Running head: CONTINGENCY LEARNING AND IMPLICIT CONTROL

Contingency Learning without Awareness: Evidence for Implicit Control

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Abstract

The results of four experiments provide evidence for controlled processing in the absence of awareness. Participants identified the colour of a neutral distracter word. Each of four words (e.g., MOVE) was presented in one of four colours 75% of the time (Experiments 1 and 4) or 50% of the time (Experiment 2 and 3). Colour identification was faster when the words appeared in the colour they were most often presented in relative to when they appeared in another colour, even for participants who were subjectively unaware of any contingencies between the words and colours. An analysis of sequence effects showed that participants who were unaware of the relation between distracter words and colours nonetheless controlled the impact of the word on performance depending on the nature of the previous trial. A block analysis of contingency-unaware participants revealed that contingencies were learned rapidly in the first block of trials. Experiment 3 showed that the contingency effect does not depend on level of awareness, thus ruling out explicit strategy accounts. Finally, Experiment 4 showed that the contingency effect results from behavioural control and not from semantic association or stimulus familiarity. These results thus provide evidence for implicit control.

Contingency Learning without Awareness: Evidence for Implicit Control

Cognitive processes that are controlled are conventionally assumed to operate in a slow, effortful, and voluntary manner (Posner & Cohen, 1984; Posner & Snyder, 1975; Shiffrin & Schnieder, 1977). Thus, when researchers discuss the influence of “controlled” processes, it is typically assumed that such processes are explicit (i.e., conscious; cf., Besner & Stolz, 1999). As such, the term “implicit control” would seem to be nonsensical, because “implicit” (i.e., unconscious) seems to preclude the possibility of control. However, etymologically speaking this is not a necessary conclusion. The Oxford English Dictionary (2001) defines control as “the power to influence people’s behaviour or the course of events.” Similarly, Merriam-Webster (2005) defines control as the “power or authority to guide or manage.” Nothing in these definitions necessitates conscious intent. Whether implicitly controlled processes are actually observable is an empirical question. As the experiments reported here demonstrate, control can be dissociated from consciousness.

Evidence for cognitive control, which is assumed to be explicit and strategic in nature, has been drawn from the Stroop literature (Stroop, 1935). In the Stroop task, identification of the print colour of colour words is slower when the word and ink colour are incongruent (e.g., the word GREEN in orange; $\text{GREEN}_{\text{orange}}$) than when they are congruent (e.g., $\text{ORANGE}_{\text{orange}}$; see MacLeod, 1991, for a review). Probably the most important demonstration of putatively controlled processes in the Stroop literature is the proportion congruent effect. The proportion congruent effect refers to the finding that the size of the Stroop effect is influenced by the proportion of congruent items in a block of trials (Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979). Specifically, the Stroop effect is much larger in a high proportion congruent block of trials than in a low proportion congruent block of trials. This effect is commonly attributed to participants explicitly learning to predict the colour from the word. Specifically, because the word usually matches the colour in a high proportion congruent block of trials, participants can capitalize on this relationship and predict the colour based on the word (e.g., if the word is BLUE, then the colour is probably blue), thus leading to a larger Stroop effect because responses would be especially fast on the expected congruent trials and especially slow for the infrequent incongruent trials. In contrast, the Stroop effect is reduced in a low proportion congruent block of trials, because participants can learn that the word rarely predicts the correct response and therefore there is no payoff that leads to fast responses on congruent trials and large costs on incongruent trials. This has often been explained in terms of a deliberate, task-wide strategy.

The idea that cognitive control over the amount of Stroop interference requires a task-wide strategy has recently been challenged. In the item-specific proportion congruent (ISPC) manipulation participants are presented with high and low proportion congruent stimuli within the same block. This is accomplished by presenting some words (e.g., BLUE and GREEN) mostly with their congruent colour (e.g., BLUE is presented 75% of the time in blue and 25% of the time in green) and other words (e.g., YELLOW and ORANGE) mostly with incongruent colours (e.g., YELLOW is presented 25% of the time in yellow and 75% of the time in orange). The Stroop effect is still larger for high proportion congruent words relative to low proportion congruent words (Jacoby, Lindsay, & Hessels, 2003; Trainham, Lindsay, & Jacoby, 1997). This ISPC effect indicates that the "strategy" participants use is not (at least always) task-wide (i.e., participants cannot simply predict that the words will match the colours, because this only applies to the high proportion congruent words). Rather, participants may generate a contingency estimate associated with each word (e.g., BLUE likely indicates the colour blue, whereas YELLOW likely indicates orange).

