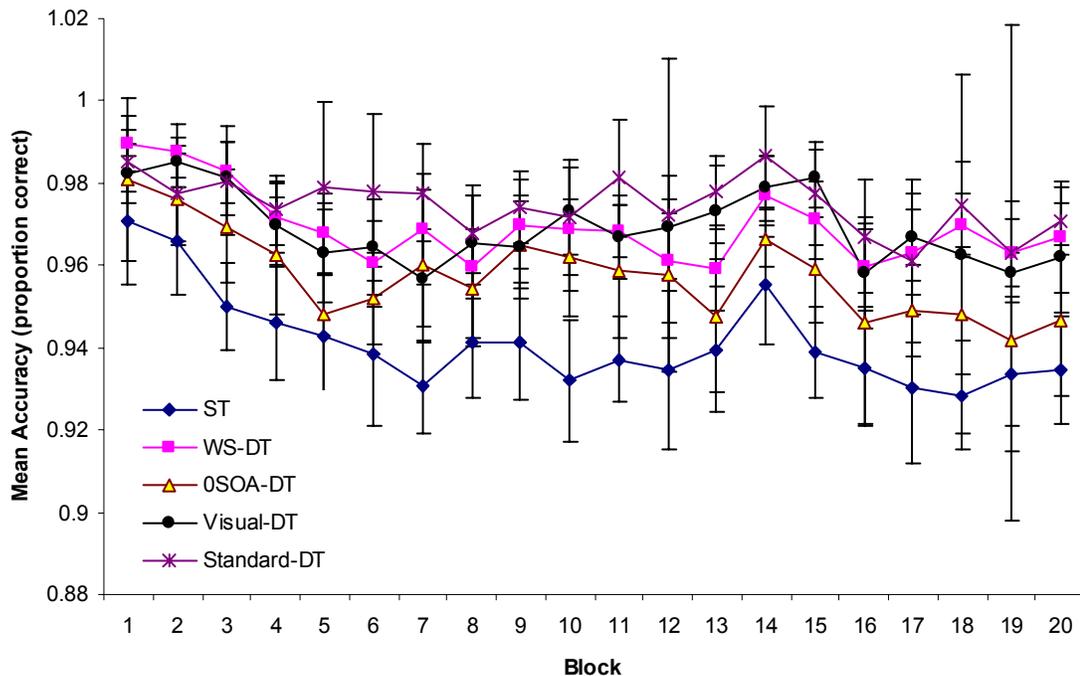


Figure 9. Mean accuracy (proportion correct) for the five groups across training block in Experiment 1. 95% confidence intervals depicted for block means within each group.

The average accuracies for the five groups were ST (94%), WS-DT (97%), OSOA-DT (96%), visual-DT (97%), and standard-DT (98%). The effect appears to have been

driven by the lower accuracy in the ST group, which reflects a small speed-accuracy tradeoff. The interaction between training block and group was not significant ( $p = .58$ ). The five groups did not differ significantly in accuracy across the training blocks.

### Summary

The training data show that each group improved considerably in their performance on the task, prior to the single task and sequence transfers. However, these data may simply reflect differences in general learning as a function of the methodological differences in the various conditions. That is, the data may not solely reflect difference in *implicit* learning across the groups. Given these reservations, the transfer data provided critical comparisons, where stronger experimental control allowed for clearer conclusions about the superiority, in terms of supporting implicit sequence learning, of the WS-DT methodology.

### **Transfer Data**

The primary measure of implicit sequence learning was the disruption in performance when the training sequence was strategically altered in Block 23. The baseline measure for pre-transfer performance was an average of the two single task blocks, Blocks 21 and 22. For the RT data, instead of simply taking the overall mean response time and accuracy for all trials in Block 21, 22, and 23, only those specific trials that were changed were used in the average dependent measures. For example, when participants expected the target to appear in the 3<sup>rd</sup> location based on the consistent sequence used in training, the target would actually appear in the 1<sup>st</sup> location. Conversely, a target within the sequence that appeared in the 1<sup>st</sup> location throughout training appeared in the 3<sup>rd</sup> location. These transfer trials should most consistently reveal

the degree of expectation and learning from participants. (Note: One participant was removed from the WS-DT group due to very low accuracy in Block 22, one of the pre-transfer blocks.)

### Response Time

Group significantly interacted with block type,  $F(4,92) = 11.91, p < .001, \eta_p^2 = .34$ , suggesting that the groups were differentially affected by the sequence transfer. Given the expected superiority of learning in the ST group, the group by block type interaction was evaluated again for the dual-task groups only, also showing a significant interaction,  $F(3,73) = 4.12, p < .01, \eta_p^2 = .15$ . This indicated that the effect of the transfer block was different across the dual-task groups.

Proportion scores were computed as a measure of disruption, taken as the proportion of pre-transfer performance over the transfer performance. These proportion scores were computed in an attempt to deal with the varying baseline RTs (i.e., the pre-transfer RTs). A univariate ANOVA and all paired comparisons were computed (Table 7.) There was an overall main effect of group on the transfer RT scores,  $F(4,92) = 8.21, p < .001, \eta_p^2 = .27$  (Figure 10). As shown in Table 7, the ST group was significantly more disrupted than the other groups. The WS-DT group was significantly more disrupted (in the RT measure) than the standard-DT group, but not the other two dual-task groups (although the interaction with the visual-DT group approached significance).

In summary, the ST group learned more about the sequence than the other groups, evidenced by the significantly greater RT disruption at transfer. The WS-DT group showed numerically greater disruption than the other dual-task groups, significantly

greater disruption than the standard-DT group (and approaching significance against the visual-DT group). Given the direction of the effects, it is likely that increasing the power

Table 7

*Analysis of Variance of Group on Non-Transformed Proportions of Pre-Transfer Blocks and the Transfer Block*

Source	<i>df</i>	<i>F</i>	$\eta_p^2$	<i>p</i>
Main Effect of Group Transformed RT Proportion Scores				
<i>Group (G)</i>	4	13.85	.37	<.001
<i>G</i> within-group error	95			
Planned Comparisons of Group by Training Blocks 1 - 20				
ST v. WS-DT	1	13.69	.26	<.005
ST v. 0SOA-DT	1	26.29	.41	<.001
ST v. visual-DT	1	31.88	.46	<.001
ST v. standard-DT	1	33.56	.47	<.001
WS-DT v. 0SOA-DT	1	1.05	.03	.31
WS-DT v. visual-DT	1	3.00	.07	.09
WS-DT v. standard-DT	1	7.01	.16	<.05
0SOA-DT v. visual-DT	1	0.83	.02	.37
0SOA-DT v. standard-DT	1	4.40	.10	<.05
Visual-DT v. standard-DT	1	1.96	.05	.17
Between-group error	35			

of this study would result in statistical significance in disruption comparisons between the WS-DT group and the other dual-task groups. The 0SOA-DT and visual-DT groups showed numerically similar disruption, and the standard-DT group showed the least disruption (Figure 10).

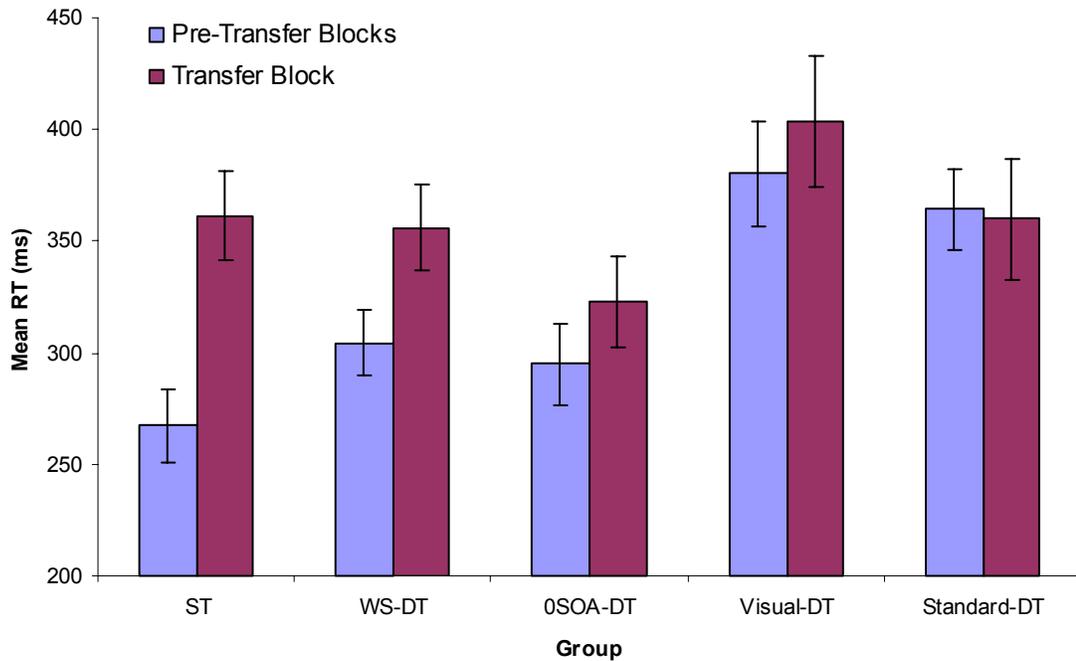


Figure 10. Comparison RTs for the average of the two preceding single-task blocks (20 and 21) and the sequence transfer block for each group in Experiment 1. 95% confidence intervals depicted for block means within each group.

