Contingency Learning and Unlearning in the Blink of an Eye:

A Resource Dependent Process

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

Recent studies show that when words are correlated with the colours they are printed in (e.g., MOVE is presented 75% of the time in blue), colour identification is faster when the word is presented in its expected colour (MOVE in blue) than in an unexpected colour (MOVE in green). The present series of experiments explored the possible mechanisms involved in this colour-word contingency learning effect. Experiment 1 demonstrated that the effect was already present after 18 learning trials. During subsequent *unlearning,* the effect extinguished equally rapidly, suggesting that only a handful of the most recently encountered trials are used to predict responses. Two reanalyses of data from Schmidt, Crump, Cheesman, and Besner (2007) ruled out an account of the effect in terms of stimulus repetitions. Experiments 2 and 3 demonstrated that participants who carry a memory load do not show a contingency effect, supporting the hypothesis that limited-capacity resources are used to retrieve a small number of trial memories in order to prepare a response. Experiment 4 demonstrated that memory resources are required for both storage and retrieval processes.

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Introduction

The ability of humans to learn about contingencies between events in the world has recently re-appeared as a major topic in experimental psychology (e.g., Allan, 2005; Beckers, De Houwer, & Matute, 2007; Mitchell, De Houwer, & Lovibond, in press). Most often, contingency learning in humans is studied using paradigms in which participants see a series of situations in which stimuli or responses co-occur and are afterward asked to judge the strength of the contingency between the stimuli or responses. Other paradigms allow one to assess learning without asking participants to explicitly judge the strength of contingencies. One version of this is the colour-word contingency learning paradigm (Schmidt, Crump, Cheesman, & Besner, 2007; see also Schmidt & Besner, 2008; Musen & Squire, 1993). For instance, Schmidt and colleagues presented four arbitrary words in four different display colours in a colour identification task using a key press response. As illustrated in Table 1, each word was presented in all colours, but more often in a particular colour (e.g., MOVE was presented 75% of the time in blue, SENT 75% of the time in green, etc.). Participants responded faster and made fewer errors on high contingency trials (where the word is presented in its correlated colour; e.g., $\text{MOVE}_{\text{blue}}$) than on low contingency trials (where the word is presented in any other colour; e.g., $\text{MOVE}_{\text{green}}$). To date, little is known about *how* contingency information is actually learned in this paradigm. The present thesis briefly reviews past work, discusses several competing accounts, and reports four new experiments and two reanalyses of old data that provide new insights into the mechanisms underlying the form of contingency learning in this paradigm.

Table 1. Example Contingency Mapping (75%)

	MOVE	SENT	LIST	TELL
blue	9	1	1	1
green	1	9	1	1
yellow	1	1	9	1
orange	1	1	1	9

There are several possible explanations for how contingency information is learned, but there are a few findings that narrow the field of potential explanations. For instance, awareness of contingency information in the paradigm used here does not seem to be necessary. Very few participants are aware of the contingency manipulation and the size of the colour-word contingency effect is unaffected by a participant's level of awareness (Schmidt et al., 2007, Experiment 3). Thus, awareness of contingencies does not seem to "buy" participants anything; the effect is the same size regardless. This suggests that, independent of the participant's awareness of the task manipulation, the processes involved in learning are implicit. A similar argument has been made from results of a flanker task in which flanking cues were predictive of the response (Carlson & Flowers, 1996), sequence learning (Song, Howard Jr., & Howard, 2007), and other paradigms (e.g., Lewicki, Hill, & Czyzewska, 1992). However, the role of awareness in contingency learning is a highly controversial issue. In particular, there is little consensus on the proper way of assessing awareness and proponents of objective measures of awareness often argue for a small amount of awareness of learned information (e.g., see Fu, Fu, & Dienes, 2007 for a detailed discussion of these issues). I simply note that, at the very least, the results of Schmidt and colleagues are difficult to reconcile with rule-based accounts that demand a role for conscious intention (although such rule-based processes may well play a role in unspeeded judgment tasks; e.g., see De Houwer, 2009; and Mitchell, De Houwer, & Lovibond, in press for discussions of propositional accounts of associative learning). As a result, in the rest of the present thesis I narrow my focus to accounts that are more implicit in nature.

Another important finding of Schmidt and colleagues (2007, Experiment 4) is that the colour-word contingency effect does not simply reduce to stimulus-stimulus association or stimulus familiarity. In the critical experiment, two colours were assigned to the left key (e.g., blue and green) and two others were assigned to the right key (e.g., yellow and orange). If MOVE was presented most often in blue, then participants were faster to make the correct left key response to $MOVE_{blue}$ *and* $MOVE_{green}$ than they were to make right key responses to $MOVE_{yellow}$ and $MOVE_{orange}$. Schmidt and colleagues observed no difference in responses to $MOVE_{blue}$ and $MOVE_{green}$. Thus, it is not the case that MOVE is *associated* with the colour blue (or else $MOVE_{green}$ would not have been speeded), nor is it critical that participants saw the stimulus $MOVE_{blue}$ more often than the stimulus $MOVE_{green}$. Rather, it is critical that MOVE is associated with a left key *response*. When the correct response matches this associated response (for blue or green print), responding is facilitated. These results inform us that the learning mechanism is picking up on the contingencies between the distracting word and the *response*, not the contingencies between the distracting word and the target *colour* (however, it should be noted that effects of stimulus-stimulus associations have been observed in other paradigms; e.g., Colzato, Raffone, & Hommel, 2006). Thus, I narrow my focus here to accounts that posit a relationship between the distracter and the response.

There are a number of accounts that could potentially explain the colour-word contingency effect. The simplest of these can be termed the *repetition account,* which explains the colour-word contingency effect in terms of transient memory effects. There are a few subtle variations of this. In one version, high contingency trials are speeded by the residual activation of the memory of recently encountered matching trials (Bertelson, 1961). For instance, high contingency trials such as $MOVE_{blue}$ would often be speeded because $MOVE_{blue}$ was recently encountered and the memory of this event is still active, allowing for a quicker response. In contrast, a low contingency trial such as $MOVE_{green}$ will rarely be speeded, because the probability of two instances of $MOVE_{green}$ occurring temporally close is much less likely.

According to a slightly different version of the repetition account, when a stimulus and response occur together the association between them is temporarily strengthened for a period of time. If the same stimulus and response are presented together shortly after this, responding will be facilitated. Again, high contingency trials are much more likely to have been recently preceded by the same word-response pairing (e.g., $MOVE_{blue}$ before $MOVE_{blue}$) than are low contingency trials (e.g., $MOVE_{green}$ before $MOVE_{green}$).

Connectionist accounts such as the simple recurrent network (SRN; Cleeremans & McClelland, 1991; Kinder & Shanks, 2001, 2003) could explain the colour-word contingency effect in terms of a highly interconnected arrangement of nodes in which each trial causes the connection weights between nodes to change. For instance, presentation of $MOVE_{blue}$ would lead to an increase in the connection strength between MOVE and the blue response (via a layer of hidden units) and a weakening of other connections (e.g., MOVE to the green response). The idea is that the system uses each trial to update the associations between stimuli and responses to gradually optimize performance by adapting to the statistical regularities in the task. Depending on the learning rates of the model, this process could happen relatively slowly or rapidly.

Finally, I consider a similar but conceptually distinct account based on the storage and retrieval of event files, the *event file account.* Hommel (1998) first introduced the notion of an event file as a temporary memory of an event that includes information about the stimuli presented along with the response that was executed. This idea is usually used to investigate the impact of trial transitions (i.e., whether the word and colour repeated, just one of the stimuli repeated, or both the word and colour alternated), but my suggestion is that these same event file memories could be used to generate response expectancies. According to this event file hypothesis (for a related account see Logan's, 1988 instance theory), participants in an experiment store a memory of each encountered trial (event). Early processing of the word leads to retrieval of a set of the most recently encountered (i.e., most accessible) event files associated with this word (e.g., MOVE leads to retrieval of event files containing MOVE) and from these a response expectancy can be generated. As a result, high contingency trials will tend to be speeded because the system will be able to detect the contingencies in the task and prepare for the high contingency response. Note that the difference between this event file account and the repetition hypothesis is that the repetition hypothesis purports that individual recently-encountered stimuli bias responding, whereas the event file hypothesis purports that several recently-encountered event files are retrieved and used to determine the likely outcome of the current trial.

As can be seen, there are a number of candidate explanations for the colour-word contingency effect. A number of important questions remain to be answered before the best account can be specified. For instance, we still do not have information about basic issues such as: (1) the number of trials needed to obtain the effect (i.e., acquisition speed), (2) whether and how fast the effect disappears when the contingencies are removed (i.e., extinction speed), and (3) whether contingency effects can be found only when sufficient memory resources are available. Just like studies of acquisition, extinction, and the effect of memory resources were crucial in developing theories about other forms of human contingency learning (e.g., De Houwer, 2009; De Houwer, Thomas, & Baeyens, 2001; Shanks, 2007), examining these three issues in the context of the current contingency learning paradigm should provide important information about the processes underlying this effect. Experiment 1 addresses the first two questions and Experiments 2, 3, and 4 address the final question.

Experiment 1

The rate of acquisition of contingency information is an important issue. For instance, if contingency information is both learned and unlearned rapidly, then this would pose a problem for a connectionist model with a low learning rate. It is already known that the colour-word contingency effect appears relatively early on in the course of an experiment. In a block analysis, Schmidt et al. (2007) found that the contingency effect was already significant in the very first block of 48 trials. The first goal of Experiment 1 is to increase the resolution of the block analysis by using smaller blocks of 18 trials. One possible outcome is that a contingency effect occurs very early on, perhaps in the first block of 18 trials, indicating that very few trials need to be experienced before contingency information can be extracted. Such a finding would be consistent with any model that is able to alter responding based on a limited sample of trials. This includes the repetition account, which explains the effect in terms of transient connections or activations and for connectionist accounts with a high learning rate. According to low learning rate connectionist accounts, however, acquisition should be slower and participants would need to accumulate experience with several blocks of trials before the effect emerges.

In an event file framework, understanding how fast a contingency is learned does not necessarily provide us with much information on how much data the system can take into account. For instance, imagine an event file account in which the system calculates the most likely response based on the identity of the word using the last 100 trials (a relatively large window) that it has encoded. Presumably, the system does not actually need 100 trials before it can start calculating; it can use whatever information it has accumulated so far (e.g., 12 instances if it is on trial 13). The system can use *up to* 100 trials, but does not necessarily need that many. In this sense, a rapid learning rate is not particularly diagnostic in discriminating between accounts stating that the system can handle, for instance, 100 versus just 10 trials of information. As explained below, the unlearning manipulation reported here is much more informative in this respect.

The second goal of Experiment 1, therefore, is to investigate the rate of *unlearning*. Partway through the experiment, contingencies were suddenly and without notice switched from 67% (in a three-choice task) to 33% (chance; i.e., each word is presented equally often in all colours). The questions being investigated are whether the color-word contingency effect is eliminated, and if so, how fast? One possibility is that participants discover the statistical regularities early on in the task and stop searching for contingencies. If so, then the contingency effect should not be extinguished by changing the probabilities. More likely, the effect will extinguish, but the rate at which this happens is diagnostic for some of the competing accounts.

The repetition account assumes that the effect results from recent exposure to other similar trials and thus also predicts rapid unlearning. Similarly, a high learning rate connectionist account predicts, by definition, a high learning rate and fast extinction. In contrast, a low learning rate connectionist account predicts, by definition, a low learning rate and slow extinction, which would be reflected by a gradual decrease in the size of the contingency effect across several unlearning blocks.

For event file accounts, if the window of trials that participants retrieve for response prediction is large (e.g., the last 100 trials), then the contingency effect should very slowly extinguish as participants are exposed to more and more uncorrelated trials. This is because it will take a great deal of unlearning before the average contingency of the last 100 trials is substantially reduced (e.g., on the 21st trial of unlearning, 80% of the trials the system is using are still from the learning phase). This slow unlearning would be reflected by a gradual decrease in the size of the contingency effect across several unlearning blocks (just like the low learning rate connectionist prediction).

For an event file account that posits that the system relies on a limited number of the most recently encountered trials, the effect should extinguishing very rapidly, perhaps in the first block of changed probabilities. For instance, if the system makes its calculations based on just the last ten trials, then by trial 11 the participant is not using a single trial from the learning phase to generate response expectancies. Thus, for event file accounts, both a large window and small window version can accommodate fast learning, but only the small window account predicts fast extinction when unlearning.

In summary, Experiment 1 investigates the rate of initial learning of contingency information and subsequent unlearning. The experiment begins with three short blocks of 18 trials in which there is a 67% contingency. Learning across blocks is analysed to assess acquisition speed. Directly following these three learning blocks were nine unlearning blocks of 18 trials each in which the contingencies were dropped to chance (33%, three choice). The decrease in the size of the contingency effect across unlearning blocks is assessed to determine extinction speed.