Although it is possible that participants could be predicting *congruency* with the word (e.g., BLUE likely indicates a matching colour, whereas YELLOW likely indicates a mismatching colour), it is probably more likely that participants use the word to predict a specific colour response. Thus, for instance, if BLUE is presented most often in blue, then BLUE will indicate a blue verbal or key press response. Similarly, if ORANGE is presented most often in yellow, then ORANGE will indicate a yellow verbal or key press response. Thus, participants may be using the *contingencies* between words and colours to predict a *specific response* rather than congruency in general. In support of this contention, Musen and Squire (1993) demonstrated contingency learning independent of any congruency relations between the words and colours. In their Experiment 2 they paired each of seven arbitrary words (e.g., SOCKS) with a colour. Words were always presented in their assigned colours, but participants were instructed to ignore the word and respond to the colour. Halfway through the experiment the words were re-paired with new colours without notice. This led to an increase in response latencies. Thus, participants learned the *contingencies* (i.e., not congruency) between the arbitrary words and the colours and used these to facilitate responding.

One methodological concern with Musen and Squire's (1993) design is that the words are perfectly correlated with the responses. Thus, it is difficult rule out the possibility that some or all of the participants were making responses by identifying the word rather than the colour, thus leading to significant impairment in responding when the words were re-paired with new colours. In order to overcome this shortcoming, the following two experiments present participants with four arbitrary words that are presented in all four ink colours, but each word is presented most often (75% in Experiment 1; 50% in Experiment 2) in one colour (e.g., MOST is presented 75% of the time in blue and 25% equally often in the remaining colours).

Interestingly, Musen and Squire (1993) also report that contingency learning appears to be implicit, which runs counter to the assumption that contingency learning effects (e.g., the proportion congruent effect) result from explicit strategy use. Experiment 1 in their paper was similar to their Experiment 2, except that instead of arbitrary words, incongruent colour words were paired with colours and then re-paired partway through (e.g., BLUE was presented in green for half the experiment, then orange for the rest). At the end of Experiment 1 (they do not report a similar analysis for Experiment 2), participants were asked to guess which colour each word was presented in for both halves of the experiment (order unimportant). Thus, participants made a seven-alternative forced choice (first guess with all seven colours) followed by a six-alternative forced choice (second guess with the remaining six colours). Importantly, Musen and Squire claim that participants did not guess contingencies at a rate higher than expected by chance. Unfortunately, they miscalculated chance to be 33.3% when chance was actually 28.6%.[1] From their graph, normal participants appeared to respond at or above 35%. Reference to the same graph clearly indicates that the 28.6% chance level is not captured by the error bars. Thus, Musen and Squire's data indicate that participants are guessing contingencies at a rate better than chance when chance is calculated correctly. As such, it remains to be determined whether participants can learn contingencies implicitly.

Because Musen and Squire's (1993) reanalysed results indicate that participants guessed the contingencies at a rate greater than chance, it may be the case that all contingency learning in their experiments was explicit (i.e., conscious). On the other hand, this is not necessarily the case. First, the observation of some explicit contingency learning does not mean that implicit contingency learning never occurred. Second, participants in Musen and Squire's study may not have been aware of the contingencies, because unconscious processes can alter a person's behaviour without them knowing it. Thus, while participants may have *guessed* contingencies at a rate higher than chance, it does not necessarily follow that these participants were *aware* of the contingencies (and, indeed, aware that they were guessing at a rate higher than chance).

One of the goals of the present experiments is to demonstrate that participants can detect and use contingencies even when they are *subjectively unaware* of (i.e., unable to report noticing) the contingencies between the arbitrary distracter words and colours. To this end, participants were told nothing about the word-colour contingencies until after the completion of the experiment, at which time participants were asked whether they noticed any contingencies. If a contingency effect is observed for those participants who were not subjectively aware of such contingencies, then this would constitute strong evidence that contingency learning can be implicit.

Summary

There are two primary goals of the current research. First, if participants use contingency information associated with distracter words to predict specific responses rather than congruency in general, then the distracter words need not be colour words. Any words that are correlated with specific colours (e.g., MOST presented most often in blue) should be able to elicit a contingency effect. Specifically, participants should respond faster on high contingency trials (e.g., $MOST_{blue}$) than on low contingency trials (e.g., $MOST_{orange}$). On the other hand, if distracter words are used to predict *congruency*, then arbitrary words cannot be used (i.e., because an arbitrary word like MOST is neither congruent nor incongruent with a colour). Thus, no difference between high and low contingency trials is expected.