### Accuracy

Overall, participants across conditions decreased in accuracy during the transfer block (92%), as compared to the average of the two preceding single task blocks (95%),  $F(1,91) = 41.48, p < .001, \eta_p^2 = .31$  (Figure 11). The main effect of group was also

significant,  $F(1,91) = 6.25, p < .001, \eta_p^2 = .22$ . However, the interaction between block condition and group was not significant ( $p = .89$ ), and simple effects were not performed. As with the RT data, proportion data were created (Block 23 divided by the average of Blocks 21 and 22), and Shapiro-Wilkes tests of normality were conducted for each group.

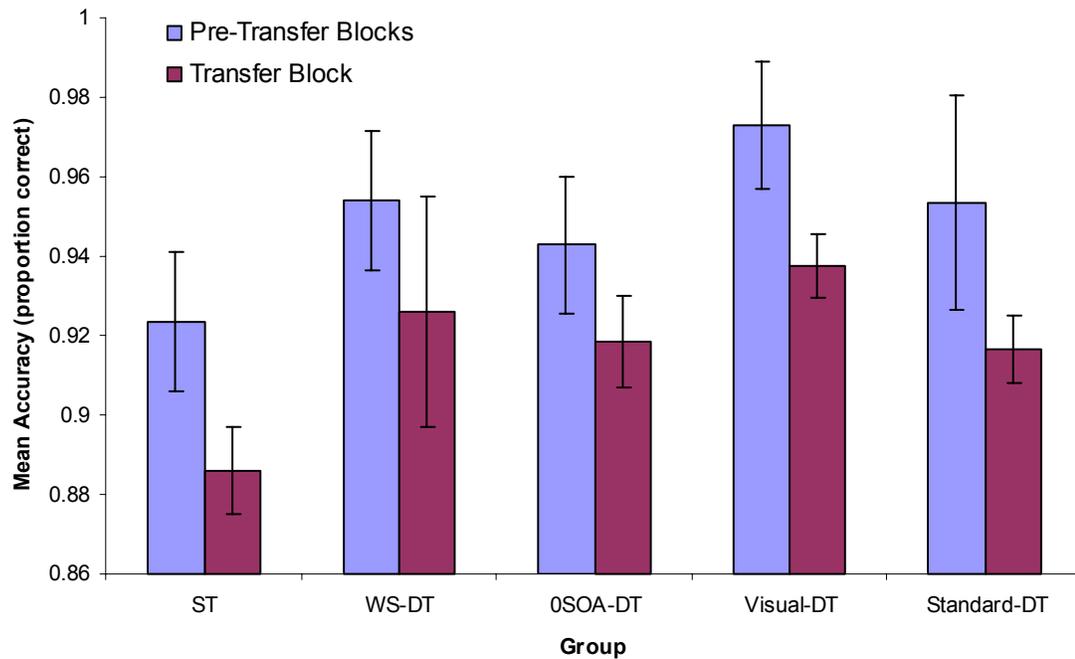


Figure 11. Comparison accuracies for the average of the two preceding single-task blocks (20 and 21) and the sequence transfer block for each group in Experiment 1. 95% confidence intervals depicted for block means within each group.

The standard-DT groups' data were not normal ( $W = .89, p = .05$ ), and an arcsine transformation was conducted. However, there was no main effect of group on the transformed data ( $p = .48$ ). These univariate ANOVAs are essentially the same as the non-significant interaction between block condition and group, above.

### **Sequence Generation Data**

Participants' responses in the generation task were compared to the sequence on which they were trained. The smallest learnable chunks from the 12-location sequence were chunks of three consecutive locations, and there were 12 such learnable chunks in the sequence. Each location was uniquely predicted by the previous two locations; thus, if participants had partially learned the sequence, they should report correct 3-location chunks, as opposed to the incorrect three alternatives. Each 3-location chunk from participants' responses in the generation task was compared to the correct and alternative chunks, and the proportion of correct chunks to total chunks was calculated.

Participants across groups constructed correct triplets 44% of the time, and the groups did not differ from one another ( $p = .53$ ). This score indicates that, when participants selected two consecutive locations, they selected a 3<sup>rd</sup> location that correctly constructed any training sequence triplet 44% of the time. It is unclear to what degree (if at all) this score is above some chance rate of guessing. A guessing rate of 25% would likely *under*-represent true chance performance for reconstructing the training sequence, because participants could acquire knowledge about the stimulus locations that were not sequence-specific, such as the sequence rule that no location would occur twice in a row (in fact, many participants volunteered knowledge of this rule in post-experiment interviews). Knowledge of this rule would raise the guessing rate to a minimum of 33%.

Using 33% as the guessing rate, participants scored significantly higher on the generation task,  $t(96) = 7.84, p < .001$ . This ability to re-create the training sequence may imply at least some degree of explicit knowledge of the sequence.

However, it is still possible that participants were simply moving their fingers around the four response keys in a way to simply mimic how they felt their hands move in the training blocks. That is, they may have been responding, in their minds, randomly, but because of the “back-and-forth” nature of the responses during training, this attempt to replicate this nature of response could result in the appearance of some explicit knowledge simply by accident. Furthermore, most participants reported, in a post-experiment debriefing, that they were aware of responding randomly on the task or simply “letting their fingers go.” On the other hand, several participants were able to correctly articulate a part of the learned sequence, indicating explicit awareness of a portion of the incidental information. The goal of this study was not to disentangle conscious from nonconscious influences on participants’ knowledge of the incidental sequence, and even if some knowledge became explicit during training (or, more likely, from participant feedback, once the task switched to the easier, single-task condition), it is likely that this would have minimal effect on the outcome of interest (i.e., within- vs. between stimulus presentation).

## **Discussion**

Several important questions were answered in this experiment. First, this was the first experiment to directly test the degree of sequence learning that occurs in the standard dual-task SRT with the learning that occurs in a within stimulus dual-task SRT. Previous research only assumed the within stimulus condition would result in more learning

(Jimenez & Mendez, 1999). Secondly, two alternative explanations for the benefits of the within stimulus condition were ruled out. The WS-DT group learned more about the sequence than the 0SOA-DT and visual-DT groups, ruling out the alternative explanations for Jimenez and Mendez's data. This is made even more compelling given the significantly better counting task performance by the WS-DT group compared to the other dual-task groups.

Most importantly, the data ostensibly supported the early encoding hypothesis (based on the CAP2 architecture) and failed to support the SRD hypothesis's predictions about sequence learning across the dual-task groups. The two long SOA groups learned less about the sequence than the WS-DT group. Furthermore, while the SRD hypothesis predicted that the two minimal SOA (the WS-DT and 0SOA-DT) groups should have undergone similar degrees of sequence learning, this was not the case, further supporting the early encoding approach to understanding within stimulus presentation in the dual-task SRT task.

However, while the sequence learning results clearly demonstrate support for the early encoding hypothesis and a lack of support for the SRD hypothesis, the overall performance data are confusing. The early encoding hypothesis does not make clear predictions regarding overall performance – it focuses on learning. The SRD hypothesis, based upon the PRP literature, does focus on primarily on performance, with its predictions for learning being a derivation of the SRD hypothesis. That is, given that the performance data directly contradict the SRD hypothesis and the significant PRP research behind it, it would be prudent to further investigate the finding before drawing such a strong contradictory conclusion.

Why did the standard-DT and visual-DT conditions (i.e., long SOA conditions) result in slower performance than the minimal SOA conditions? The explanation requires a re-conceptualization of between stimulus and within stimulus presentation in the dual-task SRT task. Figures 12 and 13 show timelines for the between stimulus and within stimulus methodologies. In the between stimulus timeline (Figure 12), note the long SOA between S1 and S2 in Trial 1. The SRD hypothesis predicts that this should result in minimal response interference for S2, resulting in faster overall performance. However, look at the task stimuli another way. Notice that S2 occurs and only 100ms later, the SRT stimulus for Trial 2 occurs. In effect, this inter-trial interval (ITI) is an SOA. The response time for Task 2 will be severely interfered with, given such a short SOA. Essentially, in the long SOA conditions, for every trial in each training block *after the first trial*, the PRP effect is interfering with participants' response to the SRT stimulus. This results in slower response times to the stimuli and, hence, slower overall performance.