The repetition account predicts rapid learning and unlearning. For connectionist accounts, if the learning rate is high, then the contingency effect should emerge rapidly in learning and extinguish rapidly in unlearning. If the learning rate is low, then the contingency effect should emerge gradually in learning and extinguish gradually in unlearning. Finally, for event file accounts, learning could possibly occur rapidly regardless of window size. Unlearning speed will depend on the number of trials the system is able to use to generate response expectancies.

Method

Participants

Ninety-eight University of Waterloo undergraduates participated in Experiment 1 in exchange for course credit.

Apparatus

Stimulus and response timing were controlled by E-Prime (Experimental Software Tools, 2002). Participants pressed the "j" key for blue, the "k" key for red, and the "l" key for green with the first three fingers of their right hand.

Materials and Design

Participants sat approximately 60 cm from the screen and viewed stimuli on a black screen. There were four stimulus words (LOCK, WIDE, REST, CRAM), but any given participant only saw three of these.[1] There were three display colours (blue, red, green). The experiment began with three learning blocks of 18 trials each. In each learning block, each of the three words was presented four out of six times (67%) in a randomly assigned colour (e.g., LOCK in blue, WIDE in red, REST in green) and once in each of the remaining colours (e.g., LOCK would be presented four times in blue, once in red, and once in green). Directly following these three learning blocks there were nine unlearning blocks, again of 18 trials each. In each unlearning block, each of the three words was now presented equally often (two out of six times) in each of the three colours. Participants were not notified of or told to expect the switch from learning to unlearning. Stimuli were presented in lowercase, bold, 18 pt. Courier New font. Stimuli within blocks were presented in random order.

Procedure

At the beginning of each trial participants saw a white fixation cross for 250 ms, followed by a blank screen for 250 ms, followed by the coloured word for 2000 ms or until a response was made. A blank screen was presented for 300 ms following a correct response, and the message “Incorrect” or “No response” was presented in red for 1000 ms following an incorrect or missed response, respectively.

Results

Trials in which participants failed to respond were deleted from analyses (less than 1 % of the data). For response latencies, only correct responses were analyzed. For each participant in each cell, response latencies that were more than 2.5 standard deviations above or below the mean were excluded from analysis (approximately 1% of the data). Other than reducing noise, these exclusion criteria do not affect the pattern of the results.[2]

Response latencies

A 2 (contingency; high, low) x 12 (block) ANOVA for response latencies yielded a significant main effect of contingency, $F(1,97) = 6.794$, $MSE = 6112$, $p = .011$, a main effect of

Table 2. Experiment 1 Response Latencies (in milliseconds) and Statistical Comparisons for Block and Contingency

	Contingency			
	High	Low	Effect	Statistic
Learning				
Block 1	593	638	45	$t(97) = 3.697$, $SE_{diff} = 12$, $p < .001$**
Block 2	567	604	37	$t(97) = 3.004$, $SE_{diff} = 12$, $p = .003$**
Block 3	540	585	45	$t(97) = 4.524$, $SE_{diff} = 10$, $p < .001$**
Unlearning				
Block 4	563	586	23	$t(97) = 2.186$, $SE_{diff} = 11$, $p = .031$*
Block 5	579	571	-8	$t(97) = .721$, $SE_{diff} = 11$, $p = .473$
Block 6	578	578	0	$t(97) = .039$, $SE_{diff} = 11$, $p = .969$
Block 7	566	569	3	$t(97) = .336$, $SE_{diff} = 9$, $p = .715$
Block 8	590	583	-7	$t(97) = .658$, $SE_{diff} = 10$, $p = .512$
Block 9	584	585	1	$t(97) = .118$, $SE_{diff} = 12$, $p = .906$
Block 10	579	580	1	$t(97) = .105$, $SE_{diff} = 10$, $p = .916$
Block 11	606	588	-18	$t(97) = 1.455$, $SE_{diff} = 12$, $p = .149$
Block 12	601	578	-23	$t(97) = 2.425$, $SE_{diff} = 9$, $p = .017$*

* $p < .05$
** p < .004 (Bonferroni correction)

block, $F(11,1067) = 3.179$, $MSE = 11788$, $p < .001$, and an interaction, $F(11,1067) = 4.736$, $MSE = 5647$, $p < .001$. Planned comparisons were conducted to determine which blocks yielded a significant contingency effect. The data and statistics are presented in Table 2. Comparisons revealed significant and relatively consistent contingency effects for all three learning blocks (Blocks 1-3). There was also a significant (but small) contingency effect in the first unlearning block immediately following learning (Block 4). For the following seven blocks (Blocks 5-11), there were no significant contingency effects and the differences were all close to zero. Unexpectedly, high contingency trials were significantly *slower* than low contingency trials in the final block (Block 12). However, given the number of statistical tests conducted and the fact that this difference is in the wrong direction for a contingency effect, this finding is likely a Type I error. Indeed, this effect is no longer significant after a Bonferroni correction (Block 4 falls below significance with this correction as well).

Error percentages

The error data are presented in Table 3. A 2 (contingency) x 12 (block) ANOVA revealed

Table 3. Experiment 1 Percentage Errors for Block and Contingency

	Contingency		
	High	Low	Effect
Learning			
Block 1	5.8	9.1	3.3
Block 2	5.3	6.6	1.3
Block 3	4.7	5.9	1.2
Unlearning			
Block 4	4.4	6.4	2.0
Block 5	3.6	4.9	1.3
Block 6	5.2	5.2	0.1
Block 7	5.9	5.6	-0.3
Block 8	6.3	4.4	-2.0
Block 9	4.7	5.3	0.7
Block 10	5.7	5.1	-0.6
Block 11	5.4	4.8	-0.4
Block 12	6.1	5.9	-0.2

a significant main effect of block, $F(11,1067) = 1.857$, $MSE = 62$, $p = .041$, but no main effect of contingency, $F(1,97) = 2.561$, $MSE = 65$, $p = .113$, nor an interaction, $F(11,1067) = 1.433$, $MSE = 66$, $p = .152$. These data are not discussed further.

Discussion

The results of this experiment clearly demonstrate that both learning and unlearning occur extremely rapidly. Initial contingency learning was significant in the very first block of 18 trials. It was initially my intention to study the time course of learning, but the learning slope is so sharp that detecting learning across blocks of this size is impossible. Unlearning seems to occur just as rapidly. There was only a very small carryover from the learning blocks into the first unlearning block, and then the effect disappeared in the following unlearning blocks. Thus, it is clear that the learning mechanism is highly responsive to the actual contingencies. This rules out a few of the accounts considered in the Introduction. The data are consistent with connectionist accounts, but only if a high learning rate is assumed. With a low learning rate, it would take the system much longer to accrue enough information to learn contingencies in the learning phase and it would take substantially more unlearning for the effect to extinguish. Similarly, the finding of rapid extinction rules out an event file account in which it is assumed that the system draws on a relatively large sample of trial memories. Fast learning and unlearning, however, is consistent with a small window event file account. Finally, the repetition account posits that the colour-word contingency effect results from transient repetition effects and is thus consistent with the observed rate of learning and unlearning.

Reanalysis 1

The repetition account of the colour-word contingency effect, as noted above, attributes the effect to either residual activation or temporary SR associations occurring more often for high contingency trials than low contingency trials. The earliest experiments I conducted using the colour-word contingency paradigm had constraints on presentation order such that no colour could be repeated from one trial to the next, thus making it impossible for such complete repetitions (e.g., $MOVE_{blue}$ could never directly follow $MOVE_{blue}$; Schmidt et al., 2007) and I have also been careful to control for n – 1 sequence effects wherever I had enough data per cell to do so (i.e., by deleting trials in which the colour repeats, thus eliminating complete repetitions, which are faster than other trials). Thus, I can already rule out an account that holds that colour-word contingency learning results from trial n – 1 repetition effects. However, these controls have not ruled out sequence effects beyond trial n – 1. For instance, it might be the case that complete repetitions on trial n – 2, n – 3, or perhaps even more distant lags also produce a speeding of responses. Thus, the contingency effect could simply be the result of the combination of benefits from various lags. I therefore conducted a reanalysis of data from Schmidt et al. (2007, Experiment 2) to test for n – 2 through n – 5 repetition effects. The critical test condition is *complete repetitions,* where both the word and colour repeat. I also coded for *word repetitions,* where the word but not the colour repeats; *colour repetitions,* where the colour but not the word repeats; and *alternations,* where neither the word nor colour repeats. The reason for selecting this particular experiment for my reanalysis is that the contingency manipulation was small enough (50% in a four choice task, where chance is 25%) to allow sufficient observations in all cells (e.g., in experiments with high contingency manipulations where each low contingency pairing only occurs once per block, as was the case in Experiment 1 here, the only way to get a complete repetition is for the last trial in one block to match the first trial in the next block).

The predictions of connectionist and event file accounts are less clear than those of the repetition account. One might argue that a connectionist model with a high enough learning rate should predict a larger influence of more recent trials (given that each new trial needs to be able to have a significant influence on connection weights). In that sense, repetition effects might be expected. However, even with high learning rates there is still an accumulation over several trials. For the event file account there is no a priori reason to expect that the most recent events should (or should not) have a greater influence on responding than later trials. The idea is that participants are retrieving a *number* of associated event files and determining the likely response based on these.

Method

A full description of the methodology for the experiment used in this reanalysis can be found in the original article (Schmidt et al., 2007, Experiment 2). The study was very similar to Experiment 1 here. Participants were 16 University of Saskatchewan undergraduates. The task was four-choice rather than three. In each block, each of four words was presented 6 out of 12 times (50%) in a randomly assigned colour and twice in the remaining colours in each of eight blocks. There was a constraint on presentation order such that the display colour could not repeat from one trial to the next. Trials were recoded for both contingency and for repetition type at four lags (n – 2, n – 3, n – 4, and n – 5). Complete repetitions were trials in which both the word and colour repeated. Word repetitions were trials in which only the word repeated. Colour repetitions were trials in which only the colour repeated. Finally, alternations were trials in which neither the word nor the colour repeated.

Results

There were very few errors in the experiment used for this and the following reanalysis (in fact, the average participant made about seven errors total, less than the number of conditions used in the following analyses). We therefore decided to restrict our analyses to response latencies. Trials on which participants failed to respond (less than 1% of the data) and incorrect responses (less than 4% of the data) were deleted. These trimming procedures do not alter the basic pattern of data reported below. The data are presented in Table 4.

Trial n – 2

A 2 (contingency; high, low) x 4 (repetition type; complete repetition, word repetition, colour repetition, alternation) ANOVA for response latencies revealed a marginal main effect for

Table 4. Reanalysis 1 Response Latencies (in milliseconds) for Lag, Repetition Type, and Contingency

	Contingency	
	High	Low
Trial n - 2		
Complete Repetition	713	719
Word Repetition	705	738
Colour Repetition	741	740
Alternation	703	729
Trial n - 3		
Complete Repetition	708	759
Word Repetition	709	732
Colour Repetition	711	747
Alternation	711	730
Trial n - 4		
Complete Repetition	701	750
Word Repetition	722	725
Colour Repetition	709	740
Alternation	711	735
Trial n - 5		
Complete Repetition	690	709
Word Repetition	712	727
Colour Repetition	709	727
Alternation	715	741

contingency, $F(1,15) = 3.178$, $MSE = 2587$, $p = .095$. Critically, there was no main effect of repetition type, $F(3,45) = 1.871$, $MSE = 2383$, $p = .148$, nor an interaction, $F(3,45) = 1.453$, $MSE = 1453$, $p = .240$.

Trial n – 3

A 2 (contingency; high, low) x 4 (repetition type; complete repetition, word repetition, colour repetition, alternation) ANOVA for response latencies revealed a significant main effect for contingency, $F(1,15) = 8.624$, $MSE = 3813$, $p = .010$. Again, there was no main effect of repetition type, $F(3,45) = .465$, $MSE = 2905$, $p = .708$, nor an interaction, $F(3,45) = .375$, $MSE = 4504$, $p = .772$.

Trial n – 4

A 2 (contingency; high, low) x 4 (repetition type; complete repetition, word repetition, colour repetition, alternation) ANOVA for response latencies revealed a marginal main effect for contingency, $F(1,15) = 3.180$, $MSE = 7190$, $p = .095$. There was no main effect of repetition type, $F(3,45) = .006$, $MSE = 6370$, $p = .999$, nor an interaction, $F(3,45) = .510$, $MSE = 5669$, $p = .677$.

Trial n – 5

A 2 (contingency; high, low) x 4 (repetition type; complete repetition, word repetition, colour repetition, alternation) ANOVA for response latencies revealed a significant main effect for contingency, $F(1,15) = 5.128$, $MSE = 2324$, $p = .039$. There was no main effect of repetition type, $F(3,45) = 1.868$, $MSE = 2499$, $p = .149$, nor an interaction, $F(3,45) = .070$, $MSE = 2089$, $p = .976$.