Second, the current research expands on the idea that controlled processes need not be explicit. To foreshadow our results, we reproduce two classical patterns of data that are taken as evidence for cognitive control. Critically, we demonstrate these patterns of data with participants who are subjectively unaware of the contingencies driving these effects, suggesting that controlled processing can be dynamic and implicit, rather than always being slow, effortful, and explicit. In Experiments 1 and 2 we demonstrate proportion congruent-like contingency learning for arbitrary words (i.e., faster responding for high contingency trials relative to low contingency trials). These experiments demonstrate the hallmark pattern of controlled processing that is observed in the proportion congruent design. This contingency learning was observed even when participants were subjectively unaware of the word-colour contingencies. That is, a contingency effect was found even for participants who reported no awareness of the fact that some words were presented more often in one colour than in the other colours. We then demonstrate that another commonly used example of cognitive control, sequential control of contingency effects, is also seen when participants are unaware of the contingencies present. Finally, we report a block analysis that indicates that contingency learning occurs rapidly in the first block of trials and is maintained throughout the experiment, ruling out an explicit strategy interpretation. Experiments 3 and 4 extend these findings by showing, respectively, that level of awareness is unrelated to the size or presence of the contingency effect and that contingency learning results from behavioural control over *responding* and not simple semantic associations between word-colour pairs or stimulus familiarity.

Experiments 1 and 2

If the ISPC effect is due solely to contingencies between the distracter words and correct responses, then it should be the case that contingencies can be learned for any set of words. In that vein, Experiment 1 uses a key press Stroop task in which neutral distracter words predict the correct colour response on 75% of the trials (e.g., the word MOVE presented in blue 75% of the time and the remaining 25% of the time in the other three display colours). In Experiment 2, the contingencies are lowered to 50%. If participants are able to pick up on these contingencies, then high contingency trials (e.g., $MOVE_{blue}$, where MOVE is presented with blue 50% of the time) should be responded to faster than low contingency trials (e.g., $MOVE_{green}$).

Method

Participants. Experiments 1 and 2 had 56 and 16 participants, respectively. Fifteen participants in Experiment 1 and all the participants in Experiment 2 were undergraduate students at the University of Saskatchewan and participated in exchange for entry into a draw for $40 or for course credit. None of the participants participated in both studies. The remaining 41 participants in Experiment 1 were undergraduate students at the University of Waterloo and participated in exchange for $4 or participation credit.

Apparatus. All stimuli were presented on a standard computer monitor and responses were made on a QWERTY keyboard. Stimulus presentation and response timing were controlled by E-Prime (Psychology Software Tools, 2002).

Materials and Design. There were four distracter words in each experiment (Experiment 1: MOVE, FALL, GRIP, SENT; Experiment 2: CAST, SLIP, FIND, REEL). Each word was presented in each of four colours (blue, green, yellow, orange) for a total of 16 unique stimuli. In each block of 48 stimuli, each word was presented in one colour nine times and in the remaining three colours once to achieve a 75% contingency (Experiment 1) or in one colour six times and in the remaining three colours twice to achieve a 50% contingency (Experiment 2). In each experiment, the four distracter words were assigned to the four colours randomly for each participant. The distracter words were matched for word length and had no repeated letters in any of the four letter positions. The words were presented in bold 18 pt. Courier New font and subtended 1.3° vertically and 4.6° horizontally. The red/green/blue (RGB) values for the stimulus colours were 0,0,255 (blue); 0,255,0 (green); 255,255,0 (yellow); and 255,125,0 (orange).

In summary, on *high* contingency trials the word appeared in the ink colour that it was most often paired with (.75 or .50). On *low* contingency trials the word was presented in one of the remaining three colours.

Procedure. Participants sat approximately 60 cm from the screen. All participants pressed the “a” key for blue, the “z” key for green, the “m” key for yellow, and the “k” key for orange (all keys were labelled with a corresponding colour patch). Stimuli were presented in the center of a black screen. At the beginning of each trial a white (255,255,255) fixation cross (“+”) was presented. After the fixation cross appeared, participants initiated a trial by pressing the spacebar with their thumb. Following a 500 ms delay, the stimulus was presented for 2000 ms or until a response was made. Correct responses were followed by a black screen for 300 ms before the next fixation cross appeared. Incorrect and null responses were followed by the messages “Incorrect” and “No response,” respectively, in red (255,0,0) for 1000 ms before the next fixation cross appeared. There were a total of 384 trials, consisting of 8 blocks of the 48 stimuli. Trials were pseudo-randomly ordered such that no colour appeared twice in succession.

Results

The dependent measures for both experiments were mean correct response latencies and percentage error. All responses shorter than 250 ms or longer than 2000 ms were considered spoiled trials and excluded from analysis (2% of the data in Experiment 1 and less than 1% of the data in Experiment 2). The first two blocks were excluded as practice.