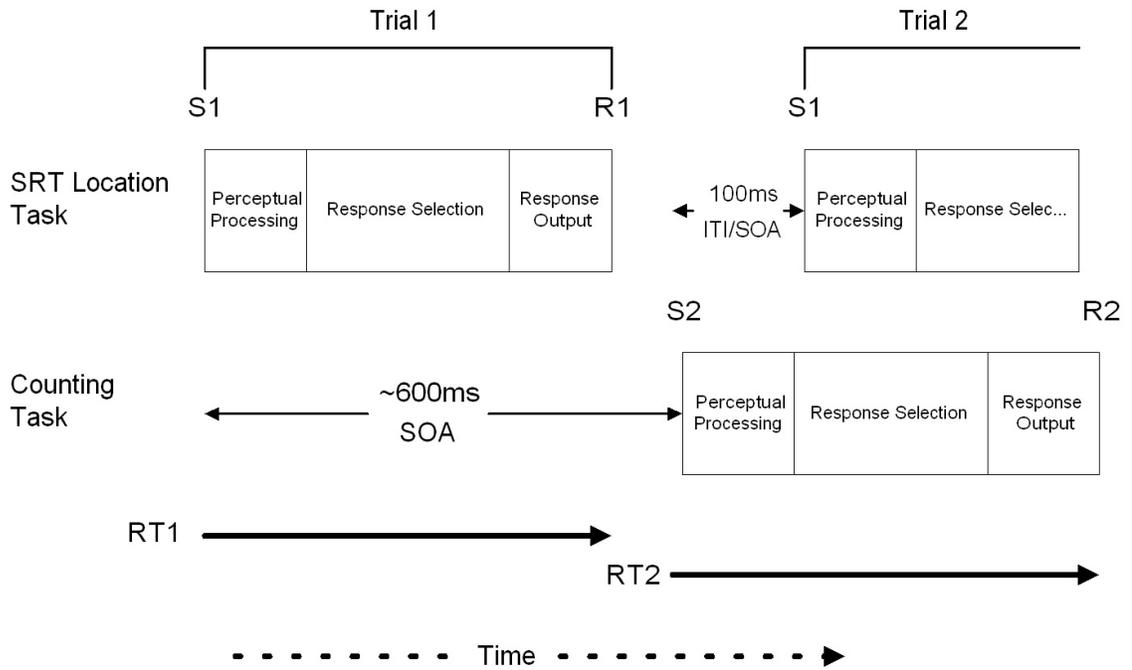


Figure 12. Dual-task timeline for a between stimulus dual-task SRT task.

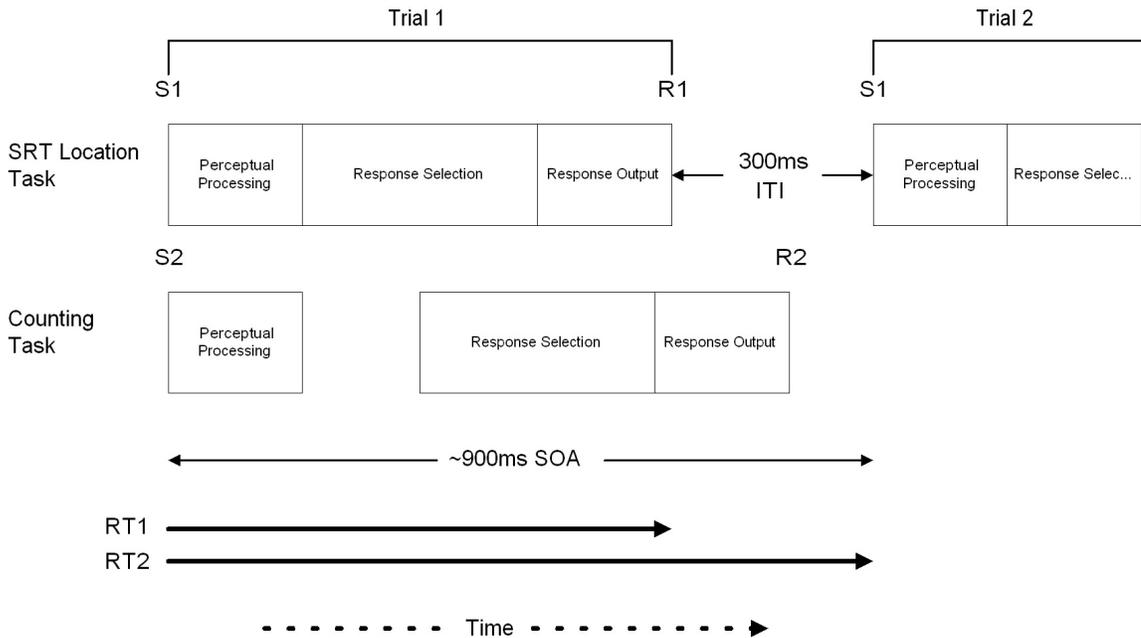


Figure 13. Dual-task timeline for a within stimulus dual-task SRT task.

In summary, the standard-DT and visual-DT conditions were actually very short SOA conditions, and the SRD model accurately predicted considerably poorer performance for these groups, compared to the WS groups. The present data are *essentially* congruous with existing dual-task data from the PRP literature (although the SRD hypothesis was not supported for the sequence learning data). However, from a methodological perspective, the slow-down in RT on Task 1 (i.e., the SRT task) is not consistent with a strict interpretation PRP effect, which states that the slow-down should occur for Task 2 (i.e., the counting task). My interpretation is that Task 1 on trial n was actually Task 2 from trial n-1, hence the slow-down occurs for Task 2. But from the participants' perspective (and from the instructions to participants), this is not how the tasks were ordered. Functionally, this does not affect the interpretation of these data, or the application of the concept behind the PRP effect.

But what about the minimal SOA groups, the WS-DT and 0SOA-DT groups? There seemed to be a very short SOA in these conditions as well, yet the performance by participants in these conditions was faster than that of participants in the standard-DT and visual-DT conditions. In the within stimulus timeline (Figure 13) (also, the timeline for the 0SOA-DT condition), both stimuli are presented at the same time. However, there was a 300ms ITI between the response to S1 and the start of the next trial. This is essentially 300ms of time to overcome any PRP effect and select and output a response. Thus, the amount of response time interference in Task 2 was likely covered by this 300ms window. Given that participants were instructed to (and reportedly did) respond to the SRT stimulus first, any response interference would have occurred for the counting task response, which was not the measure for performance anyway. Thus, while there

may have been interference with the response in Task 2, it was overcome, and processing for both tasks was likely completed before the beginning of the next trial.

In summary, the sequence learning predictions made by the early encoding hypothesis were confirmed by the data (disconfirming the SRD hypothesis's predictions for sequence learning). Also, participants in the two conditions with putatively *long* SOAs (visual-DT and standard-DT) were shown to actually have shorter SOA/ITIs than participants in the WS-DT and 0SOA-DT conditions, supporting the performance predictions of the SRD hypothesis. As discussed previously, it would have been plausible to expect the 0SOA-DT condition to yield more sequence learning because of the loading of separate working memory stores, as compared to the WS-DT condition. Both conditions have been shown to yield relatively longer SOAs and hence less demands on working memory in terms of storing responses in working memory (recall Figure 4; also see Figure 12). However, as the data clearly demonstrated, participants in the WS-DT condition learned more about the sequence of target locations than the 0SOA-DT condition. This suggests something critical about the *within* nature of the within stimulus presentation methodology. Experiment 2 was designed to further investigate within stimulus presentation, specifically as conceptualized by the early encoding hypothesis.

## CHAPTER 3

### EXPERIMENT 2

The early encoding hypothesis suggests that, in within stimulus presentation, the stimulus for the secondary task is obligatorily encoded when the stimulus for the primary task is processed, such that when the participant performs the secondary task, information about the stimulus is already available and task demands are reduced. Essentially, critical information for the secondary task is obtained “for free.” If this is the case, then manipulating the compatibility of the secondary task stimulus – response should result in a significant effect on sequence learning. That is, a condition in which stimuli activate incorrect responses should result in less sequence learning than a condition in which stimuli activate correct responses.

Consider the stimulus-response manipulation in standard Stroop stimuli where participants are required to respond with the color of the text of the color words (Stroop, 1935). In an incompatible condition, participants read the word “red” and the response “red” is activated. However, participants are required to overcome this activation and respond with “blue,” as this is the color of the text. This same activation and interference principle should result in significant interference when Stroop stimuli are used as the stimuli in the SRT task. In a within stimulus presentation condition with incompatible Stroop words, the early encoding hypothesis states that the word will be automatically encoded as the participant also encodes and responds to the location of the target. This activation of word identity must then be overcome in order to make a correct *color* counting response in the secondary task.

In Experiment 2, a dual-task SRT task with either compatible color words (the word “red” in red color and the word “blue” in blue color) or incompatible color words (the word “red” in blue color and the word “blue” in red color) was used. The prediction according to the early encoding hypothesis is that interference due to the activation of multiple responses in the incompatible condition will result in a higher probability of shifting focus of attention away from the sequence information resulting poorer formation of a target sequence representation in memory. Participants in the compatible condition should perform at least as well as a control condition (i.e., non-words in red or blue color) or perhaps even benefit from the compatibility. That is, in the compatible condition, the early encoding of all aspects of the word (in particular, identity and color) would facilitate responding on the secondary task by simplifying the response selection processing required by that task.

## **Method**

### **Participants**

Sixty college undergraduates between the ages of 18 – 25 ( $M = 19.98$ ,  $SD = 1.55$ ) participated (27 females). Participants were compensated with course credit or \$15.

### **Stimuli & Design**

The stimuli and groups were the same described in Experiment 2a. There were 20 participants in each. Sequence S2 was used from Experiment 1.

### **Procedure**

The procedure was the same as in Experiment 1, with the following exceptions. Participants completed only 10 blocks of dual-task training, before the single task and sequence transfer blocks (which were arranged identically to Experiment 1). The

purpose of this change was to reduce the levels of explicit learning that began to emerge towards the end of the 20 training blocks in Experiment 1. The SRT stimuli used in this experiment were also different. In the compatible group, participants saw primarily compatible color words as the SRT task target stimulus, while in the incompatible group, participants saw primarily incompatible color words. In the control group, participants primarily saw the letters “o o” in blue and the letters “xxx” in red (Figure 14).