Discussion

The results of Reanalysis 1 show no evidence for repetition effects at lags of two to five trials. For each of these four lags, no effect of repetition type emerged. These null findings are problematic for the repetition account, which purports to explain the contingency effect solely by the influence of these transient repetition effects. Of course, interpreting the null is always difficult. One might argue that I merely lacked statistical power to detect these lag effects. However, there is a way to demonstrate that, in fact, lag effects do not explain the contingency effect. For this I turn to Reanalysis 2.

Reanalysis 2

Reanalysis 1 indicated no evidence for n – 2 through n – 5 repetition effects. Rather than simply interpreting this null, I conduct a further analysis to demonstrate that these (absent) lag effects do not account for the contingency effect. Recall that the repetition account purports to *fully explain* the contingency effect in terms of these short-lived associations or activations. Thus, the argument is not *only* that there should be observable lag effects, but also that these lag effects should explain the variance attributed to the contingency effect. In other words, after accounting for the variance attributed to these lag effects, there should be no variance left over for the contingency manipulation to explain (i.e., because repetition effects *are* the contingency effect in this conceptualization). Thus, if the lag variables are entered into the first step of a regression analysis and then contingency is added to the model in a second step, then the new model with contingency included should *not* explain more variance. If more variance *is* explained by contingency, then this verifies that my initial analyses were not simply the result of poor statistical power. Instead, transient lag effects do not explain the contingency effect. The reader is again reminded that n – 1 repetition effects were controlled by design (i.e., colour repetitions were impossible), so only lags n – 2 and beyond need to be entered into the regression.

Method

The same data set used for Reanalysis 1 was used for Reanalysis 2. For this analysis, the full raw data set was dummy coded for participant, contingency, and the repetition type at each lag. That is, each individual trial for each participant was included as an observation in the regression and then participant number was included as a predictor in the regression along with contingency, repetition type, and lag (for an explanation of how to do regression with repeated observations per participants see Bland & Altman, 1995).

Results

Null and incorrect responses were trimmed (as in the previous analysis). These trimming procedures do not alter the basic pattern of data reported below.

Step 1 – participant, repetition type, and lag

In Step 1 of the regression, the dummy coded variables for participants and for repetition trial types at the various lags were entered as predictors and response latency was entered as the outcome variable. Unsurprisingly, this model explained a significant amount of variance, R^2 = .256, $F(27,5896) = 75.262$, $p < .001$. Note that this model explains the variance *between* participants (i.e., the multiple observations per participant were coded for participant number and instead of removing this variance, as in a traditional regression, between-participant variance was included as a predictor).

Step 2 – adding contingency

In Step 2 of the regression, all of the variables in Step 1 were included plus the new variable for contingency (high, low). The test for a change in the amount of variance explained was significant, R^2 *Change* = .001, *F Change*(1,5895) = 11.018, $p = .001$. Note that the reason for the small value of the R^2 Change is that the between participant differences account for an enormous chunk of the variation (accounted for in Step 1 of the regression). Within the full model, contingency accounts for 19 ms of variance.

Discussion

The results of Reanalysis 2 corroborate the findings of Reanalysis 1 by showing that (the non-existent) repetition effects at lags of two to five trials do not explain the contingency effect. After putting all of these repetition variables into the first step of a regression to account for what variation they could, contingency continued to explain variance in the second step of the regression. Note again that this experiment, by design, rules out n – 1 repetition effects due to the constraint on presentation order (i.e., colour repetitions were impossible). As a result of this analysis, it is safe to conclude that the colour-word contingency effect reflects more than simple priming by transient activations or SR associations as posited by the repetition account, at least as far out as five trials.

The implication of these two reanalyses for connectionist and event file accounts is less certain. One might have expected some repetition effects at recent lags for a high learning rate connectionist account, but the argument probably cannot be made that such lag repetition effects should have completely accounted for the contingency effect. No strong prediction was made for the event file account.

Experiment 2

Given how rapid learning and unlearning were in Experiment 1, it is clear that the "window" of trials that participants take into account when calculating their response prediction is remarkably small. This led me to the notion that participants may be using limited-capacity memory resources to retrieve a small number of recently encountered trials in preparing a response. This is consistent with the finding from the sequence learning literature that carrying a memory load impairs learning (Nissen & Bullemer, 1987), though it is not clear that learning between trials is necessarily always the same as learning within trials (see the General Discussion for a discussion of the similarities and differences between the colour-word contingency paradigm and several other paradigms).

Experiment 2 tests this memory resource hypothesis by examining the impact of memory load on the color-word contingency effect. Participants in one condition were given a set of five digits to remember at the beginning of each trial and were tested for recognition at the end of each trial. Forcing participants to remember five digits should create a high load on memory, which leaves little or no memory resources to retrieve trial information that can be used to learn contingencies. Other participants were also presented with five digits, but were not instructed to remember them and were not probed for recognition. Thus, there is no load on memory, which ought to enable participants to use their memory resources for learning contingencies. Thus, a contingency effect is expected in the no load condition, where a smaller (or possibly null) effect is expected in the load condition.

Method

Participants

Thirty-nine University of Waterloo undergraduates participated in Experiment 2 in exchange for course credit. None had participated in Experiment 1. Three participants were deleted from the load condition due to failing to achieve more than 70% accuracy on the memory task (see Results), leaving eighteen participants in each of the load and no load conditions.

Apparatus

The apparatus for Experiment 2 was identical to Experiment 1 with one exception. In addition to the "j," "k," and "l" keys that were pressed with the right hand to respond to colours, participants in the load condition used their left hand to press the "y" key for "yes" responses and the "n" key for "no" responses in regard to the load manipulation.

Materials and Design

The materials and design for Experiment 2 were identical to Experiment 1 with the following exceptions. There were only three stimulus words (LOCK, WIDE, REST). At the beginning of each trial, all participants were presented with a set of five random digits (0-9) horizontally presented with three spaces between each digit. Only participants in the load condition were presented with a second set of digits following a response to the target colour on each trial. For both groups of participants, there were two blocks of 60 trials each. In each block, a randomly selected digit in the memory set was changed to a new random digit on half of the trials and none of the digits changed on the other half of the trials. Orthogonal to this, each of the three words was presented eight out of ten times (80%) in an assigned colour and once in each of the remaining colours (e.g., LOCK 80% in blue).

Procedure

At the beginning of each trial participants saw a white fixation cross for 250 ms, followed by a digit memory set for 2000 ms. Participants in the load condition were instructed to remember these digits in order; participants in the no load condition were informed of the digits, but were not asked to remember them. Next, there was a blank screen for 250 ms, followed by the coloured word for 2000 ms or until a response was made. The message “Correct,” “Incorrect,” or “No response” was presented in white for 500 ms following correct, incorrect, and null responses, respectively. For participants in the no load condition, the next trial started. For participants in the load condition, a second set of digits was presented until participants decided whether one of the digits had changed by pressing the “y” key (for “yes”) or the “n” key (for “no”). This was followed by a second feedback screen, which was identical to the first (except that null responses were impossible).

Results

The data of three participants in the load condition were deleted, two because of failure to achieve at least 70% accuracy on the memory task (indicating that they probably were not doing the secondary task) and one because their performance on the memory task was almost perfectly wrong (likely because they were responding on the basis of whether the digits had stayed the same, rather than whether they had changed). Null responses were deleted (less than 3% of the data), as were trials in which participants failed at the memory test in the load group (about 14% of the data). Because I was interested in trial n contingency effects and not sequential effects all trials where the word or colour was the same as that on the preceding trial were deleted. For response latencies, only correct responses were analyzed. In addition, for each participant in each cell, response latencies that were more than 2.5 standard deviations above or below the mean were excluded from analysis (approximately 2% of the data). With one exception (noted in a footnote below), these exclusion criteria do not alter the general pattern of the data.

Table 5. Experiment 2 Response Latencies (in milliseconds) for Contingency and Load			
	Contingency		
	High	Low	Effect
No Load	649	738	89
Load	850	849	-1

Response latencies

The response latencies for Experiment 2 are presented in Table 5. A 2 (contingency; high, low) x 2 (memory load; load, no load) ANOVA for response latencies revealed a significant main effect of contingency, $F(1,34) = 8.029$, $MSE = 4395$, $p = .008$, a main effect of memory load, $F(1,34) = 12.482$, $MSE = 34944$, $p = .001$, and an interaction, $F(1,34) = 8.354$, $MSE = 4395$, $p = .007$, in which there was a larger contingency effect for the no load group relative to the load group. Planned comparisons revealed that participants in the no load group responded faster to high contingency trials (649 ms) than to low contingency trials (738 ms), $t(17) = 4.785$, $SE_{diff} = 19$, $p < .001$. In contrast, participants in the load group did not respond faster to high contingency trials (850 ms) than to low contingency trials (849 ms), $t(17) = 0.035$, $SE_{diff} = 25$, $p = .972$.[2]

Error percentages

Percentage errors for Experiment 2 are presented in Table 6. A 2 (contingency) x 2 (memory load) ANOVA for error percentages revealed a marginal main effect of contingency, $F(1,34) = 3.472$, $MSE = 66$, $p = .071$, and a significant main effect of memory load, $F(1,34) = 6.283$, $MSE = 119$, $p = .017$. The interaction was not significant, $F(1,34) = 0.448$, $MSE = 66$, $p =$

Table 6. Experiment 2 Percentage Errors for Contingency and Load			
	Contingency		
	High	Low	Effect
No Load	4.2	6.4	2.2
Load	9.3	14.2	4.9

.508. Planned comparisons revealed no significant differences in errors between high and low contingency trials for participants in the no load group (4.2 and 6.4%, respectively), $t(17) = 2.278$, $SE_{diff} = 2.2$, $p = .312$, and in the load group (9.3 and 14.2%), $t(17) = 1.546$, $SE_{diff} = 3.1$, $p = .141$.

Discussion

The results of Experiment 2 demonstrate quite dramatically that the color-word contingency effect makes strong demands on memory. Participants put under a memory load did *not* show a contingency effect (or at least the effect was significantly attenuated), whereas those participants *not* put under a memory load *did* show a contingency effect. This is consistent with the idea that limited-capacity memory resources are required for colour-word contingency learning. Specifically, the argument is that when memory resources are taxed with a secondary task, there are no (or less) resources left over to store and/or retrieve event files that can be used to learn contingencies. The system requires memory resources to be free in order for event files to be stored and contingency information to be learned.

Experiment 3

A potential problem with the methodology of Experiment 2 is that the trial sequence was somewhat different for participants in the load and no load conditions. For participants in the load condition, not only did they need to remember the digits presented at the beginning of the trial, but after responding to the print colour they were also presented with a second set of digits and were required to make a decision whether a digit had changed or not. It therefore may be the case that the disappearance of the contingency effect in the load condition of Experiment 2 was actually a result of the presentation of this second set of digits and/or the decision participants had to make in response to them. To address this concern, Experiment 3 uses a high load and low load condition to better equate the tasks.

Method

Participants

Sixty University of Waterloo undergraduates participated in Experiment 3 in exchange for course credit. None had participated in any of the previous experiments. Two participants were deleted from the high load condition and two from the low load condition for having less than 70% accuracy on the memory task, leaving twenty-eight participants in each of the high and low load conditions.

Apparatus

The apparatus for Experiment 3 was identical to Experiment 2 in all respects.

Materials and Design

The materials and design for Experiment 3 were identical to Experiment 2 with one exception. Instead of a load and no load group, participants were divided into a high and low load group. The high load group was identical in all respects to the load group of Experiment 2.

The low load group was identical in all respects to the high load group except that they were only given two, rather than five, digits to remember. Thus, with only two digits to remember, memory is not heavily loaded, leaving some memory resources for storing trial information to learn contingencies. As a result, a contingency effect is expected in the low load condition, but a small or null contingency effect is expected in the high load condition.

Procedure

The procedure for both groups was identical in all respects to the procedure for the participants in the load group in Experiment 2.

Results

The data of two participants in the high load condition and two in the low load condition were deleted because of less than 70% accuracy on the memory task. Null responses were deleted (less than 3% of the data), as were trials in which participants failed on the memory test (about 11% and 8% of the data in the high and low load conditions, respectively). Because we were interested in trial n contingency effects and not sequential effects all trials where the word or colour was the same as that on the preceding trial were deleted. For response latencies, only correct responses were analyzed. In addition, for each participant in each cell, response latencies that were more than 2.5 standard deviations above or below the mean were excluded from analysis (approximately 2% of the data). These trimming procedures do not alter the basic pattern of data reported below.