Experiment 1. Experiment 1 yielded faster response latencies to high contingency trials

(669 ms) than low contingency trials (729 ms). This 60 ms effect was significant, $t(55) = 9.203$, $p < .001$, $SE_{diff} = 7$. After completing the task, participants were asked the question: "While you were doing the task, did you notice that certain words were printed in one colour more often than in the other colours?"[2] The majority of participants were oblivious to any contingencies between the words and responses. Twenty-two participants claimed to have noticed. When probed to report the associations they noticed, a few participants claimed to have used the words strategically. However, the vast majority of contingency-aware participants were only vaguely aware of contingencies (e.g., a typical response was "I think I saw MOST in yellow a lot"). Thus, at least some of the participants were subjectively aware of the 75% contingencies. However, removing these participants from the analysis does not alter the findings; high contingency trials (679 ms) were still faster than low contingency trials (734 ms). This 55 ms effect was significant, $t(33) = 6.054$, $p < .001$, $SE_{diff} = 9$.

There were very few errors in Experiment 1. There were fewer errors on high contingency trials (2.5%) than on low contingency trials (4.6%), $t(55) = 4.063$, $p < .001$, $SE_{diff} = .005$, consistent with the response latencies. Again, removing contingency-aware participants did not alter the findings; high contingency trials (2.7%) generated fewer errors than low contingency trials (4.1%), $t(33) = 2.120$, $p = .042$, $SE_{diff} = .006$.

Experiment 2. Experiment 2 also yielded faster response latencies to high contingency trials (698 ms) than low contingency trials (725 ms). This 27 ms effect was significant, $t(15) = 3.780$, $p = .002$, $SE_{diff} = 7$. After completing the task, participants were asked whether they noticed contingencies, as in Experiment 1. None of the participants claimed to have noticed. Thus, a 50% contingency level seems to prevent subjective detectability, at least for this sample.[3]

There were very few errors in Experiment 2. There were fewer errors on high contingency trials (1.3%) than low contingency trials (2.5%), $t(15) = 2.179$, $p = .046$, $SE_{diff} = .006$, consistent with the response latencies.

Discussion

The results of these two experiments demonstrate that participants are able to detect and use contingencies between colour-unrelated distracter words and colours. Responses were faster and errors were more infrequent when a word was presented in its high contingency colour than when the word was presented in any of the remaining three colours with both the 75% (Experiment 1) and 50% (Experiment 2) contingencies.

Interestingly, the majority of participants in Experiment 1 and *all* participants in Experiment 2 were subjectively unaware of the word-colour contingencies. Nevertheless, contingency-unaware participants still showed a contingency effect. Thus, the results of these experiments clearly indicate that contingency learning can be implicit. These results corroborate Musen and Squire's (1993) results demonstrating implicit learning of word-colour contingencies, even when the word holds no congruency relationship with the colour. Further, these findings add to the growing body of literature using related paradigms demonstrating that contingency learning can occur in the absence of awareness (e.g., Crump, Gong, & Milliken, in press; Lewicki, 1986; Lewicki, Hill, & Czyzewska, 1992, 1997; cf., Hendrickx, De Houwer, Baeyens, Eelen, & Van Avermaet, 1997a, 1997b) and challenge the idea that cognitive control processes must be conscious.

The findings from Experiments 1 and 2 also provide support for the notion of *implicit control.* Using contingency information to predict responses (e.g., in the proportion congruent version of the Stroop task) is considered a controlled process (e.g., Jacoby et al., 2003; Logan, Zbrodoff, & Williamson, 1984). Thus, these results indicate that control and awareness are dissociable given that control occurs in the absence of subjective awareness when learning contingencies.

Sequential Analysis

To strengthen the claim that control can be exerted implicitly, we report an analysis of sequential effects that are most easily understood in terms of control. Specifically, it is often observed that participants will alter the way they perform a task based on what happened on the preceding trial (e.g., Besner & Risko, 2005). For instance, it has been observed that Stroop-like effects are larger for trials following a congruent trial than for trials following an incongruent trial (Gratton, Coles, & Donchin, 1992). Arguably, this occurs because on congruent trials the word matches the colour. Hence, participants are more inclined to use the distracting word information on the following trial, leading to more Stroop interference if the word is incongruent and more facilitation if the word is congruent. In contrast, on incongruent trials the word mismatches the colour. Thus, on the following trial participants are less inclined to use the distracting word information, leading to a reduced Stroop effect.

Sequential effects such as those described for Stroop-like designs are conventionally assumed to result from controlled processing. According to the present proposal that participants are capable of implicit control, participants should be more likely to use contingency information following high contingency trials (where the word effectively predicts the response) than following low contingency trials (where the word predicts the wrong response) even when subjectively unaware. Thus, if participants exert implicit control over the use of contingency information, then the contingency effect should be larger following high contingency trials than low contingency trials. In contrast, if the claim that control can be exerted without awareness is incorrect, then no sequential control should be observed (see Kunde, 2003, for the claim that sequential control requires awareness). Thus, a finding of sequential control in the present analysis would constitute strong support for the claim that control can be exerted implicitly and challenge the conventional wisdom that sequential control necessarily reflects trial-by-trial shifts in explicit strategies.