Task instructions varied between blocks, such that on alternating blocks, participants were instructed to make one of two responses based on the color of the stimulus or based on the stimulus word itself (Table 8). Although more interference occurs when a color response is required (see MacLeod, 1991 for a review), response demands were alternated between color and word so that participants would not be able to automatize the secondary task. For example, in the incompatible condition, if participants only made color responses, the consistent mapping between the word “blue” and the color red would quickly be learned and little interference would likely occur. Also, in each condition, the pairing of stimulus identity and stimulus color was not perfectly consistent; instead, three to five trials in each condition had inconsistent stimuli.

Table 8

*Sequence of Target Stimuli for Each Condition for the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> Blocks in Experiment 2*

Block	Condition		
	Compatible	Incompatible	Control
1 <sup>st</sup>	Word “blue”	Word “red”	Letters “xxx”
2 <sup>nd</sup>	Word “red”	Word “blue”	Letters “o o”
3 <sup>rd</sup>	Color blue	Color blue	Color blue
4 <sup>th</sup>	Color red	Color red	Color red

For example, in the incompatible condition, a highly infrequent SRT target stimulus would be the word “blue” colored blue, and in the control condition, the letters “o o” would be colored red.

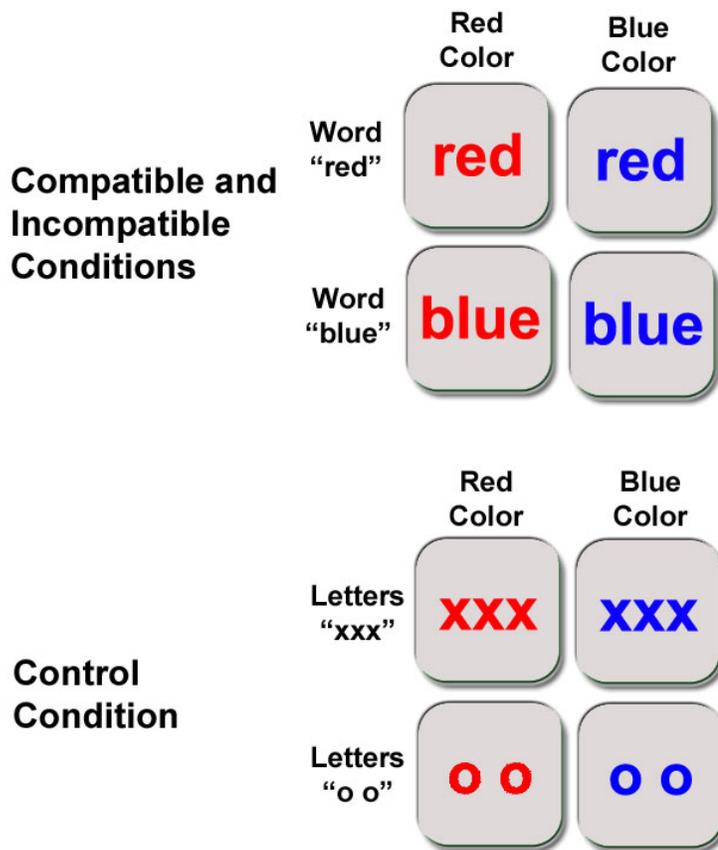


Figure 14. Target stimuli for Experiment 2.

In pilot testing, there was no effect of the compatibility manipulation when mapping between color and text was perfectly consistent or when block instructions alternated *only* between counting blue colored stimuli and counting red colored stimuli. It was reasoned that changing the mapping to 95 – 97% and adding instruction conditions that required participants to also count the word blue and the word red would prevent participants in the incompatible group from adjusting their stimulus-response mappings and automatizing these new mappings (i.e., recognizing that the word “red” would

*always* be colored blue) (see Dulaney & Rogers, 1994). If participants in the incompatible group adjusted their mappings, this would essentially equate the compatible and incompatible conditions, resulting in an undesirable comparison and possibly a null effect of the manipulation. Lastly, because several participants were lost due to poor counting performance in Experiment 1, participants were more encouraged to stay within reasonable counting task accuracy in the task instructions for Experiment 2.

## **Results**

### **Secondary Counting Task Data**

The groups did not significantly differ in counting task performance ( $p = .67$ ), although there was a main effect of training block,  $F(9,504) = 3.18, p < .005, \eta_p^2 = .05$ , indicating a slight decrease in accuracy towards the later blocks. The interaction between these two variables was significant,  $F(18,504) = 1.65, p < .05, \eta_p^2 = .06$ , but the effect was small. Functionally, it does not seem to be a meaningful effect. All three groups were highly accurate, relative to participants in Experiment 1, and the groups did not differ from one another (Figure 15).

### **Training Data**

#### Response Time

Across the 10 training blocks, the three groups significantly improved their time to respond,  $F(9,513) = 65.71, p < .001, \eta_p^2 = .54$ , with no main effect of group ( $p = .70$ ) and no group by block interaction ( $p = .99$ ) (Figure 16). Note the two distinct “humps” at Blocks 5 and 6 and Blocks 9 and 10. Along with Blocks 1 and 2, these blocks were word response blocks, which were ostensibly more difficult than color response blocks (see

Table 8). The improvements in RT at Block 8 may also be due to the brief break participants were required to take prior to that block.

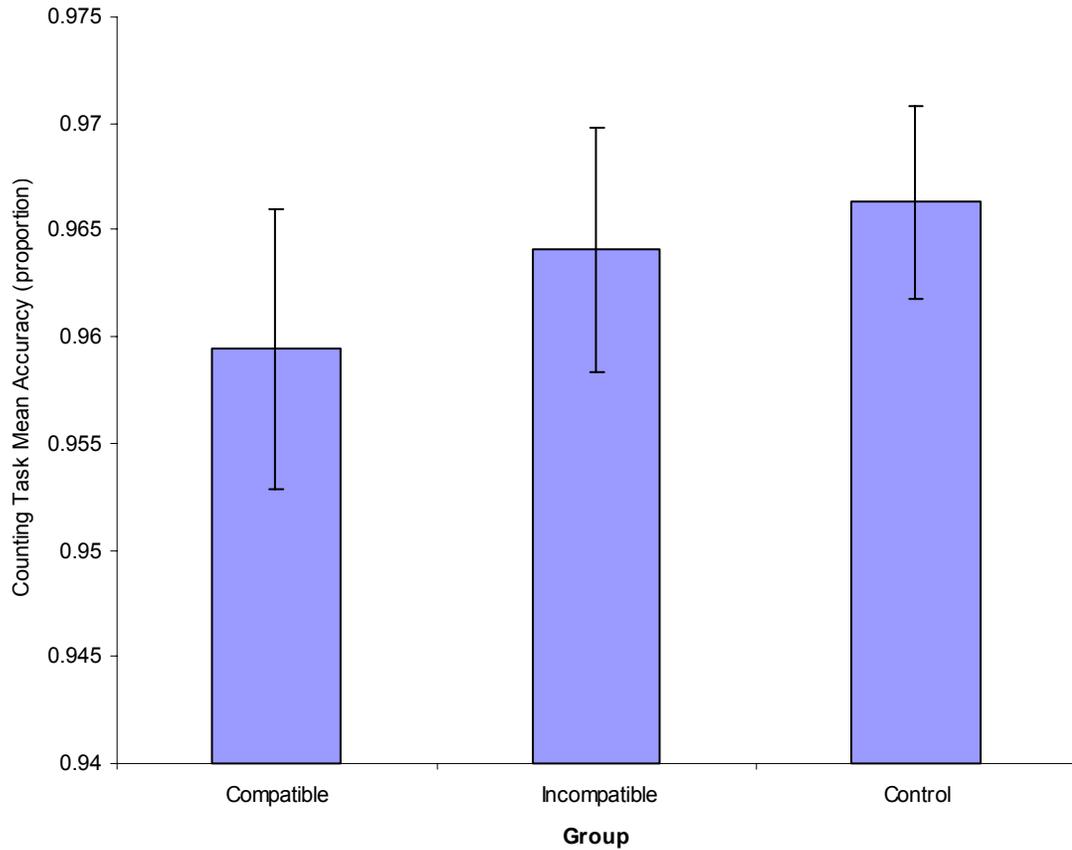


Figure 15. Mean accuracy (proportion correct) for the secondary counting task in Experiment 2 (with standard error bars).

## Accuracy

Accuracy declined slightly across the 10 training blocks,  $F(9,513) = 4.33$ ,  $p < .001$ ,  $\eta_p^2 = .56$ , but the groups did not differ from each other ( $p = .54$ ) and group did not interact with training block ( $p = .57$ ) (Figure 17). The significant improvement in accuracy at Block 8 is likely due to the brief break,  $F(1,57) = 16.58$ ,  $p < .001$ ,  $\eta_p^2 = .23$ .