Response latencies

The response latencies for Experiment 3 are presented in Table 7. A 2 (contingency; high, low) x 2 (memory load; high, low) ANOVA for response latencies yielded a significant main effect of contingency, $F(1,54) = 16.921$, $MSE = 7611$, $p < .001$, and an interaction, $F(1,54) =$

Table 7. Experiment 3 Response Latencies (in milliseconds) for Contingency and Load

	Contingency		
	High	Low	Effect
Low Load	779	886	107
High Load	846	874	28

5.667, *MSE* = 7611, *p* = .021, in which there was a larger contingency effect for the low relative to the high load group. The main effect of memory load was not significant, *F*(1,54) = .453, *MSE* = 47878, *p* = .504. Planned comparisons revealed that participants in the low load group responded faster to high contingency trials (779 ms) than to low contingency trials (886 ms), *t*(27) = 4.055, SE_{diff} = 26, *p* < .001. In contrast, participants in the high load group did not respond significantly faster to high contingency trials (846 ms) than to low contingency trials (874 ms), *t*(27) = 1.446, SE_{diff} = 20, *p* = .160.

Error percentages

Percentage errors for Experiment 3 are presented in Table 8. A 2 (contingency) x 2 (memory load) ANOVA for error percentages was conducted. The main effect of contingency, *F*(1,54) = .219, *MSE* = 44, *p* = .642, the main effect of memory load, *F*(1,54) = 1.263, *MSE* = 72, *p* = .266, and the interaction, *F*(1,54) = .565, *MSE* = 44, *p* = .455, were not significant. Planned comparisons revealed no significant differences in errors between high and low contingency trials for participants in the low load group (4.5 and 4.1%, respectively), *t*(27) = 0.216, SE_{diff} = 1.7, *p* = .830, or in the high load group (5.4 and 6.9%), *t*(27) = .808, SE_{diff} = 1.9, *p* = .426.

Table 8. Experiment 3 Percentage Errors for Contingency and Load

	Contingency		
	High	Low	Effect
Low Load	4.5	4.1	-0.4
High Load	5.4	6.9	1.5

Discussion

The results of Experiment 3 again demonstrate that the color-word contingency effect is dependent on limited-capacity memory resources. Participants put under a high memory load did *not* show a contingency effect (or at least the effect was significantly attenuated), whereas those participants put under a low memory load *did* show a contingency effect. These findings are consistent with the results of Experiment 2 using a (high) load versus no load manipulation.

Experiment 4

The results of Experiment 3 leave several unanswered questions about the *specific* role of memory resources in contingency learning. One possibility is that memory resources are required for the binding of features and responses into event files. I term this the *encoding hypothesis.* That is to say, participants need memory resources in order to initially *make and store* event files. Thus, if memory resources are taxed by a difficult enough secondary task, then event files will not be created and there will, resultantly, be no event files (or perhaps incomplete event files) to retrieve to use to predict responses. If this view is correct, then it is *not* simply the case that participants are not showing a contingency effect while under load; rather, participants have not learned anything about the contingencies in the task.

A second possibility is that participants *are* able to create and store event files while under a memory load, but they are *unable* to retrieve these event files while under load. I term this the *retrieval hypothesis.* In this sense, participants put under memory load are learning contingency information, but are simply unable to use this learning in the presence of the secondary task.

A third possibility is that participants require memory resources *both* for the creation of event files *and* for the subsequent retrieval of event files. I term this the *resource hypothesis.* According to this hypothesis, memory resources are needed more broadly to carry out the various memory functions required for contingency learning. Thus, memory load, according to this hypothesis, impairs both storage and subsequent retrieval processes.

To test these various accounts, two groups of participants were tested in Experiment 4. Both groups underwent an initial Learning Block (36 trials) in which contingencies were introduced, followed by a Transfer Block (36 trials) in which contingencies were removed. The critical test block in Experiment 4, as discussed below, is the Transfer Block. Note that although unlearning is rapid when contingencies are removed, transfer was observed in the initial unlearning block in Experiment 1. For Group 1, memory load was high for learning and low for transfer. For Group 2, memory load was low for learning and high for transfer. As described below, a control experiment was also run that was identical except that memory load was low for both learning *and* transfer.

If the encoding hypothesis is correct (i.e., memory resources are required for the creation of event files), then no contingency learning occurs under a high memory load. Thus, if the memory load is removed, no transfer of learning should occur. Thus, participants in Group 1 will not learn contingencies while under load in the Learning Block and should therefore not show any transfer in the Transfer Block. Alternatively, if the *retrieval* hypothesis is correct and participants *are* storing event files while under load in the Learning Block (but are simply not able to retrieve and use them while under load), then there should be a transfer of learning in the Transfer Block when the load is removed (i.e., a significant contingency effect). This latter result would constitute support for the retrieval hypothesis, by showing that learning can be achieved under load, but can only be applied once the load is removed (as evidenced by transfer). If memory resources are required for encoding *and* retrieval (the resource hypothesis), then no transfer should be observed.

If the retrieval hypothesis is correct, then event file contingency knowledge can only be used to predict responses when sufficient resources are available. Thus, if participants successfully learn contingencies under a low load, then none of this learning should transfer when a high load is introduced. Thus, participants in Group 2 who initially learned under low load should not be able to transfer learning into the high load Transfer Block because resources are not available for retrieval. Alternatively, if the *encoding* hypothesis is correct and memory resources are only needed for initial encoding of event files, then transfer should be observed. In other words, according to the encoding hypothesis it does *not* matter if memory is *currently* loaded, so long as contingency information has been learned. Lastly, if memory resources are required for both binding *and* retrieval (the resource hypothesis), then no transfer should be observed (due to retrieval being impaired).

To summarize, the encoding hypothesis predicts that contingency effects will be observed when participants are not highly loaded while learning, thus predicting transfer in Group 2 but not in Group 1. The resource hypothesis predicts that contingency effects will be observed when participants are *currently* not highly loaded (i.e., when they are able to retrieve event files), thus predicting transfer in Group 1 but not in Group 2. Finally, the resource hypothesis predicts that both encoding *and* retrieval cannot be accomplished under load, thus predicting no transfer in either of the two groups. Given the latter possibility, a control experiment was also conducted to ensure that transfer can occur within the specific parameters used in this experiment. The control experiment was identical to the main experiment save for the fact that memory load was low in both the learning and transfer blocks.

As a final note, one could also argue that the load manipulation, rather than affecting limited-capacity resources, may be increasing noise in the stimulus representation. In other words, the claim is that the encoding of the main stimuli is “messier” when processing the additional load stimuli, thus making learning more difficult. I term this the *messy encoding hypothesis.* If this hypothesis true, then an effect on encoding should be expected. I can see no reason why such an account would also predict an effect of the secondary task on retrieval. As long as the contingencies were learned under low load (Group 2), presentation of the word should be sufficient to retrieve the high contingency response, regardless of whether the system is currently loaded. Thus, the encoding hypothesis and messy encoding hypothesis make the same predictions.

Method

Participants

Eighty University of Waterloo undergraduates participated in Experiment 4 in exchange for course credit, with forty in each of the two groups. Seven participants in Group 1 and seven participants in Group 2 were deleted due to less than 70% accuracy on the memory task, leaving 33 participants per group. Another 33 participants from the same participant pool were in the control experiment. One participant was deleted due to less than 70% accuracy on the memory task, leaving 32 participants. None of the participants had participated in any of the previous experiments.

Apparatus

The apparatus for Experiment 4 was identical to Experiment 2.

Materials and Design

The materials and design for Experiment 4 were identical to Experiment 3 with the following exceptions. For both groups of participants, there were two blocks of 36 trials each. In the initial Learning Block, each of the three words was presented 8 out of 12 times (67%) in an assigned colour and once in each of the remaining colours. In the subsequent Transfer Block, each of the three words was presented 4 out of 12 times in each colour (33%, chance). Orthogonal to this, a randomly selected digit in the memory set was changed to a new random digit on half of the trials and none of the digits changed on the other half of the trials. For one group of participants (Group 1), load was high (five items) in the Learning Block and low (two items) in the Transfer Block. For the other half of the participants (Group 2), load was low in the Learning Block and high in the Transfer Block. Participants were counterbalanced across groups. In the control experiment, load was low for both blocks. The critical question of interest is which groups of participants show transfer.

Procedure

The procedure for Experiment 4 was identical in all respects to Experiment 3.

Results

Trials on which participants failed to respond (less than 1% of the data) and trials on which participants made an error on the memory task (approximately 14% of the data) were removed. Correct response latencies were trimmed by removing trials for each participant in each cell that were over 2.5 standard deviations from the mean (less than 2% of the data). Seven participants in Group 1 and seven participants in Group 2 were deleted due to less than 70% accuracy on the memory task in the main experiment; one participant in the control experiment was removed from analyses based on the same criterion. These trimming procedures do not affect the basic pattern of results described below.

Control: Low Load Learning – Low Load Transfer

Participants in the control experiment were given 67% contingencies to learn under low load in the Learning Block and then were presented with chance 33% contingencies under low load in the Transfer Block in order to ensure transfer was possible in the task.

Response latencies. Response latency data for the control experiment are presented in Table 9. A *t*-test on the Learning Block revealed that high contingency trials (891 ms) were responded to significantly faster than low contingency trials (930 ms), $t(31) = 2.759$, $SE_{diff} = 14$, $p = .010$. Critically, a *t*-test on the Transfer Block revealed a significant transfer effect; high

Table 9. Experiment 4 Response Latencies (in milliseconds) for Group, Block, and Contingency			
	Contingency		
	High	Low	Effect
Control			
Learning Block (Low)	891	930	39*
Transfer Block (Low)	788	815	27*
Group 1			
Learning Block (High)	1015	1032	17
Transfer Block (Low)	860	839	-21
Group 2			
Learning Block (Low)	924	983	59*
Transfer Block (High)	900	897	-3

* $p < .05$

contingency trials (788 ms) were responded to significantly faster than low contingency trials (815 ms), $t(31) = 2.393$, $SE_{diff} = 11$, $p = .023$. Thus, transfer can be observed in this version of the paradigm.

Percentage error. Percentage error data for the control experiment are presented in Table 10. A *t*-test on the Learning Block control data revealed that high contingency trials (3.8%) did not generate significantly different errors than low contingency trials (3.1%), $t(31) = .532$, $SE_{diff} = 1.1$, $p = .599$. Additionally, a *t*-test on the Transfer Block revealed no significant difference between high contingency trials (3.1%) and low contingency trials (4.3%), $t(31) = .847$, $SE_{diff} = 1.4$, $p = .403$.

Group 1: High Load Learning – Low Load Transfer

The first group of participants were given 67% contingencies to learn under high load in the Learning Block and then were presented with chance 33% contingencies under low load in the Transfer Block in order to test the retrieval hypothesis. If participants need memory resources for retrieval, but not for encoding, then participants will encode contingency information in the Learning Block that they will retrieve in the Transfer Block where a transfer effect is expected.

Table 10. Experiment 4 Percentage Errors for Group, Block, and Contingency			
	Contingency		
	High	Low	Effect
Control			
Learning Block (Low)	3.8	3.1	-0.7
Transfer Block (Low)	3.1	4.3	1.2
Group 1			
Learning Block (High)	3.6	5.4	1.8
Transfer Block (Low)	2.2	2.8	0.6
Group 2			
Learning Block (Low)	2.6	7.4	4.8*
Transfer Block (High)	3.5	3.0	-0.5

* $p < .05$

Response latencies. Response latencies for Group 1 are presented in Table 9. A *t*-test on the Learning Block revealed that high contingency trials (1015 ms) were not responded to significantly faster than low contingency trials (1032 ms), $t(32) = .801$, $SE_{diff} = 23$, $p = .429$. Critically, a *t*-test on the Transfer Block revealed no significant transfer effect; high contingency trials (860 ms) were not responded to faster than low contingency trials (839 ms), $t(32) = 1.131$, $SE_{diff} = 19$, $p = .267$. Note that the numbers were numerically in the wrong direction. Thus, there was no evidence for the hypothesis that participants can learn under load.

Percentage error. The percentage error data for Group 1 and are presented in Table 10. A *t*-test on the Learning Block revealed that high contingency trials (3.6%) did not generate significantly different errors than low contingency trials (5.4%), $t(32) = 1.034$, $SE_{diff} = 1.7$, $p = .309$. Additionally, a *t*-test on the Transfer Block revealed no significant transfer effect; high contingency trials (2.2%) did not generate significantly different errors than low contingency trials (2.8%), $t(32) = .717$, $SE_{diff} = 0.9$, $p = .479$.

Group 2: Low Load Learning – High Load Transfer

The second group of participants were given 67% contingencies to learn under low load in the Learning Block and then were presented with chance 33% contingencies under high load in the Transfer Block in order to test the binding hypothesis. If participants need memory resources for encoding, but not for retrieval, then participants will show a transfer effect even though they are under high load (because the contingencies were encoded during initial low load learning).