Results

Contingency-unaware participants from Experiments 1 and 2 were combined into a single data set to analyse sequence effects. The dependent measures for this analysis were mean correct response latencies and percentage error. All responses shorter than 250 ms or longer than 2000 ms were considered spoiled trials and excluded from analysis. The first two blocks were excluded as practice.

If control is exerted implicitly on a trial-by-trial basis, then the contingency effect should be smaller following low contingency trials than following high contingency trials. The response latencies for the sequence analysis are presented in Figure 1. A 2 (trial n-1 contingency; high, low) x 2 (trial n contingency; high, low) ANOVA for response latencies confirms the critical interaction between trial n-1 and trial n contingency, $F(1,49) = 4.585$, $MSE = 1349$, $p = .037$.[4] The contingency effect was 23 ms larger following high contingency trials than low contingency trials. Planned comparisons revealed that the trial n contingency effect was significant for both the trial n-1 high contingency condition (high: 676 ms; low: 729 ms; difference: 53 ms), $t(49) = 6.573$, $p < .001$, $SE_{diff} = 8$, and the trial n-1 low contingency condition (high: 680 ms; low: 710 ms; difference: 30 ms), $t(49) = 3.452$, $p = .001$, $SE_{diff} = 9$. Thus, the contingency effect was reduced following low contingency trials, but not eliminated.

Nothing in the error data contradicts the response latencies findings. Percentage errors for the sequence analysis are also presented in Figure 1. A 2 (trial n-1 contingency; high, low) x 2 (trial n contingency; high, low) ANOVA for percentage error did not yield a significant interaction between trial n-1 and trial n contingency, $F(1,49) = .753$, $MSE = .1$, $p = .390$.

Discussion

In the sequential analysis, contingency-*unaware* participants across both experiments were shown to control the influence of the distracter word on colour identification based on the contingency (high or low) of the previous trial, despite a lack of subjective awareness of these contingencies. That is, participants were more likely to use contingency information following a high contingency trial where the word accurately predicts the colour (thus leading to a larger contingency effect) than following a low contingency trial. This challenges the idea that sequential control requires awareness and supports the claim that control can be implemented implicitly.

Block Analysis

A contingency effect was observed in both Experiments 1 and 2. Because this effect was observed even for participants who were subjectively unaware of contingencies, we have argued that contingency learning is implicit. If this assertion is correct, then it would be expected that contingency learning occurs rapidly at the very beginning of the experiment. If, other the other hand, contingency learning resulted from conscious strategy, then it would be expected that contingency learning would not be evidenced until partway through the experiment when enough information has been accumulated to begin predicting responses. To help discriminate between these two alternatives, we conducted a block analysis on Experiments 1 and 2. The implicit account of the contingency effect predicts an early and stable effect. The explicit account, on the other hand, predicts that the effect will not be observed until later blocks. Seeing as there are only 48 trials in a block, it is not clear how a participant could see enough trials to consciously recognize that the display words are not uncorrelated with the display colours, then consciously study more trials to determine which word is presented with which colour, then decide that it may be useful to predict the colour based on the word, then map each word to a key, and finally begin implementing this explicit strategy soon enough to influence responding to enough trials in the very first block of 48 trials to generate a sizable contingency effect.

Results

Contingency-unaware participants from Experiments 1 and 2 were combined into a single data set to analyse block effects. The dependent measures for this analysis were mean correct response latencies and percentage error. All responses shorter than 250 ms or longer than 2000 ms were considered spoiled trials and excluded from analysis. All eight blocks were included in the analysis.

The results for the block analysis are presented in Figure 2a. A 2 (contingency; high, low) x 8 (block) ANOVA for response latencies revealed a significant contingency main effect, $F(1,49) = 41.926$, $MSE = 9091$, $p < .001$, indicating that participants responded faster overall to high contingency trials. There was also a main effect for block, $F(7,343) = 9.949$, $MSE = 6581$, $p < .001$, indicating that overall response latencies decreased throughout the experiment. Critically, the interaction was not significant, $F(7,343) = 1.485$, $MSE = 2215$, $p = .171$. (The small trend evident in this statistic was due to the fact that the contingency effect was slightly smaller in the first block where initial learning was occurring. Exclusion of this block reduces this trend, $F(6,294) = .923$, $MSE = 2263$, $p = .478$.) Planned comparisons were nevertheless conducted; a significant block effect was observed for all eight blocks (all $ts(49) > 2.421$, $ps < .020$).