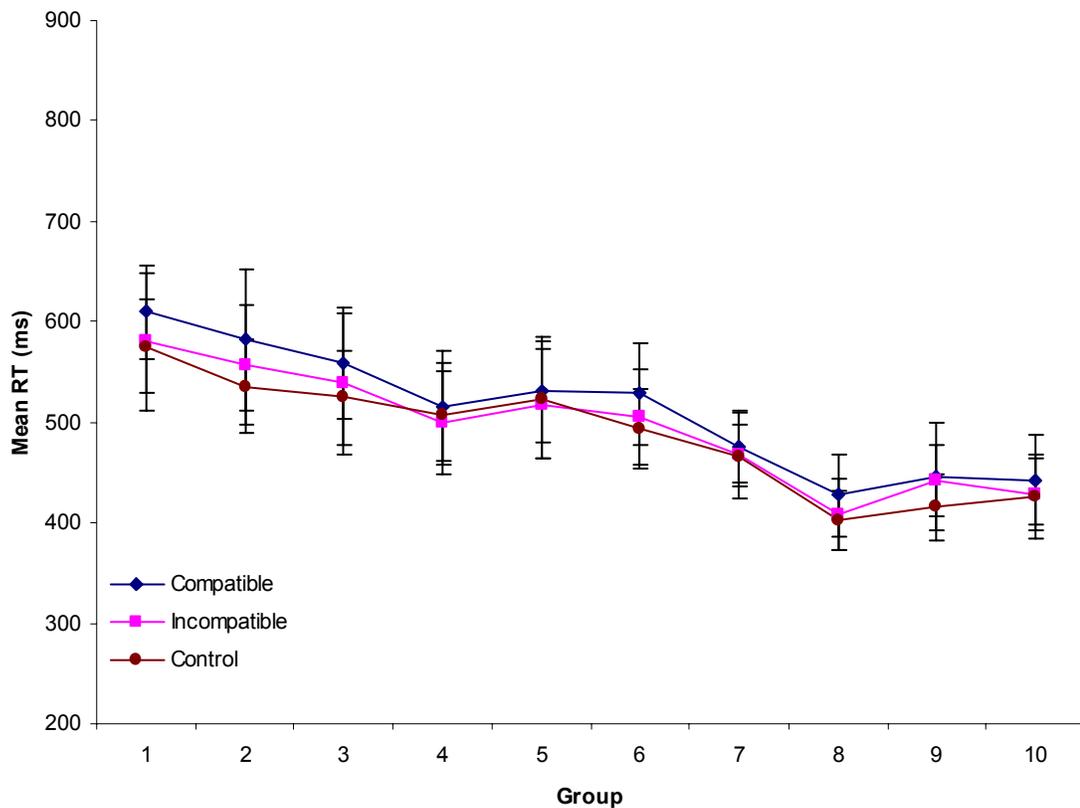


Figure 16. Mean RT (ms) for the five groups across training block in Experiment 2.

95% confidence intervals depicted for block means within each group.

## Summary

The training data did not reveal any differences in performance. In fact, the all three groups showed very similar performance across the training blocks. There did not appear to be any detrimental effect of the incompatible secondary task or any beneficial effect of the compatible secondary task.

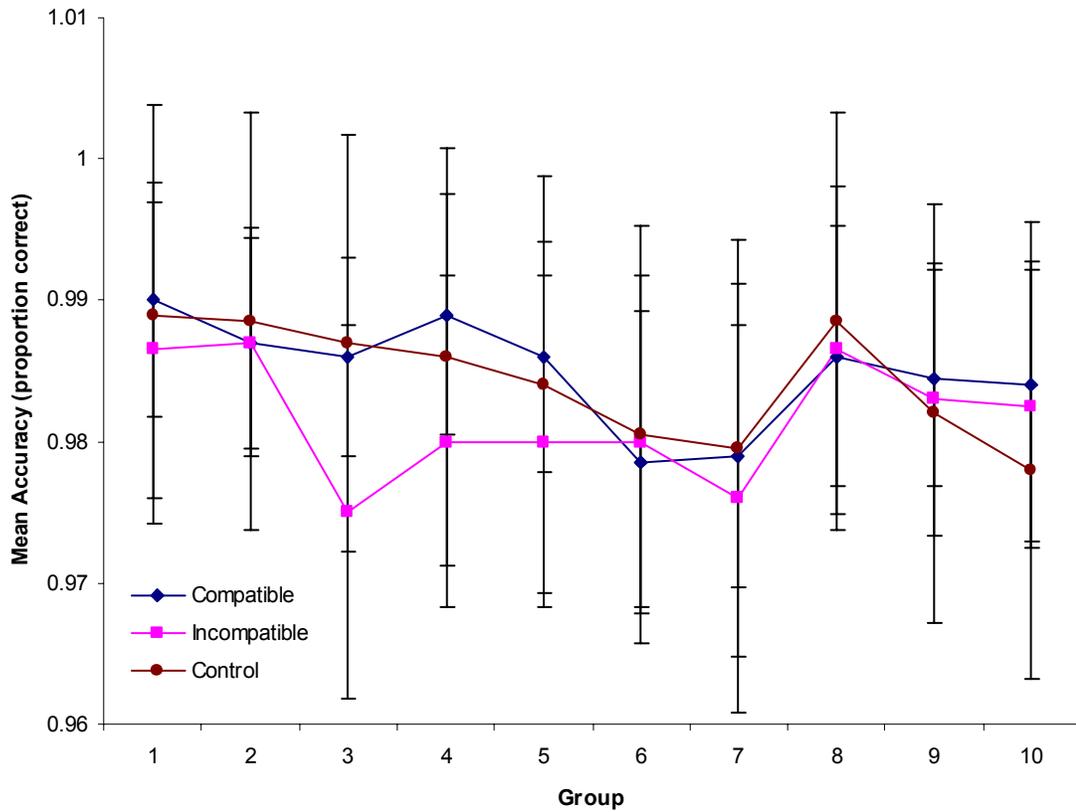


Figure 17. Mean accuracy (proportion correct) for the five groups across training block in Experiment 1. 95% confidence intervals depicted for block means within each group.

## **Transfer Data**

### Response Time

Across groups, the transfer block (Block 13) resulted in significant disruption in RT, as measured against the average of the two single task pre-transfer blocks (Blocks 11, 12),  $F(1,57) = 142.66, p < .001, \eta_p^2 = .72$ . There was no main effect of group ( $p = .65$ ), and the groups were not differentially disrupted in their RT however ( $p = .65$ ) (Figure 18).

### Accuracy

Across groups, participants were significantly less accurate in Block 13 (the transfer block) compared to the average of the two previous blocks,  $F(1,57) = 7.77, p < .01, \eta_p^2 = .12$  (Figure 19). The groups were not differentially affected by the transfer block however ( $p = .34$ ). Across the three blocks, there was a small overall effect of group,  $F(2,57) = 3.32, p < .05, \eta_p^2 = .10$ , driven by the higher accuracy of the control group overall. As can be seen in the figure, the accuracy performance of the compatible and incompatible groups were very similar across training and transfer.

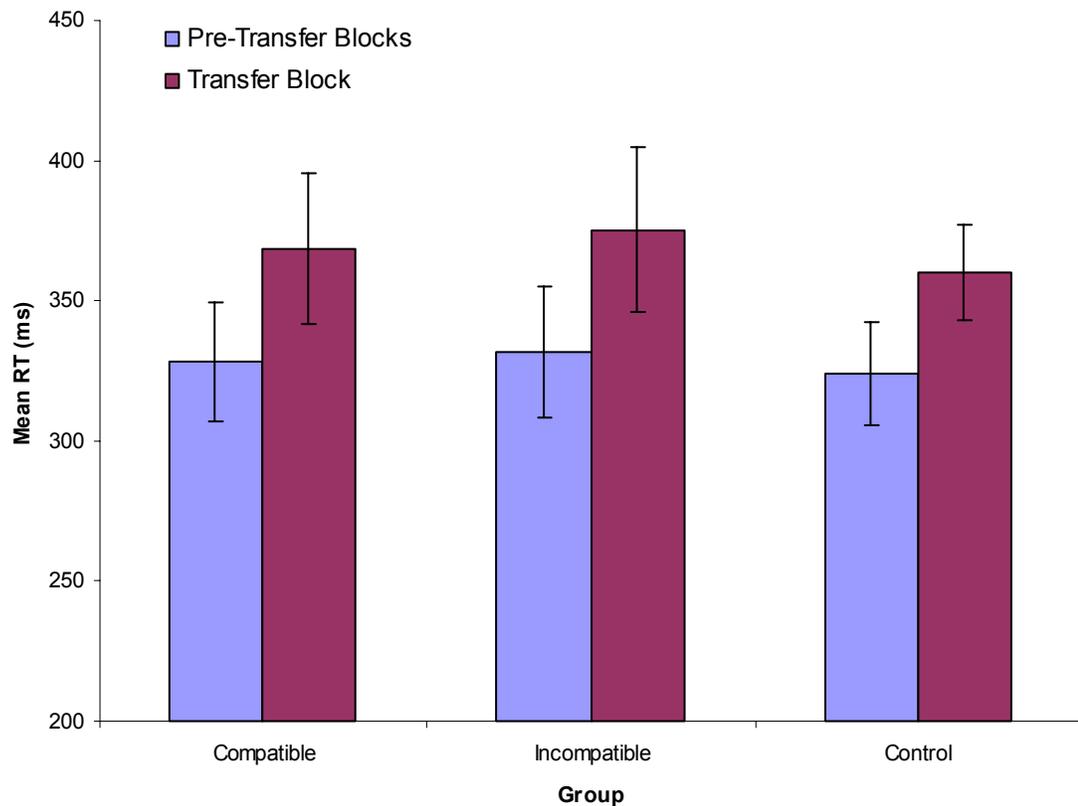


Figure 18. Comparison RTs for the average of the two preceding single-task blocks (20 and 21) and the sequence transfer block (with standard error bars). For each group in Experiment 2.