Response latencies. Response latencies for Group 2 are presented in Table 9. A *t*-test on the Learning Block revealed that high contingency trials (924 ms) were responded to significantly faster than low contingency trials (983 ms), $t(32) = 3.013$, $SE_{diff} = 20$, $p = .005$. Critically, a *t*-test on the Transfer Block revealed no significant transfer effect; high contingency trials (900 ms) were not responded to faster than low contingency trials (897 ms), $t(32) = .159$, $SE_{diff} = 18$, $p = .875$. Note that the numerical difference was again in the wrong direction. Thus, there was no evidence for the hypothesis that participants can retrieve and apply learning while under load.

Percentage error. The percentage error data are presented in Table 10. A *t*-test on the Learning Block revealed that high contingency trials (2.6%) generated significantly less errors than low contingency trials (7.4%), $t(32) = 2.916$, $SE_{diff} = 1.6$, $p = .006$. Additionally, a *t*-test on the Transfer Block revealed no significant transfer effect; high contingency trials (3.5%) did not generate significantly different errors than low contingency trials (3.0%), $t(32) = .390$, $SE_{diff} = 1.2$, $p = .699$.

Discussion

The results of Experiment 4 provide support for the resource hypothesis. Participants in Group 2 were not able to encode event files under high load, as indicated by the lack of transfer in the Transfer Block when the load was reduced. Further, participants in Group 1 were not able to retrieve stored event files in the Transfer Block when put under high load. Data from the control experiment confirm that transfer is observable in this task setup. Thus, the combined results suggest that memory resources are required for both encoding and retrieval, in support of the resource hypothesis. These data are also inconsistent with the messy encoding account that proposed to explain the lack of a contingency effect under load as being due to noise in stimulus representation during encoding.

General Discussion

The results of past work and the experiments and reanalyses presented here help to narrow the range of potential explanations for color-word contingency learning. The available data suggest that contingencies are acquired implicitly (Schmidt et al., 2007), that the critical contingency is between the word and the response (Schmidt et al., 2007), that learning and unlearning of contingencies is extremely rapid (Experiment 1), that the effect does not result from repetition effects (Reanalyses 1 and 2), and that contingency learning requires limited-capacity memory resources (Experiments 2-4) for both storage and retrieval (Experiment 4). Given these criteria, we can begin to piece together a model of learning in this paradigm.

My favoured account of colour-word contingency learning assumes that participants use event files to represent contingency information. According to this event file hypothesis, on each trial a representation of the stimuli and response that was made are bound into an event file memory. These event files are then stored in an episodic store. On each trial, after the word is processed a number of matching event files are retrieved and a response expectancy is determined. For instance, as the participant processes the word MOVE, they will retrieve a number of event files that are associated with this (the most recently encountered ones being the most accessible) and use these to determine that blue is the most probable response. In a sense, this is a blending of Hommel's event file idea and Logan's (1988) instance theory.

The results of the experiments and reanalyses presented here are completely consistent with the event file account. The rapid learning of contingencies in Experiment 1 is consistent, because it will only take a handful of trials for participants to have been exposed to a number of high contingency pairings, while only seeing one or two low contingency pairings. Thus, right from the start, participants should be able to begin (implicitly) predicting responses. In addition, because memory has a limited capacity and only so many event files can be retrieved, it will only take a small amount of unlearning before participants are no longer retrieving event files from the preceding learning phase (i.e., because the more-recently encountered unlearning trials are more accessible). As such, the rapid unlearning observed in Experiment 1 is also consistent with the event file hypothesis. Finally, the results of Experiments 2 though 4 are consistent with the event file hypothesis, because participants should require memory resources to carry out the memory functions required to store and subsequently retrieve event files, and memory load impairs these functions.

The rapid learning and unlearning of Experiment 1 are also consistent with the connectionist account, so long as the learning rate is assumed to be high. It is less clear that the connectionist account should predict the effects of memory load from Experiments 2 to 4, but presumably models such as the SRN can be easily modified to allow a role for limited-capacity resources in storage and retrieval processes. Note that the primary difference between the proposed event file hypothesis and connectionist models such as the SRN is the way in which learned information is represented. In the SRN, information is distributed across a network of hidden units. In the event file hypothesis, trial information is stored in discrete event files. Further research will need to be conducted to distinguish between these two possibilities.

Finally, I was able to rule out a repetition account in Reanalyses 1 and 2 by demonstrating that there were no lag effects that were able to explain the variance attributed to the contingency manipulation.

Relation to Past Research

The colour-word contingency learning paradigm shares obvious similarities with numerous other cognitive paradigms. However, these paradigms also differ in a number of ways from the paradigm used in the present studies, including the type of stimuli and responses that are involved in the task, the speed of judgment, and several other factors. Although commonalities surely exist, it remains to be seen which common processes underlie which effects of contingencies on performance. Until this issue is examined further, care should be taken when generalizing the conclusions from these studies to contingency learning in other paradigms (and vice versa). In the following sections I discuss the relation of the current paradigm to three other broad categories of paradigms: conflict paradigms (e.g., Stroop, Eriksen flanker), judgement tasks (e.g., evaluative conditioning, hidden covariation detection), and sequential learning.

Conflict Paradigms. The one paradigm that most of my colleagues seem to equate with the colour-word contingency learning paradigm is the Stroop task. Nonetheless, of the three types of paradigms discussed here, conflict paradigms such the Stroop task are arguably the *least* similar to the present contingency paradigm. On the surface, the colour-word contingency task is very similar to a Stroop task: participants are presented with coloured words and are asked to ignore the identity of the word and respond to the print colour. However, aside from this surface similarity, it can be argued that the two tasks are in fact quite different.

A Stroop task has no inherent contingency built into the task. In a properly designed Stroop task, each word should be presented equally often in each colour (unfortunately, this is rarely the case; see Schmidt & Besner, 2008 for a discussion of why this is a problem). Instead, conflict paradigms such as the Stroop task are based on over-trained relations that are partially semantic in nature (e.g., De Houwer, 2003; Risko, Schmidt, & Besner, 2006; Schmidt & Cheesman, 2005). Although some may argue that colour words have an inherent contingency built into them (i.e., because the word BLUE is semantically related to the colour blue and the blue response), it is doubtful that a semantic relationship is the same thing as a contingency, especially since Schmidt et al. (2007, Experiment 4) demonstrated that the contingency effect is purely response based, not semantic.

But perhaps the most convincing evidence that the effects observed in conflict paradigms are not the result of the same processes as the effects observed in our colour-word contingency task is the dissociation in the direction of the effects. Conflict paradigms, as the name suggests, generate interference-based effects. In the Stroop task, for instance, the difference in response latencies between congruent (e.g., $\text{BLUE}_{\text{blue}}$) and incongruent trials (e.g., $\text{BLUE}_{\text{green}}$) results almost entirely from the *slowing* of incongruent trials (relative to a baseline condition; e.g., $\text{MAKE}_{\text{green}}$). It is argued that this slowing results from *competition* between the distracting word and the target. Evidence for *facilitation* for congruent words is weak (see MacLeod, 1991 for a review). In our colour-word contingency paradigm, on the other hand, the response latency effect is entirely derived from *facilitation* of high contingency trials, with no corresponding interference for low contingency trials (Schmidt & Besner, 2008). It has been argued that this *facilitative* effect results from the retrieval of event files in order to anticipate and prepare for the high contingency response (Schmidt & Besner, 2008). Thus, not only is there a clear dissociation in the direction of the effects (*interference* in conflict paradigms versus *facilitation* in contingency learning), but it is also clear that the conceptualization of the mechanisms driving these effects is quite different (*competition* in conflict paradigms versus *response preparation* in contingency learning).

In summary, while conflict paradigms (especially Stroop) share many surface similarities with the colour-word contingency paradigm, they are arguably quite different. Conflict paradigms are based on over-trained relations, are partially semantic in nature, and are driven almost entirely by interference. In contrast, colour-word contingency learning is based on newly-trained covariations, is non-semantic, and is driven entirely by facilitation. Thus, the informativeness of data from conflict paradigms for our contingency learning work is questionable.

Judgement Tasks. The colour-word contingency learning paradigm shares similarities with various judgement tasks. For instance, in the hidden covariation paradigm, participants learn the contingencies between facial characteristics and personality characteristics (Lewicki, 1985, 1986; Lewicki, Hill, & Czyzewska, 1997; but see Hendrickx, De Houwer, Baeyens, Eelen, & Van Avermaet, 1997a, 1997b). Similarly, in the evaluative conditioning paradigm participants' liking of objects is altered by being paired with valenced words (see De Houwer et al., 2001 for a review). However, there are also many important differences. For instance, in these judgement paradigms the contingencies are typically 100% (e.g., in hidden covariation detection, Facial Characteristic X is *always* presented Personality Characteristic Y). In colour-word contingency learning, contingencies are less than chance. First, it is interesting that participants are able to detect a regularity in a noisy (i.e., non-100% contingency) dataset. Second, it is not certain whether detecting regularities in a noisy versus noiseless dataset involves identical processes (e.g., the latter case may lend itself more to explicit recognition of contingencies and be more prone to strategic influences).

Also, the colour-word contingency task involves speeded responses as the dependent measure, whereas judgement tasks such as evaluative conditioning most often involve a relatively slower judgment response (e.g., a judgement of the valence of an object). Changes in the *rate* of processing do not necessarily imply that the system will reach a different *response.* That is, just because a contingency may help to make a judgement *faster,* it does not follow that the participant will necessarily be any more likely to make a given response (e.g., Stimulus B may cause a participant to select Response B regardless of whether they select the response quickly or slowly). Additionally, response latencies are sometimes used in these judgement tasks (e.g., Lewicki, 1986), but these judgment responses are overall much slower than rapid identification responses, so it remains unclear whether effects occurring in a few hundred milliseconds are simply a "scaled down" version of the effects occurring at a few thousand milliseconds. In particular, the relatively slower judgement responses may include more explicit (rather than implicit) processes.

Sequential Learning. Of all the paradigms discussed here, sequential learning may be the most similar to the colour-word contingency paradigm. In the typical sequential learning paradigm participants are presented with a series of target stimuli to respond to (no distracters) and the stimuli follow a predictive sequence (Nissen & Bullemer, 1987). Most sequence learning research has participants respond to a sequence that is either random or 100% predictive (i.e., the same series of stimuli keep repeating). Learning is determined as the difference in response times between these two conditions. More similar to the colour-word contingency paradigm, some research with sequence learning has been done using probabilistic sequences (i.e., where the next item in the sequence is predictable, but not perfectly; Jimenez & Mendez, 1999; Song et al., 2007).

In many ways, the colour-word contingency learning paradigm may seem redundant with the sequential learning paradigm, because both are speeded reaction time tasks that involve the learning of the relationship between stimuli and subsequent responses. However, the paradigms do differ in fundamental ways that may (or may not) prove significant. For instance, my paradigm involves participants retrieving trial memories on a trial-by-trial basis (i.e., participants cannot know what response to expect until they have begun to process the word). In sharp contrast to this, in the sequence learning paradigm participants learn a long repeating series of stimuli and responses. This may result in strategic differences in learning and may also affect the rate of learning. Additionally, instead of learning the association of stimuli to responses, in sequence learning participants may be learning the series of responses (which is impossible in the colour-word contingency learning paradigm, because there is no response sequence).

Another fundamental difference between the contingency learning paradigm and the sequence learning paradigm is the type of information being retrieved. For colour-word contingency learning, participants retrieve individual events to determine what response is likely given the word. In contrast, for sequence learning participants must retrieve a series of events to determine what event is likely to follow. Put differently, if presentation of Stimulus A leads to retrieval of Memory X (i.e., an event that contained Stimulus A), then participants will use Memory X to predict the response in my contingency learning paradigm, but would need to retrieve Memory X+1 to predict the next item in sequence learning. What differences in learning this will lead to is unclear. More importantly, given these numerous fundamental differences, it cannot simply be assumed that every result found in sequence learning will also be found in colour-word contingency learning, or vice versa.

Summary. As I have highlighted, the colour-word contingency paradigm shares many similarities with other paradigms used to study contingency learning, but also has some differences. Thus, it appears premature to assume that an effect observed in one paradigm necessarily generalizes to the colour-word contingency paradigm (or vice versa). That said, there are some important ways in which the current results parallel findings from other contingency learning paradigms. Experiment 1 demonstrated extremely rapid learning of contingency information. This finding is consistent with the rapid learning found in the hidden covariation detection paradigm, where response biasing has been demonstrated after exposure to as few as one or two consistent trials (Lewicki, 1985; Lewicki, 1986). In the sequence learning task, learning has been shown to take about seven blocks of a ten-trial sequence (Nissen & Bullemer, 1987).