The error data were consistent with the response latencies. Mean percentage errors are presented in Figure 2b. A 2 (contingency; high, low) x 8 (block) ANOVA yielded a main effect of contingency, $F(1,49) = 9.404$, $MSE = .003$, $p = .004$, indicating that participants made less errors overall to high contingency trials. There was no main effect of block, $F(7,343) = 1.724$, $MSE = .001$, $p = .102$. The interaction was not significant, $F(7,343) = .777$, $MSE = .002$, $p = .607$.

Discussion

The results of the block analysis support the contention that contingency learning is implicit. In both the response latency and error data a contingency effect occurred in the first block and was maintained throughout the experiment. Not only is this consistent with the implicit control interpretation, but it is inconsistent with an account holding that contingencies are learned and used explicitly. If the contingency learning effects observed here were due to explicit learning, then it would have taken a few blocks for participants to integrate information about contingencies to plan a response strategy.

Experiment 3

So far, we have argued that our proportion congruent-like contingency effects and sequential trial effect result from implicit control. The claim that these controlled processes can be implemented implicitly is supported by the fact that these effects were observed even for contingency-unaware participants. The claim that the effect is implicit is also supported by the block analysis, which showed that learning occurs very rapidly. Experiment 3 was conducted to investigate whether level of awareness of contingencies is necessarily related to the size or presence of a contingency effect. Participants were therefore categorized based on their level of awareness and compared.

Another goal of Experiment 3 is to broaden our focus to include objective measures of awareness. The focus of the previous experiments was on *subjective* awareness of contingency information. It is unknown whether a contingency effect would still be observed for participants that are unaware based on an *objective* measure of awareness (i.e., where participants are assumed to be “unaware” if they cannot guess contingencies at a rate greater than expected by chance).

Participants in Experiment 3 were asked whether they were aware of contingencies and were then asked to guess which colour each word was presented in most often. Based on these responses, participants were grouped into three categories: subjectively aware (aware), subjectively unaware but above chance guessing (unaware), and at or below chance guessing (chance). If contingency learning is implicit, then this would imply that level of awareness (i.e., aware > unaware > chance) should not affect the size of the contingency effect. However, it may be the case that chance participants may not have detected contingencies at all. In that case, no effect would be observed for this group. Experiment 3 therefore tests whether level of awareness (aware, unaware, chance) modulates or is independent of the contingency effect.

Method

Participants. Forty-four undergraduate students at the University of Waterloo participated in exchange for $4 or participation credit.

Apparatus. The apparatus for Experiment 3 was identical in all respects to Experiments 1 and 2.

Materials and Design. The materials and design for Experiment 3 was identical in all respects to Experiment 2.

Procedure. The procedure for Experiment 3 was identical in all respects to Experiment 2, with one exception. Instead of being asked verbally by the experimenter whether they noticed contingencies, participants were asked the same question by the computer and then were asked to guess the colour that each of the four words was printed in most often.

Results

The dependent measures for Experiment 3 were mean correct response latencies and percentage error. All responses shorter than 250 ms or longer than 2000 ms were considered spoiled trials and excluded from analysis (less than 1% of the data). The first two blocks were excluded as practice.

The response latency data for Experiment 3 are presented in Figure 3. A 2 (contingency; high, low) x 2 (awareness; aware, unaware, chance) ANOVA for response latencies yielded a significant main effect of contingency, $F(1,41) = 28.438$, $MSE = 326$, $p < .001$, indicating an advantage for high contingency trials over low contingency trials. The ANOVA also revealed a theoretically-uninteresting main effect of awareness, $F(2,41) = 4.561$, $MSE = 21862$, $p = .016$, indicating that aware participants responded overall faster than the other two groups. Critically, however, there was no interaction between contingency and awareness, $F(2,41) = .203$, $MSE = 326$, $p = .817$, indicating that level of awareness was unrelated to size of the contingency effect. Planned comparisons were nevertheless conducted, revealing a significant contingency effect for aware participants, $t(9) = 2.679$, $p = .025$, $SE_{diff} = 8$, unaware participants, $t(14) = 4.445$, $p = .001$, $SE_{diff} = 5$, and chance participants, $t(18) = 2.808$, $p = .012$, $SE_{diff} = 7$.