Summary

As with the first 10 blocks, the transfer data showed no differences in performance. The groups were significantly disrupted in their performance, but equally so. Each group appeared to learn the sequence information to the same extent. The RT disruption was comparable to that of the WS-DT group in Experiment 1.

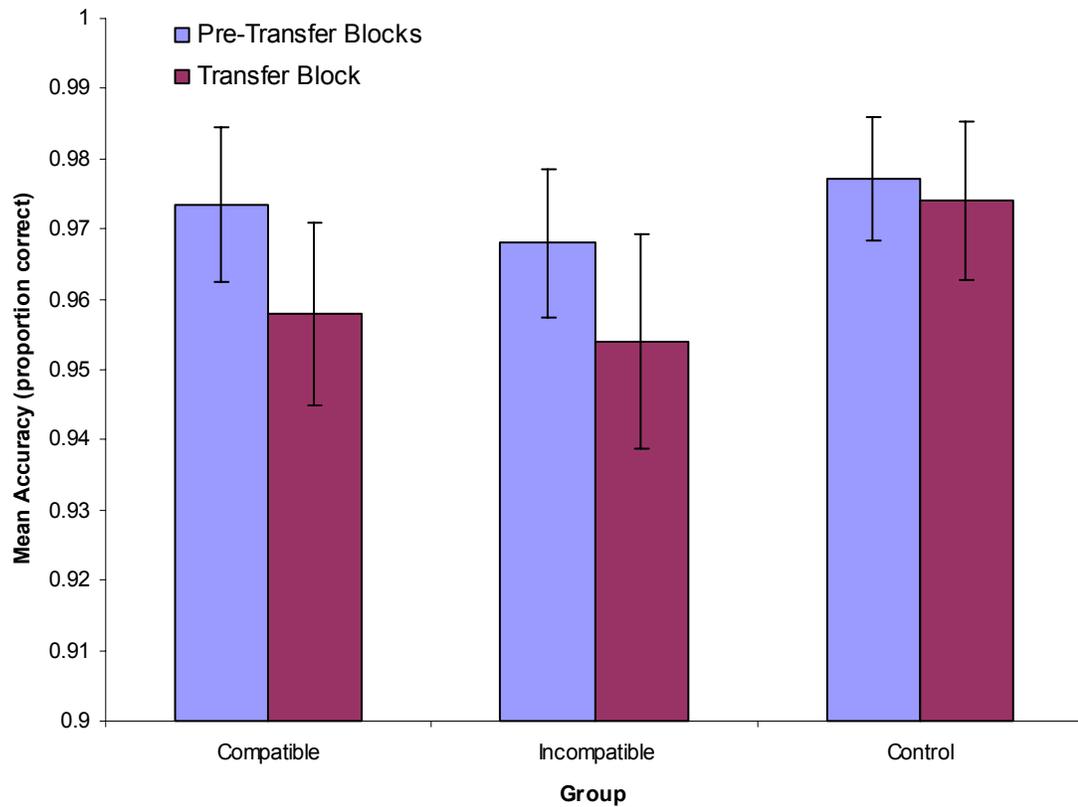


Figure 19. Comparison accuracies for the average of the two preceding single-task blocks (20 and 21) and the sequence transfer block (with standard error bars). For each group in Experiment 2.

### Manipulation Check

A post-hoc experiment was performed to assess the effect of the compatibility manipulation, given the apparent ineffectiveness of the manipulation. In this experiment, participants performed compatible and incompatible versions of a single-task choice response time (CRT) task for the same stimuli used in Experiment 2. Across eight blocks of 96 trials, participants in the compatible condition responded significantly faster than participants in the incompatible condition. Given the greater complexity of the task in

Experiment 2, the significant effect in the manipulation check is likely an underestimation of the effect in Experiment 2. See Appendix A for a full treatment of the manipulation check experiment.

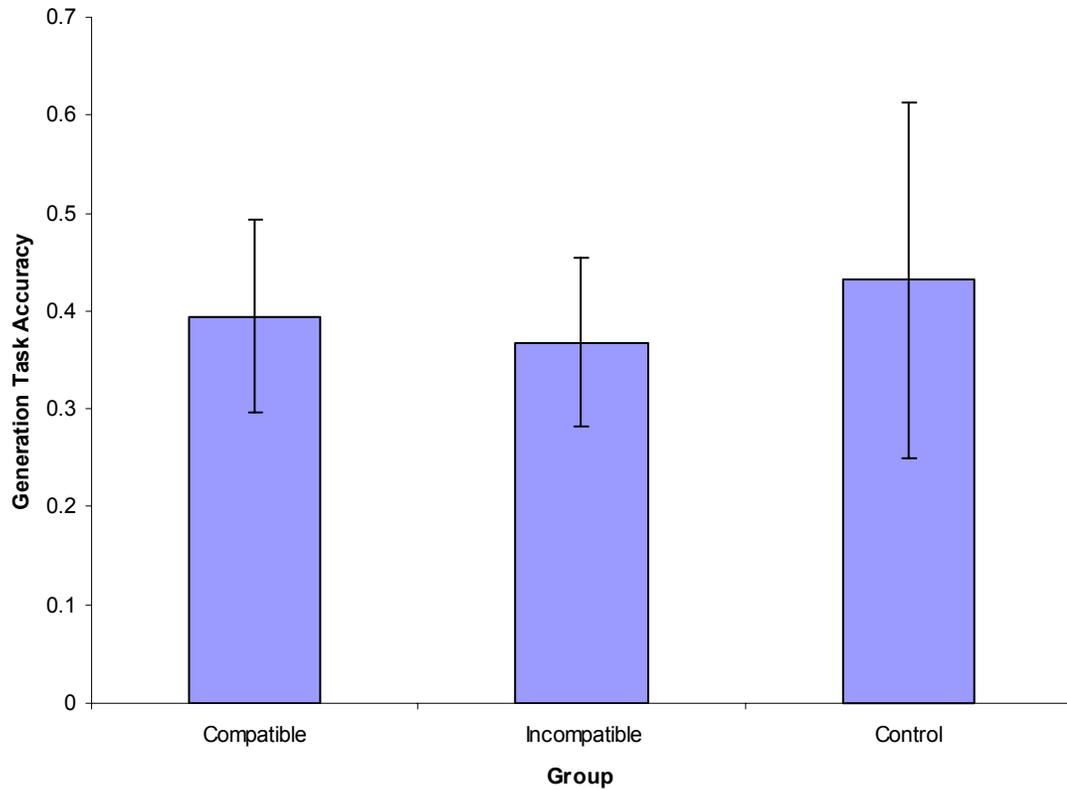


Figure 20. Generation task accuracy for each group in Experiment 2 (with standard error bars).

## Sequence Generation Data

Figure 20 shows the average percentage of time that participants in each group correctly completed any triplet from the training sequence (note that one participant from the incompatible condition was removed from these particular analyses because of not following instructions and pressing a single key for the entire block). As in Experiment 1, participants correctly responded at the triplet level higher than 33% chance performance,  $t(58) = 4.05, p < .001$ . The main effect of group was not significant ( $p = .32$ ), indicating that all groups had a similar degree of knowledge about the sequence.

## Discussion

The data from Experiment 2 may be summed up simply: The compatibility manipulation did not affect implicit learning or overall performance. There were no RT or accuracy differences in training or at transfer across the three different conditions (Figures 18 and 19). As can be seen clearly from the figures, the three groups began the task performing very similarly and their performance remained very close across training. When the groups switched to single task, their performance remained within 5-10ms for each of the five single task blocks (including the transfer block). However, the incompatible counting task was ostensibly of greater difficulty than the compatible version (see the main effect of group in Appendix A). This greater difficulty was designed specifically to test the Why then would the compatibility manipulation result in a null effect?

The secondary tasks were designed to create a cognitive load manipulation on the response selection process. In the incompatible condition, when the location of the target is identified for the SRT task, the color and word information are simultaneously

encoded, but these two stimuli aspects are contradictory and should activate different responses in the secondary counting task. For example, when the block instructions were to count “red stimuli” and the stimulus for a trial was the word “red” in blue color, a “counting” response would be activated due to the word “red” but this response would be countered by an “ignore” response (the correct response) due to the actual color of the word stimulus.

A simple explanation for Experiment 2 is that the compatibility manipulation resulted in interference in the incompatible condition that was below some capacity threshold for a detectable difference. That is, despite a significant Stroop effect for response time in the CRT experiment (Appendix A), the additional processing required by the incompatible condition (relative to the compatible or control conditions) was insufficient to affect response times to the SRT stimulus *or* to affect the sequence learning in the SRT task. Similarly, it is also possible that, due to methodological issues described previously (i.e., alternating the target feature between blocks and reducing the within-block consistency of stimuli to 95-97%), the incompatible group was simply *not different enough* from the compatible group. Furthermore, the similarity issue could have been compounded by strategic approaches by participants to circumvent the incompatibility. For example, a small number of participants in the incompatible condition voluntarily reported that they intentionally blurred their vision in an attempt to reduce the Stroop interference from the stimuli. This would make the compatible and incompatible groups much more similar, possibly removing any behavioral differences. The potential for this strategy was known to me prior to conducting the experiment (it was the primary impetus for reducing the stimuli consistency to 95-97%), but I decided

not to explicitly instruct participants against this strategy, as such instructions may have simply functioned to provide a useful strategy to participants. Lastly, the null effect may be meaningful, perhaps suggesting that sequence learning is impervious to certain manipulations.