It is fascinating, however, that learning occurs so fast even in the colour-word contingency paradigm where contingencies are not 100%. Rapid learning in a probabilistic task has also been reported by Jacoby, Lindsay, and Hessels (2003) using an item specific proportion congruent manipulation (which Schmidt & Besner, 2008 have argued is simply a colour-word contingency effect incidentally observed within the context of a conflict paradigm). Although they did not provide individual *t*-tests for each block, visual inspection of their data suggests that a contingency effect was present in their very first block of 16 trials. Although there are not many studies on the learning rate in contingency learning paradigms (and I am not aware of any work on unlearning), it does appear that, in general, the human cognitive system is capable of very rapid learning (and unlearning) of covariations.

The results of Experiments 2 through 4 produced evidence that contingency learning in the colour-word paradigm is impaired when memory is loaded with a secondary task. Indeed, a similar result has been found in the sequence learning task, where minimal learning was found for participants under load (Nissen & Bullemer, 1987). Although more work is certainly needed, it is interesting that apparently very simple learning processes that are generally reported to occur without awareness (e.g., Lewicki, 1986; Nissen & Bullemer, 1987; Schmidt et al., 2007) seem to be dependent on the availability of memory resources (see Hassin, 2005 for a discussion of implicit working memory).

Conclusions

The colour-word contingency paradigm is a useful tool to study contingency learning. It is very simple, easy to program, and produces highly reliable results. In the four experiments presented here it was discovered that learning and unlearning of contingencies in this paradigm is very rapid and is dependent on memory resources. Two reanalyses of old data ruled out a repetition account of these data. I have suggested that a viable explanation for these (and other findings) is that participants encode and subsequently retrieve a finite set of event files and use these event files to extract contingency information to be used to predict responses. Connectionist accounts such as the SRN could likely be modified to account for the current results, as well. The current results thus serve to constrain the types of viable accounts of contingency learning to those that are fast and those that require a role for limited-capacity memory resources.

Footnotes

[1] This was a programming error. Four words (rather than three) were randomly assigned to an array of size four for each participant. The program only needed three words and only referenced the first three positions of this array. Thus, whichever word was assigned to the forth position of the array for a given participant was simply never referenced and never presented to the participant. Note that this in no way confounds my results.

[2] Unlike Experiments 2 and 3 to follow, immediate repetition trials were not trimmed in this experiment (i.e., trials in which the preceding trial had the same word and/or colour). The reason that this is a particularly important trimming procedure is because complete repetition trials (i.e., trials in which both the word and the colour are repeated) are responded to very quickly and these trials are disproportionately represented in the high contingency condition. In fact, due to the blocked structure of the task, the only way it is possible to have a complete repetition in the low contingency condition is for the last trial of one block to match the first trial of the next block. I opted not to perform this trimming procedure in Experiment 1 for two reasons. First, there were already so few observations per cell (in fact, only 10 of the 98 participants had an observation left in every cell after this trim). Second, sequential effects do not confound analyses in the unlearning blocks, given that complete repetitions are no longer disproportionately represented in the high contingency cells. Moreover, analyses with repetition trials removed yield similar (howbeit substantially noisier) results. The same is true of Experiment 4.

[3] If the confounded repetition trials are not removed, this effect is significant, but still significantly smaller than the effect for the load participants.

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Appendix – Participant Means

Experiment 1 Response Latency Participant Means (in milliseconds)

	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Block 7		Block 8		Block 9		Block 10		Block 11		Block 12	
	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low
1	470	584	404	459	458	468	430	503	471	471	452	459	473	493	525	461	481	455	539	485	489	523	482	451
2	612	932	633	786	564	550	818	654	573	491	587	624	644	735	699	741	537	599	596	651	641	769	846	779
3	723	810	570	648	683	782	764	756	811	923	618	745	614	587	800	787	649	682	641	665	611	523	782	678
4	713	900	573	733	575	532	679	677	1122	864	1138	1119	665	619	1055	865	769	637	739	784	747	871	657	669
5	511	575	677	517	545	575	577	667	706	706	514	633	504	501	570	639	497	563	566	492	560	743	570	650
6	612	588	512	559	539	473	693	559	438	522	596	602	502	436	518	497	512	489	544	530	507	439	460	483
7	622	588	581	609	610	594	505	414	454	573	486	472	435	470	488	514	554	585	562	503	527	535	713	499
8	434	396	407	407	406	413	426	428	474	445	477	451	452	495	511	390	420	430	521	469	383	403	462	421
9	672	748	850	539	583	561	764	660	572	495	593	595	580	536	523	628	744	658	807	674	543	558	947	740
10	715	669	611	723	806	703	617	678	451	634	743	713	502	453	559	651	685	638	578	575	1016	648	806	685
11	399	558	439	502	489	464	438	497	399	500	688	415	378	471	417	430	404	565	430	494	539	447	501	589
12	528	579	439	415	403	447	458	477	471	457	545	436	503	440	500	513	556	528	538	541	495	570	518	528
13	600	1101	513	560	559	631	578	533	504	596	631	694	662	631	611	684	665	710	775	717	792	663	670	628
14	512	484	510	503	440	479	451	455	502	491	508	520	472	493	435	515	568	477	532	487	517	495	467	497
15	511	571	495	519	510	562	471	460	501	491	467	485	590	527	712	644	699	565	535	562	468	544	519	479
16	509	601	484	451	480	491	583	520	597	535	653	562	442	446	553	524	586	548	570	597	718	599	613	559
17	393	440	356	353	416	383	397	444	500	430	380	481	392	417	524	473	511	467	442	467	467	382	470	394
18	596	567	692	639	561	530	576	571	499	565	562	509	561	558	585	604	561	560	552	520	549	525	505	611
19	451	451	536	453	493	562	543	620	564	520	653	648	461	542	692	534	597	645	622	588	639	654	699	531
20	503	691	459	457	543	472	485	547	587	477	472	468	482	498	550	532	550	574	658	651	674	609	518	539
21	664	571	633	674	628	748	662	990	655	861	655	656	452	593	622	587	552	452	580	505	692	863	840	868
22	476	632	489	426	533	648	514	505	619	558	553	610	497	600	555	561	512	568	511	579	507	505	547	541
23	539	539	564	577	413	425	619	530	568	470	552	492	563	538	559	560	522	599	632	425	446	448	498	528
24	658	713	580	562	618	591	629	593	585	749	586	644	603	627	527	545	635	579	590	640	598	423	630	518
25	649	524	519	636	468	536	509	500	468	666	646	563	536	523	708	565	476	729	545	741	549	670	553	485
26	749	789	791	746	679	555	660	662	731	599	558	594	523	605	542	698	558	821	689	663	777	696	528	558

27	684	511	524	617	464	495	516	551	415	458	458	540	503	498	632	476	607	386	734	511	785	678	432	481
28	540	667	587	574	552	603	721	615	573	778	605	792	622	794	769	762	640	719	595	652	801	784	820	660
29	587	662	574	784	456	560	513	477	471	638	595	516	497	454	633	658	670	542	466	426	633	592	611	718
30	663	550	783	1291	730	887	761	901	571	880	608	847	654	683	510	631	721	681	581	663	646	713	698	580
31	462	456	542	580	537	561	485	549	611	583	542	569	571	620	679	676	603	631	804	645	661	676	658	681
32	1085	1032	774	1091	891	1035	723	779	991	837	911	877	690	777	644	585	551	638	578	709	534	807	621	695
33	759	626	515	599	565	535	550	767	595	494	460	500	484	522	589	565	569	577	477	488	924	574	629	662
34	642	763	456	528	467	537	482	470	490	525	468	463	536	562	556	463	435	524	490	505	575	579	594	493
35	705	710	631	686	563	555	518	528	532	564	512	461	468	600	616	533	462	515	426	491	701	628	520	485
36	441	568	461	440	445	417	408	450	538	415	488	467	446	519	485	453	454	478	502	444	441	440	476	441
37	437	421	401	443	425	461	435	559	474	449	403	415	438	491	493	433	550	538	498	538	403	426	492	457
38	467	515	548	427	476	514	531	521	440	479	514	511	556	493	489	517	485	504	496	511	652	565	486	523
39	515	487	566	614	501	536	425	530	469	558	436	453	531	536	532	547	529	480	451	518	499	496	453	461
40	973	730	874	863	734	1171	461	871	596	571	549	825	667	706	757	755	739	716	654	664	772	593	746	759
41	538	652	582	712	567	616	836	740	672	669	843	798	841	916	816	1077	847	851	668	766	660	679	1095	902
42	587	540	491	696	459	458	505	481	568	525	507	507	433	482	447	524	474	434	641	521	543	497	500	543
43	560	742	502	540	531	511	686	623	666	558	776	561	607	632	548	746	484	632	481	648	450	755	518	512
44	670	569	570	612	552	658	635	583	701	581	617	515	604	854	607	593	541	679	633	622	646	646	619	569
45	697	605	494	855	718	494	775	685	930	681	545	588	874	662	754	676	872	877	854	859	712	513	666	706
46	672	621	615	661	559	686	593	770	884	639	595	537	533	635	590	491	637	517	508	478	575	544	715	736
47	650	605	554	553	526	498	569	738	586	652	586	701	482	621	578	686	606	624	539	632	641	629	670	489
48	841	862	607	660	531	536	590	630	686	704	615	638	739	605	567	516	521	532	618	567	449	513	551	577
49	788	771	785	500	469	724	751	719	505	425	575	524	716	623	581	733	870	814	536	508	485	476	649	759
50	651	670	542	598	556	735	583	606	591	500	636	728	591	654	523	720	605	570	640	596	543	489	892	708
51	550	581	525	486	564	465	399	455	614	562	444	553	601	622	643	824	559	681	521	458	602	762	836	730
52	644	519	637	652	984	1146	537	714	583	695	556	625	608	570	725	533	612	533	858	631	625	717	652	663
53	651	636	740	790	663	743	819	707	775	666	575	619	575	637	706	627	929	680	716	781	857	877	584	655
54	542	619	666	709	608	561	582	563	463	531	524	555	726	524	679	502	545	484	601	469	599	707	540	533
55	450	829	518	583	494	523	459	463	482	548	557	470	508	489	511	537	426	466	450	504	515	474	670	508
56	467	396	500	546	513	497	577	645	546	480	528	570	612	571	622	568	719	551	513	567	688	567	571	553
57	482	546	445	405	396	507	447	432	526	514	430	421	537	456	495	479	446	469	438	399	503	454	478	492

58	855	628	971	1081	669	873	610	827	630	707	783	540	731	686	533	735	814	694	760	722	820	720	503	672
59	460	464	436	437	461	433	457	553	383	421	564	450	515	427	532	442	478	579	407	424	687	524	494	518
60	589	673	657	900	666	969	618	765	779	720	808	670	658	512	714	725	503	818	568	676	491	508	572	530
61	476	635	478	670	544	570	644	537	537	583	447	440	527	543	510	418	596	619	573	584	536	620	459	497
62	678	799	618	626	498	595	592	615	656	603	618	545	874	691	734	593	573	609	507	478	496	738	548	477
63	586	616	506	589	541	587	482	647	670	595	485	527	566	698	601	547	605	577	612	694	606	599	577	667
64	780	1043	867	629	621	706	523	515	678	555	597	571	845	623	483	505	512	662	618	671	703	697	623	735
65	690	647	489	736	491	475	549	580	442	508	571	552	509	527	734	538	763	478	551	566	551	580	607	490
66	601	643	691	511	641	686	812	741	675	514	936	596	751	634	745	691	751	737	675	757	909	699	629	567
67	648	749	703	751	570	709	642	689	738	678	709	701	682	718	727	724	598	550	493	479	552	668	630	671
68	941	841	944	895	823	883	986	854	747	997	823	960	655	606	647	788	1117	806	572	898	1239	779	691	683
69	595	632	500	584	521	593	465	512	482	576	608	522	525	501	540	529	553	482	444	527	526	461	507	547
70	429	503	452	429	374	483	399	436	456	520	461	483	457	481	462	488	507	464	490	483	556	539	451	461
71	501	456	494	439	507	482	451	523	441	397	446	468	479	470	455	521	420	464	531	482	519	530	490	497
72	531	590	471	443	527	459	500	492	594	561	515	620	533	531	537	555	495	566	472	500	467	535	426	484
73	756	1037	544	660	471	642	455	510	414	403	405	504	437	487	570	447	639	543	477	601	847	807	443	512
74	505	576	530	813	545	567	493	441	569	566	557	541	582	499	583	635	532	518	769	621	815	608	543	574
75	580	835	561	519	432	655	574	526	518	577	724	494	554	512	574	486	662	458	578	647	573	498	541	478
76	737	661	794	894	602	607	552	569	639	594	555	588	610	542	476	701	725	665	969	917	497	586	812	572
77	802	932	491	731	553	681	492	751	677	651	788	624	664	776	598	595	609	1040	898	547	722	762	631	582
78	493	565	483	454	492	454	516	537	571	601	641	532	455	574	717	580	705	662	524	588	530	514	553	593
79	525	655	448	511	421	481	440	436	459	486	449	484	565	474	432	485	490	565	464	484	630	483	538	442
80	632	615	680	530	543	571	635	575	579	602	590	533	669	501	467	542	559	598	735	539	575	545	723	586
81	718	655	494	554	455	480	485	476	476	508	515	458	510	514	488	465	506	401	505	552	511	523	471	495
82	570	847	506	490	590	796	739	544	727	574	782	863	671	915	980	844	514	438	499	575	515	568	538	724
83	486	516	523	548	517	609	473	541	501	445	629	567	482	535	543	536	508	482	443	500	570	455	472	427
84	435	483	492	475	487	431	546	674	541	442	452	530	453	523	778	620	388	530	538	704	525	525	530	469
85	492	562	494	520	470	465	402	389	467	462	508	490	532	514	489	444	468	476	638	527	513	490	546	488
86	416	602	469	495	441	446	453	486	478	566	448	539	514	542	474	439	456	500	448	404	542	410	472	525
87	729	774	640	516	522	613	490	501	468	431	459	452	466	451	701	616	614	738	674	853	479	639	743	661
88	637	727	755	685	616	470	810	1161	863	607	530	918	604	695	808	508	598	630	648	694	630	559	597	764