The error data for Experiment 3 are also presented in Figure 3. A 2 (contingency; high, low) x 2 (awareness; aware, unaware, chance) ANOVA revealed a significant main effect of contingency, $F(1,41) = 18.669$, $MSE < .001$, $p < .001$, indicating an advantage for high contingency trials over low contingency trials. The ANOVA yielded no main effect of awareness, $F(2,41) = 1.803$, $MSE = .002$, $p = .179$. Critically, there was no interaction between contingency and awareness, $F(2,41) = .508$, $MSE < .001$, $p = .605$, indicating that level of awareness was unrelated to size of the contingency effect. Planned comparisons were nevertheless conducted, revealing a significant contingency effect for aware participants, $t(9) = 3.051$, $p = .014$, $SE_{diff} = .006$, and unaware participants, $t(14) = 2.899$, $p = .012$, $SE_{diff} = .005$, as well as a marginally significant effect for chance participants, $t(18) = 1.882$, $p = .076$, $SE_{diff} = .006$.

Discussion

The results of Experiment 3 clearly show that not only *can* control be engaged without awareness, but that level of awareness is *unrelated* to the magnitude of the contingency effect. It did not matter whether participants were subjectively aware of contingencies, subjectively unaware but above chance guessing, or even guessing at chance; equivalent contingency learning in both the latency and error data was observed across groups. This suggests that contingency learning is inherently implicit, which contradicts traditional interpretations of contingency effects that assume conscious strategy (e.g., standard accounts of the proportion congruent effect).

Experiment 4

So far we have presented a behavioural control account of our data. That is to say, we argue that participants learn contingency information implicitly and then directly use this information to control responses. There are, however, at least two alternative accounts of the data presented thus far. The first alternative is the semantic association account, which holds that rather than using contingencies to predict *responses*, participants are simply forming meaningful associations between *stimulus* words and colours that frequently co-occur. For instance, if the word MOVE is presented in blue 75% of the time, then the stimulus word MOVE and the stimulus colour blue become meaningfully related by virtue of this contingency association (similar to Hebbian learning). Thus, participants would be using the word to predict the *stimulus* colour, not the *response* according to the semantic association account.

Similar to this semantic association account, another alternative is a stimulus familiarity account. According to the stimulus familiarity account, participants respond to word-colour pairs that they have seen more often (e.g., $\text{MOVE}_{\text{blue}}$) faster than to word-colour pairs that they have seen relatively less often (e.g., $\text{MOVE}_{\text{green}}$) simply by virtue of the fact that they are more familiar with them. Thus, the cognitive system is not sensitive to contingencies, but rather to frequencies of event pairs. Thus, it could simply be the case that participants respond faster to high contingency trials because they have seen these word-colour stimulus pairs more often than the word-colour stimuli for low contingency trials.

There are therefore at least three accounts of the contingency effect. The behavioural control account preferred here posits that learned contingency information is used to predict responses. The semantic association and stimulus familiarity accounts both posit that the effect emerges as a result of stimulus interactions (i.e., the learning of associations and the learning of frequency of event pairs, respectively). To help discriminate between these accounts we used a manipulation conceptually similar to that used by De Houwer (2003) and Schmidt and Cheesman (2005) in the Stroop paradigm. Specifically, for each participant, two colours were assigned to a left response key (e.g., blue and green) and two other colours were assigned to a right response key (e.g., yellow and orange). As in Experiment 1, each of four words was presented most often in one colour (e.g., $\text{MOVE}_{\text{blue}}$). According to the semantic association and stimulus familiarity accounts, “high contingency” trials are trials in which the *stimulus* word is presented in the *stimulus* colour it is most often presented in (e.g., $\text{MOVE}_{\text{blue}}$). On the other hand, according to the behavioural control account high contingency trials are trials in which the correct *response* (e.g., a left key press response) is the *response* that is usually made in the presence of the distracter word (e.g., the correct response is the left key for both $MOVE_{blue}$ and $MOVE_{green}$, which represent 75% + 8.3% = 83.3% of the trials where MOVE is the distracter). This creates three trial types: (1) stimulus match trials, where the word is presented in the colour it is most often presented with and the response key predicted by the word matches the correct response (e.g., $MOVE_{blue}$, where MOVE is presented 75% of the time in blue and 83.3% with the left key as the correct response), (2) response match trials, where the word is *not* presented in the colour that it is most often presented in, but the response key predicted by the word matches the correct response (e.g., $MOVE_{green}$, where MOVE is presented 8.3% in green and 83.3% with the left key as the correct response), and (3) response mismatch trials, where the word is presented in one of the remaining low contingency colours that is associated with the competing response key (e.g., $MOVE_{yellow}$ or $MOVE_{orange}$, where MOVE is presented 8.3% in each of these colours and 17.7% the right key is the correct response).