## **CHAPTER 4**

### **CONCLUSIONS**

#### **General Discussion**

In Experiment 1, the within stimulus conditions demonstrated greater sequence learning than other dual-task conditions. The within stimulus conditions in Experiment 2 also demonstrated significant sequence learning. However, sequence learning was unaffected by the Stroop compatibility manipulation in Experiment 2.

#### **The “Overshadowing” Explanation**

The long SOA conditions in Experiment 1 (WS-DT condition and, the now misnamed, 0 SOA-DT condition) demonstrated fast performance relative to the short SOA conditions, in part, due to the allowance for participants in these conditions to complete the secondary counting task within the ITI between trials. Essentially, the ITI “overshadowed” any response interference that may have occurred in the counting task, allowing the subsequent trial to progress separately from the processing of the previous trial. It is possible that Experiment 2 runs into a similar “overshadowing” issue. That is, the response interference experienced by the incompatible condition was resolved during the ITI (see Figure 13). Given that the manipulation check for the compatibility effect (see Appendix A) yielded a maximum RT difference of 105ms (in the first block), it is possible that the long ITI (300ms) overshadowed the interference effect on the RT measure.

Based on a general capacity limitation approach, in this explanation, working memory can hold only so much information (i.e., multiple stimuli, multiple responses,

etc.), and when multiple stimuli are activated in working memory, the cognitive system requires sufficient time to process the responses to these stimuli or the system will become overloaded and, in this case, sequence learning will suffer (due to inefficient binding of location information from previous trials in working memory). For example, if the ITI in within stimulus presentation conditions were 50ms (instead of 300ms, as in Experiment 2), the response to the stimulus for the secondary task could not be processed before the stimulus for the subsequent trial is presented and loaded into working memory. This would particularly be the case for the incompatible condition, where the stimulus must be maintained in working memory longer, as the incompatibility between the stimulus and the correct response is solved. In this case, performance on the location task in the *subsequent* trial would likely suffer, as the short ITI would not “overshadow” the deleterious effect of the incompatible stimulus-response pair.

This explanation addresses the lack of a *performance* difference between the compatible and incompatible conditions in Experiment 2, but it does not provide a convincing explanation for the lack of a *learning* difference. Response times on the location task may be interfered, but it does not necessarily follow that the binding of previous locations in working memory would also be interfered. For example, in Experiment 1, participants in the 0 SOA-DT condition outperformed participants in the standard-DT condition, but the degree of sequence learning between the two conditions was not significantly different. It is unclear how the overshadowing explanation would account for the lack of a learning difference, although “overshadowing” may explain the performance of the short SOA conditions in Experiment 1 and the lack of a performance

difference in Experiment 2. Perhaps a better explanation for the lack of a learning difference can be seen in the differences between the two experiments.

### **Multiple Stimuli vs. Multiple Responses**

In the between stimulus conditions in Experiment 1, multiple stimuli were stored in working memory, whereas in the within stimulus condition, only a single stimulus was stored. The effect of the obligatory, early encoding in within stimulus presentation is that only a single stimulus is loaded into working memory, where as in between stimulus presentation, multiple stimuli are loaded in working memory. This resulted in a less efficient binding of previous trials' location information in working memory, thus hindering implicit sequence learning. For example, in the between stimulus conditions of Experiment 1, the SRT stimulus and the counting task stimulus were both loaded into working memory. The attentional process responsible for sorting multiple stimuli in working memory and making correct responses to these stimuli was more heavily taxed than under within stimulus conditions, where only a single stimulus was loaded, and this apparently negatively affected the binding of sequential target information (i.e., the processes involved in the SRN model of sequence learning, described in the Introduction).

Thus, in Experiment 1, a comparison was made between a condition in which a single stimulus was loaded into working memory versus a condition in which multiple stimuli were loaded into working memory. This resulted in better sequence learning in the single stimulus loading condition. However, in Experiment 2, a comparison was made between a condition in which a single *response* was loaded into working memory versus a condition in which multiple responses were loaded into working memory. That

is, in the compatible condition, only a single response was activated by the SRT stimulus. If the color word “red” appeared (also colored red), the participant performed the secondary counting task with only a single response activated by this stimulus. In the incompatible condition, two responses were activated by the SRT stimulus. If the color word “red” appeared (colored *blue*), two responses were activated, and the participant would (ideally) suppress the incorrect response and select the correct one.

Curiously, this differential loading of working memory did not result in either performance or learning differences between these two conditions, *despite* the significant effect of compatibility in the manipulation check experiment. A significantly more difficult task (as demonstrated in the experiment described in Appendix A) in which response selection load was increased did not appear to interfere with the binding of stimulus location information in working memory. Despite a null result in Experiment 2, the data from this experiment suggest a possible answer to the overarching question of this study: What is the critical aspect of within stimulus presentation such that it results in preserved implicit sequence learning, relative to between stimulus presentation?

In fact, the process of selecting a response amongst multiple activated responses in working memory may not interfere with the formation of a sequence representation (when the task involves within stimulus presentation of the features that elicit the multiple responses), but when multiple stimuli are activated, sequence learning suffers. Given this, perhaps the critical aspect of within stimulus presentation, as pertains to implicit sequence learning, is the immediate availability of multiple features from the same object (Duncan, 1984; Logan & Etherton, 1994), whereas making more difficult

judgments (i.e., selecting a response from multiple, activated responses) about the stimulus has no effect on sequence learning.

One might argue that a greater response selection difficulty manipulation (than what was conducted in Experiment 2) would result in an effect, contradicting my suggestion about multiple features and multiple objects. Undoubtedly, if the secondary counting task was made sufficiently difficult in within stimulus presentation condition (e.g., adding a perceptual degradation manipulation), sequence learning would eventually suffer. However, this would likely be due to a severe overlap between the counting task in one trial and the SRT task in the subsequent trial, such that the SRT task itself was fundamentally changed. The response selection load manipulation would not directly affect sequence learning, but the additional processing in conjunction with the processing of the SRT task across trials would likely create multiple changes in the way the SRT task was performed. This is certainly an area that warrants further investigation.

### **Practical Relevance**

This study supported the original (although untested) conclusions of Jimenez and Mendez (1999) that within stimulus presentation will result in preserved implicit sequence learning relative to between stimulus presentation. The success of within stimulus presentation seems to lie in our ability to encode multiple features at once, which occurs as a result of object-based attentional selection mechanisms. Implicit sequence learning remained robust under within stimulus presentation conditions even when the task was made more difficult by increasing the response selection demands of the task. Additional research is needed to investigate other limitations on the effect of within stimulus presentation. One limitation I tested was that the formation of a sequence

representation would be hindered when multiple responses were generated to a stimulus in a within stimulus presentation condition. However, sequence learning appeared to be immune to this response loading *in the present methodology*. Explanations for this null effect may be theoretical or methodological, and further research is needed. Possibly, the manipulation was not strong enough (despite the findings presented in Appendix A), but equally possibly, sequence learning under within stimulus presentation conditions is more resistant to the effect of the activation of multiple responses than to the effect of the activation of multiple features.

The proposed comparison between multiple stimuli and multiple responses is related to the functional limitations of attention (e.g., selection-for-action, Allport 1989; Neumann, 1987; 1996). The attentional system is designed to handle the processing of multiple streams of information, but given the effector limitations (e.g., we have only two hands), we are not physically capable of acting on multiple objects (exceeding the number of available effectors at least). Similarly, the SRD model of dual-task performance places constraints on the *output* of multiple responses, but allows for the earlier processing of multiple responses. The findings from Experiment 2 suggested that within stimulus presentation allows sequence learning to progress unimpeded when multiple responses were activated (in this case, two responses) relative to a condition where only one response was activated; however, in Experiment 1, when multiple stimuli were active in working memory, learning suffered relative to a condition where only a single stimulus was active.

What I have demonstrated in this research is that implicit learning can take place under attentionally demanding conditions (i.e., multiple tasks), and also that this learning

can be improved when presented to participants in certain ways – namely when incidentally related features are presented within stimuli that comprise the task that is being performed versus presented outside the task being performed. Imagine a task where several incidental relationships are built into the various elements within the task display. Explicitly informing people about the relationships will lead them to actively search for them, resulting in performance decrements (see Reber, 1989 for a review). However, if participants learn the relationships, this knowledge can be used to support their task performance. The present research suggests that maintaining attention on the stimuli that comprise the incidental features and relationships will result in more efficient learning of the relationships. This may seem fundamentally obvious, but historically, implicit learning has been thought of as a passive acquisition of covarying stimuli, essentially capacity-free (e.g., Nissen & Bullemer, 1987; see also Reber, 1989).

In addition to the concept of within stimulus presentation, implicit learning in general can potentially contribute significantly to training systems. For example, users could be shown many instances of a particular stimulus configuration, such that their attention is trained to detect certain configurations of stimuli or to orient to various spatial locations (*cf.* Chun & Jiang, 1998). Training to detect can occur within a larger training context, such that activation for target configurations of task elements occurs while the trainee is interacting with the elements in other ways. Research like the present study has shown that such learning is possible and functionally meaningful.