89	461	515	447	518	456	429	392	448	466	425	441	487	458	493	553	595	465	549	523	521	468	642	621	567
90	570	674	626	598	559	667	477	471	473	513	552	548	612	559	529	596	482	492	604	539	476	458	523	559
91	539	494	470	545	515	441	432	516	523	459	511	491	558	543	410	496	485	514	454	485	630	437	597	598
92	484	501	557	553	455	613	720	513	741	662	571	545	486	505	544	704	560	779	484	525	609	441	644	692
93	575	624	481	569	501	584	475	596	525	537	748	626	689	659	535	522	621	630	554	661	670	721	711	636
94	543	699	524	485	464	604	554	444	455	544	468	510	488	522	417	448	676	572	566	592	611	606	516	576
95	513	598	544	643	451	745	661	550	559	510	606	518	812	528	505	482	449	518	674	487	460	461	795	483
96	465	515	455	470	478	425	525	549	526	500	549	704	519	561	484	491	480	492	411	518	662	575	618	547
97	387	367	441	435	428	416	412	457	692	546	452	534	493	461	499	517	573	450	525	468	489	557	641	436
98	487	467	553	715	528	582	515	505	545	574	582	630	555	628	593	530	644	545	643	609	580	585	629	552

Experiment 1 Percentage Error Participant Means

	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Block 7		Block 8		Block 9		Block 10		Block 11		Block 12	
	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low
1	0	17	8	0	0	0	0	8	0	0	0	0	0	0	0	0	0	17	17	0	0	8	0	8
2	8	0	0	0	0	0	0	0	0	0	17	0	17	0	0	8	0	0	0	8	0	0	0	0
3	0	0	0	0	8	17	0	17	0	0	0	9	33	8	0	8	17	0	33	25	0	8	17	8
4	0	20	8	17	8	0	17	8	0	25	0	9	17	8	33	8	17	0	0	8	17	0	0	0
5	8	17	8	0	17	0	33	8	0	17	0	0	0	0	17	0	0	8	0	0	0	0	0	8
6	0	0	8	0	0	0	0	0	0	8	0	0	0	0	0	0	0	8	0	0	0	0	17	8
7	8	50	0	0	9	0	0	0	17	0	17	0	0	8	0	8	0	8	17	0	0	8	0	17
8	0	0	0	0	0	0	17	8	17	0	0	0	0	8	0	0	0	17	0	17	0	0	0	8
9	8	20	25	0	0	0	0	33	0	8	0	17	0	8	33	8	17	17	17	8	0	0	33	0
10	17	0	17	0	17	33	17	0	0	0	0	0	0	0	0	8	0	8	0	0	0	25	33	0
11	0	0	0	17	25	0	0	0	17	0	0	0	0	0	0	17	17	0	0	0	0	8	17	0
12	0	17	33	17	8	17	0	17	0	8	33	17	0	33	17	0	17	0	0	17	17	25	17	0
13	0	0	8	0	8	0	0	8	0	0	0	0	0	0	17	0	0	8	17	8	17	17	0	0
14	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	8	0	0	0	8	0	0	0	8
15	0	0	0	0	0	33	0	0	0	8	0	8	0	0	0	0	0	8	0	0	0	0	0	0
16	0	20	0	0	17	0	0	0	0	0	0	0	0	0	33	8	0	0	17	8	0	0	0	8
17	17	0	17	0	17	17	17	0	0	33	17	0	17	17	0	0	0	0	17	0	0	8	17	8
18	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
19	8	17	0	0	0	17	0	8	0	8	0	17	17	17	17	0	0	17	0	17	50	8	0	8
20	20	0	0	0	8	17	0	0	0	8	0	8	0	8	0	0	0	0	0	17	0	8	33	8
21	8	0	0	17	0	0	0	17	0	8	0	8	0	0	33	8	0	8	0	0	0	0	17	8
22	0	17	8	0	0	17	0	0	0	17	0	17	0	0	0	0	17	8	0	0	0	8	17	8
23	0	17	8	0	8	33	33	0	0	0	17	8	17	0	0	0	0	0	0	8	0	17	17	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	8
25	0	0	0	0	0	0	0	0	17	0	0	8	0	0	0	0	0	0	0	0	0	8	0	0
26	36	33	0	17	8	0	0	0	0	0	0	17	33	8	0	0	0	8	0	8	17	8	0	0
27	8	17	8	17	0	0	0	17	0	0	17	17	0	17	17	8	17	0	17	8	17	17	17	8

28	0	0	8	0	0	0	0	8	0	9	0	8	0	9	0	0	0	8	0	0	0	0	0	8
29	0	17	8	0	8	0	17	17	0	17	0	0	0	8	17	0	0	0	0	8	17	9	0	25
30	0	0	0	25	0	0	0	0	0	0	0	8	0	0	0	17	17	0	0	0	0	0	0	8
31	8	0	0	0	8	0	17	0	0	0	0	8	0	0	0	0	0	8	0	0	0	0	0	0
32	10	33	8	0	0	17	0	8	17	0	0	0	0	0	0	9	33	0	0	0	0	8	0	0
33	0	0	8	0	0	0	0	8	0	0	0	0	0	8	0	0	0	0	0	0	17	0	0	17
34	0	17	0	0	8	0	17	0	0	8	0	0	0	0	33	0	0	0	0	9	0	17	0	0
35	8	17	8	0	0	0	0	0	0	8	0	17	0	8	0	8	0	8	0	0	0	8	0	0
36	0	17	0	0	8	0	0	0	0	0	17	8	0	8	0	0	0	0	17	8	0	0	0	0
37	17	17	8	0	8	17	17	0	17	0	50	0	0	8	0	8	0	8	0	8	17	0	0	0
38	0	17	0	33	0	0	0	0	0	17	0	8	17	8	0	8	33	0	0	0	0	0	0	8
39	0	17	0	33	0	17	0	0	0	8	0	25	0	17	0	0	17	8	0	8	0	0	0	0
40	12	25	8	0	17	0	0	17	0	0	0	0	0	0	0	0	17	0	0	8	0	0	17	17
41	0	0	8	0	0	17	0	25	0	0	17	0	0	17	17	0	0	0	0	17	0	8	25	33
42	0	0	0	17	0	0	0	8	0	0	0	0	0	0	0	8	0	0	0	8	0	0	0	8
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
44	0	33	0	0	0	33	0	17	0	8	0	8	0	17	0	0	0	8	17	8	0	0	33	8
45	0	0	8	0	8	17	0	0	0	0	0	0	0	0	0	9	0	0	0	17	17	8	0	0
46	0	17	0	0	8	0	17	0	0	0	0	0	0	0	0	0	0	0	0	8	17	0	17	17
47	33	0	8	33	0	0	0	25	0	8	0	8	17	8	0	8	0	8	0	17	0	0	0	0
48	8	20	0	0	0	0	0	17	0	8	17	17	0	0	0	0	0	0	0	8	33	8	0	0
49	17	0	0	0	0	0	0	0	0	0	0	8	0	18	0	0	0	8	0	0	0	0	0	8
50	8	0	0	0	0	0	17	0	17	0	0	0	0	0	0	8	17	0	0	0	0	8	0	8
51	50	50	33	33	25	17	33	25	50	8	0	17	0	17	0	8	17	17	0	17	17	8	0	0
52	0	0	0	0	8	0	0	8	0	0	0	0	17	0	0	0	0	8	0	0	0	8	0	8
53	0	0	8	0	8	0	0	0	0	0	17	0	0	8	0	0	0	25	17	0	0	8	0	9
54	0	0	0	17	8	0	0	17	17	0	0	0	17	0	0	8	17	8	17	0	17	0	0	17
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	8	0	8	0	0	8	0	8	17	8	0	18	0	0	17	8	17	8	0	8	0	0
57	0	17	0	17	8	17	0	0	0	17	17	0	20	0	17	17	0	0	0	0	0	8	0	0
58	0	0	0	0	0	0	0	0	0	8	17	0	0	8	0	0	17	8	17	0	0	0	17	0

59	0	33	8	17	17	0	17	17	0	0	17	8	17	25	17	8	0	25	0	8	0	8	0	0
60	0	0	0	17	0	0	0	8	0	8	0	0	17	0	0	0	0	8	0	0	0	0	17	8
61	8	0	0	17	0	0	0	0	0	0	0	8	0	0	0	17	0	0	0	0	0	0	0	8
62	0	0	8	17	8	0	0	8	17	0	17	8	0	8	17	0	0	8	17	8	0	17	17	17
63	8	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	17	8	0	8	17	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	17	0	17	17	0	17
65	17	0	17	0	17	0	17	8	0	0	17	8	17	17	0	8	17	0	17	8	17	0	17	17
66	0	0	8	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	17	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	8	0	0	0	0
68	17	17	9	0	8	0	0	0	0	8	0	0	0	0	0	9	33	0	17	8	17	8	33	8
69	0	0	0	0	0	0	17	0	17	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0
70	8	17	8	17	0	0	0	0	0	17	0	8	17	0	17	0	0	0	17	8	0	0	0	8
71	8	0	0	0	8	0	0	17	0	0	0	8	0	0	0	8	0	8	17	8	33	0	0	8
72	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	0	0	0	17	0	0	0	0	0	0	0	8	0	8	0	8	0	8	17	0	0	8	0	8
74	0	0	0	17	0	17	0	8	17	8	33	0	0	0	0	17	0	0	0	8	0	0	0	0
75	17	0	0	0	8	20	0	8	0	8	17	0	17	0	17	0	0	9	17	17	17	0	17	0
76	8	17	0	17	0	0	17	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	17	0
77	8	0	0	0	0	0	0	8	0	8	0	0	17	8	0	8	0	17	0	0	20	0	0	0
78	0	0	0	0	8	17	0	0	0	0	0	0	0	0	17	0	0	8	17	0	0	0	17	0
79	0	0	0	0	0	0	0	8	0	8	0	8	17	0	0	8	0	8	17	0	0	8	0	0
80	25	25	33	33	0	17	0	8	0	17	17	0	40	25	33	8	17	8	33	25	0	17	0	42
81	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	8	0	8	17	0	0	8	0	8
82	0	0	8	0	8	0	0	17	17	8	0	17	33	0	17	9	0	9	0	8	0	0	17	0
83	8	0	8	0	0	17	0	0	0	8	0	0	0	8	0	8	0	0	0	0	17	0	0	0
84	8	17	17	0	17	0	0	17	0	0	17	8	0	8	17	0	17	0	17	8	0	8	0	17
85	17	17	25	17	8	0	0	8	33	17	0	17	0	17	0	17	0	8	0	8	0	8	0	8
86	8	50	0	33	17	0	0	8	0	0	0	17	0	8	17	8	0	17	0	8	0	8	0	0
87	30	0	25	0	0	17	17	0	17	8	0	0	17	8	0	25	0	0	0	8	0	8	0	17
88	8	17	17	17	17	17	25	42	0	8	33	17	33	30	17	8	17	30	17	8	17	17	17	8
89	9	17	8	17	0	0	17	17	0	8	17	0	0	8	0	17	0	8	0	0	17	0	0	0

90	8	17	0	17	8	0	0	8	17	8	17	0	17	8	17	8	0	8	0	0	0	0	0	8
91	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0
92	0	0	8	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	8	17	8	17	17	17	17	0	33	0	0	17	33	0	33	0	0	0	0	0	17	0	33	8
94	8	17	8	0	0	0	17	8	0	8	17	0	0	0	0	0	17	17	0	17	0	8	17	0
95	8	17	0	0	0	0	0	8	0	17	0	17	33	17	17	0	0	8	17	0	17	17	0	25
96	0	17	0	17	0	0	0	8	0	8	0	8	0	0	0	0	0	0	0	0	0	8	0	0
97	0	0	0	17	0	33	0	17	0	17	0	0	0	0	33	0	0	0	17	0	0	0	17	8
98	8	0	8	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0