While the previous example focused on how to support performance in a training scenario, implicit learning research can also be used to achieve an opposite effect, such as making a task considerably more difficult. With the relative unaware nature of implicitly

acquired knowledge, a transfer manipulation would result in a confusing situation for users (as was the case when the sequence was transferred to a non-practiced sequence in these experiments). This may have applications in the games and entertainment industry, where creating confusion and challenging scenarios is a critical problem for game designers. Consider a game where the user interacts with a set of visual elements that are consistently related to each other, such as a first-person shooter where enemies move in specific, complex, *consistent* formations or where other variables consistently predict some aspect of the enemy's behavior. As the user progresses through levels of the game, standard difficulty manipulations may be instantiated (such as increasing the number of enemies, increasing the attack power of enemies, etc).

But these manipulations lack an important aspect of challenge in game design; they affect difficulty, but there is often little additional problem-solving required to overcome the enemy. If the consistent relationships were covertly changed, users' *tacit* expectations would begin to work against them, resulting in a unique kind of challenge. Essentially, users must adapt to something I refer to as *transfer confusion*. Not only does the task/game become more difficult because the enemy's activity is unexpected, but it becomes more difficult because something very different is expected. Thus, transfer confusion should result in a situation in which users do not just lack expectation (as would be the case in a completely new situation), but they have the wrong expectations. The concept of skill transfer has a long history in the attention and automaticity literature (see Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), and, in combination with the non-conscious nature of implicitly acquired knowledge, this kind of skill transfer represents a potentially potent and challenging disruption to game users.

Returning to the training issue, this same principle can also be applied “game-like” (“game-like” in the implementation of the task, not in the gravity of the task) domains such as military wargame simulations. It is important for soldiers on the ground to maintain control and intelligently deal with confusion and unexpected elements. The transfer confusion can provide a scenario by which a soldier’s ability to cope with confusion can be measured, as well as trained. If this aspect of implicit learning is to further studied, considerable research is required on the transfer of implicitly acquired knowledge. It is currently unclear whether implicitly acquired knowledge is as inflexible and context-dependent in its representation in the mind as the knowledge representations assessed in studies of implicit *memory* (see Roediger, 1990). If implicitly acquired knowledge is to be used to support performance or disrupt performance, it must be shown to be flexibly applied to different contexts, such that users’ behavior reflects this knowledge.

## APPENDIX A

### MANIPULATION CHECK FOR EXPERIMENT 2

#### Method

##### Participants

Thirty-six college undergraduates (Age:  $M = 19.31$ ,  $SD = 16.43$ ) participated (16 females). Participants were compensated with course credit or \$10. There were three groups (described below): compatible (13 participants), incompatible (13 participants), and control (10 participants). One participant from the incompatible group was removed due to a failure to follow instructions and very poor performance, yielding 12 participants in this condition.

##### Stimuli & Design

The visual stimulus set consisted of eight strings – the word “red” colored red, the word “red” colored blue, the word “blue” colored blue, the word “blue” colored red; and four control strings, the letters “o o” in red and blue colors and the letters “xxx” in red and blue colors (Figure 15). No auditory tones were used.

##### Procedure

The purpose of this experiment was to provide a manipulation check for the compatibility manipulation to be employed in Experiment 2. Participants in each condition performed a task with a surface similarity to the standard SRT task. A target string appeared in one of four spatial locations, but participants were required to press one of two response keys, depending on the identity of the target. Location information was irrelevant. Participants in the compatible condition received primarily compatible

color words (i.e., the word “red” appeared in red color and the word “blue” appeared in blue color), while participants in the incompatible condition received primarily incompatible color words (i.e., the word “red” appeared in blue color and the word “blue” appeared in red color). The control condition saw “o o” stimuli that primarily appeared in blue color and “xxx” stimuli that primarily appeared in red color. The slight inconsistency between stimulus color and stimulus word and the alternation of the four instructional sets across blocks were the same as described in the methodology for Experiment 2. When participants were instructed to respond based on color, they pressed the “Z” key for red colored words and the “M” key for blue colored words. When participants were instructed to respond based on the word itself, they pressed the “Z” key for the word “red” and the “M” key for the word “blue.”

## **Results & Discussion**

### **Response Time**

Across groups, participants improved their RT,  $F(7,224) = 16.28, p < .001, \eta_p^2 = .34$ . The three groups did not significantly differ from each other overall ( $p = .09$ ), and the interaction between group and block was not significant ( $p = .12$ ). However, because the comparison of interest was between the compatible and incompatible groups, analyses were conducted just on these two groups.

Across these two groups, the effect of block remained significant,  $F(7,161) = 9.06, p < .001, \eta_p^2 = .28$ . The compatible group was also significantly faster than the incompatible group, across blocks,  $F(1,23) = 4.44, p < .05, \eta_p^2 = .16$ . Curiously, the compatible group was numerically faster in their responses for colors than for words (which occurred on alternating blocks, resulting in the “see-saw” RT pattern in Figure 21), while the

incompatible group was ostensibly much less affected by the instructional manipulation (the control condition also responded faster in the color response blocks). This suggested that participants in the incompatible condition treated the two forms of the task similarly. Combined with the overall poorer performance, this in turn suggested that the incompatible task was sufficiently difficult to override any differences in the two versions of the incompatible task (color counting and word counting).

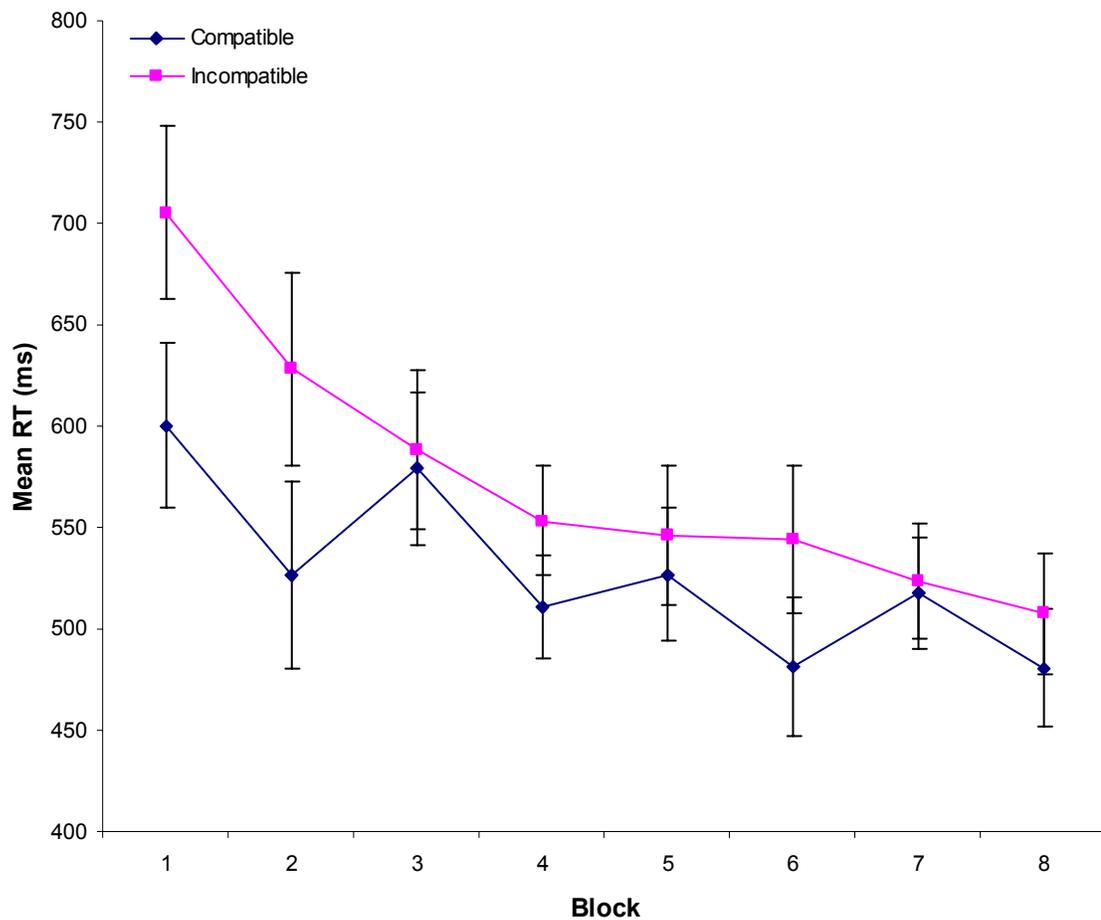


Figure 21. Mean RT (ms) for the two groups in the manipulation check experiment (Appendix A) across blocks (with standard error bars).

## **Accuracy**

There were no significant effects for the accuracy measure, including main effect of group ( $p = .85$ ), main effect of block ( $p = .15$ ), and the interaction between the two ( $p = .53$ ).

## **Summary**

The RT data demonstrated that the compatible condition yielded faster overall performance than the incompatible condition. Furthermore, because this experiment was single task and a simple CRT task, it is reasonable to expect that this would *underrepresent* the magnitude of the disruption effect in the incompatible condition in Experiment 2.

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