Reanalysis 1 Response Latency Participant Means (in milliseconds)								
	n – 2							
	Complete Repetition		Word Repetition		Colour Repetition		Alternation	
	high	low	high	low	High	low	high	low
1	542	598	519	506	501	546	476	482
2	730	633	744	809	749	718	741	762
3	786	872	844	779	843	819	731	781
4	798	780	842	869	797	911	829	775
5	587	593	576	568	575	585	569	599
6	608	803	533	578	590	617	529	594
7	711	648	683	697	709	764	647	678
8	629	592	603	651	769	690	661	700
9	737	769	667	846	792	800	706	779
10	719	696	690	732	693	703	705	691
11	696	713	709	714	693	690	715	731
12	695	822	698	785	798	780	743	783
13	1038	954	937	1010	999	969	980	997
14	684	648	769	758	821	756	775	819
15	867	777	905	843	919	841	852	862
16	598	623	578	684	620	678	618	667

	n – 3							
	Complete Repetition		Word Repetition		Colour Repetition		Alternation	
	high	low	high	low	High	low	high	low
1	476	532	515	489	459	496	496	519
2	735	842	709	753	757	782	748	737
3	716	880	776	817	750	797	783	781
4	785	1279	804	813	828	852	832	829
5	609	504	617	568	536	663	564	574
6	552	742	560	614	576	620	551	595
7	676	717	637	674	656	677	679	725
8	742	689	586	703	668	701	660	667
9	767	819	648	804	739	772	720	806
10	689	747	698	703	720	692	704	702
11	630	676	713	710	782	716	698	714
12	654	904	755	746	753	853	737	769
13	930	873	1069	983	911	996	991	999
14	815	674	780	800	795	794	761	782
15	807	867	914	857	835	868	877	835
16	753	541	577	684	619	691	592	658

	n – 4							
	Complete Repetition		Word Repetition		Colour Repetition		Alternation	
	high	low	high	low	High	low	high	low
1	551	499	497	526	504	505	477	505
2	663	747	760	725	722	791	759	741
3	779	737	737	799	723	792	785	795
4	902	886	875	824	860	842	791	830
5	602	610	552	553	530	550	581	617
6	567	532	527	596	565	606	555	613
7	594	623	734	658	661	747	674	706
8	636	582	698	717	627	638	664	691
9	721	1522	765	734	723	813	706	796
10	701	701	732	718	701	689	700	698
11	681	627	695	722	686	697	719	719
12	689	757	798	800	779	801	726	758
13	938	973	997	970	1081	1023	971	991
14	700	760	701	794	793	847	796	759
15	886	879	862	845	857	823	871	861
16	603	565	621	619	534	680	614	689

	n – 5							
	Complete Repetition		Word Repetition		Colour Repetition		Alternation	
	high	low	high	low	High	low	high	low
1	495	493	506	513	463	491	496	514
2	753	655	793	795	722	725	735	748
3	778	830	777	771	711	792	786	799
4	778	1096	799	841	811	768	835	844
5	555	665	554	563	534	608	587	587
6	485	512	568	582	568	624	559	613
7	697	637	634	686	692	713	667	707
8	613	785	640	654	608	684	686	688
9	687	661	693	765	769	816	711	804
10	692	696	699	690	692	708	708	703
11	696	715	744	756	701	696	700	704
12	698	668	734	742	708	755	751	802
13	965	811	1007	1016	974	943	982	1011
14	724	750	847	761	860	776	758	796
15	828	785	793	861	881	821	892	859
16	595	580	599	644	652	703	592	671

Experiment 2 Response Latency Participant Means (in milliseconds)

No Load			Load		
	Contingency			Contingency	
	high	low		high	low
1	773	937	2	773	801
3	678	667	4	1023	825
5	722	885	6	1112	915
7	791	772	8	966	987
9	525	575	10	739	752
11	788	1066	12	614	668
13	536	531	14	904	819
15	565	644	16	696	722
17	548	569	18	677	682
19	679	815	20	606	605
21	519	567	22	816	817
23	671	819	24	1034	1109
25	692	808	26	1175	1086
27	597	735	28	918	800
29	734	806	30	723	912
31	683	850	32	808	993
33	613	639	34	792	802
35	565	604	36	918	983

Experiment 2 Percentage Error Participant Means					
No Load			Load		
	Contingency			Contingency	
	high	low		high	low
1	2	0	2	2	11
3	16	0	4	8	8
5	7	0	6	17	0
7	0	12	8	22	29
9	2	18	10	4	0
11	7	9	12	2	10
13	2	0	14	10	0
15	4	17	16	3	12
17	0	0	18	5	33
19	0	0	20	33	43
21	3	11	22	5	0
23	5	0	24	5	0
25	0	17	26	7	0
27	12	10	28	13	33
29	3	14	30	11	10
31	2	0	32	6	29
33	10	0	34	9	37
35	0	8	36	6	0

Experiment 3 Response Latency Participant Means (in milliseconds)					
Low Load			High Load		
	Contingency			Contingency	
	high	low		high	low
1	664	779	2	1104	943
3	559	770	4	878	1224
5	822	1076	6	661	630
7	806	968	8	922	950
9	650	714	10	873	865
11	699	948	12	698	762
13	753	1131	14	751	679
15	784	907	16	879	954
17	881	1245	18	837	903
19	777	858	20	790	749
21	748	760	22	703	814
23	796	960	24	861	1037
25	722	756	26	897	933
27	810	894	28	829	761
29	762	671	30	921	969
31	860	824	32	959	929
33	1174	1418	34	1002	1146
35	768	913	36	764	895
37	754	689	38	1125	1120
39	999	819	40	950	924
41	737	751	42	663	646
43	729	761	44	687	688
45	601	511	46	1080	907
47	640	652	48	913	937
49	695	972	50	533	555
51	615	723	52	869	879
53	1119	1388	54	826	990
55	890	954	56	717	703

Experiment 3 Percentage Error Participant Means					
Low Load			High Load		
	Contingency			Contingency	
	high	low		high	low
1	0	0	2	6	0
3	2	0	4	13	30
5	2	0	6	3	0
7	2	0	8	5	14
9	0	0	10	7	0
11	3	0	12	5	0
13	6	17	14	8	0
15	12	0	16	8	10
17	4	0	18	15	33
19	4	11	20	0	0
21	4	14	22	2	0
23	2	0	24	7	0
25	6	0	26	0	0
27	2	0	28	4	17
29	20	0	30	2	0
31	9	33	32	4	0
33	8	17	34	0	8
35	9	0	36	2	18
37	7	0	38	12	0
39	4	0	40	5	0
41	2	0	42	4	9
43	2	0	44	4	0
45	0	14	46	8	40
47	0	0	48	8	0
49	7	0	50	0	0
51	2	10	52	11	14
53	7	0	54	0	0
55	0	0	56	7	0

Experiment 4 Control Response Latency Participant Means (in milliseconds)				
	Learning (Low)		Transfer (Low)	
	Contingency		Contingency	
	high	low	high	Low
1	737	911	720	630
2	943	1044	828	849
3	649	634	652	657
4	850	921	819	883
5	680	611	633	629
6	662	772	526	566
7	1358	1345	1241	1368
8	654	771	620	654
9	644	597	742	754
10	1330	1221	1380	1404
11	1280	1349	873	987
12	775	739	637	760
13	943	1010	774	780
14	605	570	564	572
15	762	763	667	700
16	882	952	666	790
17	806	789	752	750
18	934	888	818	926
19	761	783	766	751
20	702	683	548	508
21	1177	1189	832	820
22	1125	1367	1007	1020
23	1201	1239	765	967
24	676	797	580	551
25	735	658	547	581
26	770	813	764	741
27	973	1146	979	931
28	943	977	817	861
29	1424	1493	1214	1244
30	819	828	731	755
31	911	1027	1043	973
32	813	888	715	708

Experiment 4 Control Percentage Error Participant Means				
	Learning (Low)		Transfer (Low)	
	Contingency		Contingency	
	high	low	high	Low
1	0	0	0	0
2	0	0	0	5
3	5	9	0	4
4	5	0	0	0
5	10	10	0	9
6	0	0	0	0
7	0	0	0	0
8	15	9	17	5
9	0	0	0	0
10	5	14	0	11
11	0	0	0	12
12	0	10	9	0
13	0	0	0	9
14	0	0	0	0
15	4	0	0	4
16	0	9	0	5
17	0	0	0	0
18	9	0	0	0
19	9	11	0	0
20	18	0	0	28
21	12	0	37	32
22	24	8	8	5
23	0	0	11	0
24	4	0	17	0
25	0	0	0	0
26	0	0	0	0
27	0	9	0	0
28	0	0	0	4
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	0	11	0	4

Experiment 4 Response Latency Participant Means (in milliseconds)									
	Group 1					Group 2			
	Learning (Low)		Transfer (Low)			Learning (Low)		Transfer (Low)	
	Contingency		Contingency			Contingency		Contingency	
	high	low	high	Low		high	low	high	low
1	1176	1240	1027	1061	2	1038	1057	1157	1018
3	903	989	771	811	4	973	1043	900	1037
5	1157	1312	1171	965	6	878	857	690	740
7	1052	936	1025	1121	8	896	864	895	890
9	799	824	749	666	10	1200	1317	1027	988
11	1044	1315	745	837	12	785	1049	781	822
13	991	920	748	840	14	963	879	852	898
15	885	834	893	817	16	788	803	701	826
17	900	856	851	700	18	957	1136	928	951
19	1154	1065	787	780	20	955	1168	1178	960
21	772	699	534	495	22	1118	858	960	966
23	1236	1157	924	966	24	982	975	1071	839
25	880	794	754	679	26	872	1003	748	768
27	1186	1165	1036	978	28	897	836	838	935
29	912	1125	874	779	30	1040	1213	709	722
31	764	596	777	864	32	897	931	1078	921
33	1279	1435	1062	913	34	699	739	728	729
35	948	1102	803	705	36	1158	1185	1143	1208
37	1292	1119	1037	1099	38	923	1134	1044	989
39	996	1033	622	577	40	696	814	895	743
41	1292	1279	980	722	42	1065	1028	1005	1040
43	1083	1286	848	910	44	954	975	994	962
45	713	767	636	679	46	840	779	659	667
47	1134	985	910	1008	48	903	919	939	905
49	1099	1154	764	836	50	852	980	769	745
51	1067	1294	959	996	52	797	1027	757	816
53	843	928	1075	855	54	989	1169	890	1140
55	913	907	707	727	56	1054	1145	1060	1037
57	918	773	700	780	58	953	883	927	1079
59	1385	1521	1233	1117	60	705	667	570	573
61	913	1098	707	868	62	1055	1234	1077	1022
63	1037	872	681	712	64	850	901	888	848
65	762	700	1019	845	66	756	882	830	812

Experiment 4 Percentage Error Participant Means									
	Group 1					Group 2			
	Learning (Low)		Transfer (Low)			Learning (Low)		Transfer (Low)	
	Contingency		Contingency			Contingency		Contingency	
	high	low	high	Low		high	low	high	low
1	0	0	0	0	2	0	0	0	0
3	5	0	9	0	4	0	10	0	0
5	0	0	0	5	6	0	0	0	4
7	0	0	10	9	8	5	10	0	5
9	9	0	0	4	10	5	0	0	0
11	0	0	0	0	12	5	0	0	4
13	0	0	0	0	14	5	0	0	0
15	0	0	0	0	16	0	9	8	14
17	5	0	0	0	18	5	27	8	0
19	0	29	9	0	20	4	9	8	0
21	0	0	0	0	22	0	0	0	4
23	16	43	8	0	24	0	0	0	5
25	5	25	0	5	26	11	0	8	0
27	0	0	0	0	28	10	11	0	10
29	0	0	9	0	30	0	0	0	4
31	12	27	0	5	32	0	20	0	0
33	0	0	0	0	34	0	0	0	4
35	5	0	0	0	36	0	9	17	5
37	0	0	0	0	38	0	11	20	0
39	7	11	8	4	40	0	0	0	0
41	11	0	0	0	42	10	22	0	4
43	0	0	0	5	44	0	0	0	9
45	5	0	0	4	46	0	11	0	0
47	0	12	0	11	48	5	0	0	4
49	0	0	9	4	50	0	0	17	10
51	0	0	0	0	52	0	27	8	5
53	5	22	0	0	54	12	0	0	0
55	6	0	0	4	56	0	0	12	0
57	5	9	0	10	58	0	17	0	0
59	0	0	9	5	60	0	9	9	0
61	12	0	0	13	62	5	27	0	4
63	11	0	0	0	64	0	8	0	5
65	0	0	0	5	66	5	8	0	0