To review, according to the semantic association and stimulus familiarity accounts, stimulus match trials should be faster than response match trials, because the word-colour pairs for stimulus match trials (e.g., $MOVE_{blue}$) are more frequent than the word-colour pairs for response match trials ($MOVE_{green}$). Additionally, both of these accounts predict no difference between response match (e.g., $MOVE_{green}$) and response mismatch trials ($MOVE_{yellow}$), because the prevalence of word-colour pairs for both trial types is identical (8.3%). In contrast, the behavioural control account predicts the exact opposite pattern of results. No difference is predicted between the stimulus match and response match trials, because for both trial types the response key is accurately predicted (e.g., the left key is the correct response 83.3% of the time for the word MOVE, so it does not matter whether the display colour is blue or green). Additionally, a difference is expected between response match and response mismatch trials. On response match trials the correct response is accurately predicted and on response mismatch trials the incorrect response is predicted.

Method

Participants. Eighteen undergraduate students from the University of Waterloo participated in exchange for $4 or participation credit.

Apparatus. The apparatus for Experiment 4 was identical in all respects to Experiments 1 and 2.

Materials and Design. The materials and design for Experiment 4 were identical in all respects to Experiment 1, with the exception of new response mappings and the resulting three trial types. To review, on stimulus match trials the word was presented in the ink colour that it was most often presented in (75%), on response match trials the word was presented in the other colour assigned to the high contingency response key, and on response mismatch trials the word was presented in one of the remaining two colours assigned to the low contingency response key.

Procedure. The procedure for Experiment 4 was identical in all respects to Experiment 1, with one exception. Instead of having each of the four colours assigned to its own response key, two colours were assigned to the left “f” key and the remaining two were assigned to the right “j” key. Assignment of colours to keys was completely counterbalanced across participants.

Results

The dependent measures for Experiment 4 were mean correct response latencies and percentage error. All responses shorter than 250 ms or longer than 2000 ms were considered spoiled trials and excluded from analysis (less than 1% of the data). The first two blocks were excluded as practice. Colour repetitions were also removed from analysis (25% of the data) and a word repetition factor (repetition, non-repetition) was added to the model to partial variance. The reason for removing colour repetitions and partialling word repetitions is that complete repetitions (i.e., when both the word and the colour are repeated) speed responses, but are not equi-prevalent in all conditions. Specifically, complete repetitions are nearly impossible in the response match and response mismatch conditions, whereas complete repetitions are quite common in the stimulus match condition. By deleting colour repetitions, complete repetitions are impossible but word repetitions (which may also speed responding) are not equi-prevalent across conditions, so either word repetitions had to be deleted or the effect of word repetitions had to be partialled (the data is essentially identical either way, with the same statistical tests significant).

The response latencies are shown in Figure 4. A 3 (trial type; stimulus match, response match, response mismatch) x 2 (word repetition; repetition, non-repetition) ANOVA yielded a significant main effect of trial type, $F(2,34) = 5.234$, $MSE = 1709$, $p = .010$. There was no main effect of word repetition, $F(1,17) = .003$, $MSE = 2183$, $p = .959$, or an interaction, $F(2,34) = .112$, $MSE = 2648$, $p = .894$. Planned comparisons support the behavioural control account of the contingency effect. Responses to response match trials (557 ms) were significantly faster than response mismatch trials (583 ms), $t(17) = 2.674$, $p = .016$, $SE_{diff} = 10$. There was no support, however, for the semantic association or stimulus familiarity accounts of the contingency effect. Responses to stimulus match trials (555 ms) were not significantly different from response match trials (557 ms), $t(17) = .179$, $p = .860$, $SE_{diff} = 9$, and power to detect an effect of equivalent size to the behavioural control effect observed was sufficiently high at .754.

The error data are also shown in Figure 4. A 3 (trial type; stimulus match, response match, response mismatch) x 2 (word repetition; repetition, non-repetition) ANOVA for percentage error revealed a significant main effect of word repetition, $F(1,17) = 5.991$, $MSE = .007$, $p = .026$, indicating that word repetition trials generated less errors than non-repetition trials. Despite the consistency of the error and latency data, the main effect of trial type failed to reach statistical significance, $F(2,34) = 1.648$, $MSE = .006$, $p = .207$. There was no interaction, $F(2,34) = .540$, $MSE = .005$, $p = .588$.

Discussion

The results of Experiment 4 show that pairings of stimuli do not simply form semantic connections or breed familiarity, but instead directly cause changes in our behaviour (at least in the present context). In addition, we have already shown that this occurs implicitly, without awareness.

If human behaviour can be modified in ways that we do not intend by the pairings of stimuli that we do not even acknowledge, then is it possible that a range of human behaviours are simply reactionary in this way? Is our perception of “will” or “intent” simply an illusion? Clearly, these deep philosophical questions are far beyond the scope of the present investigation, but the importance of understanding such non-conscious influences on human behaviour cannot be understated. The present findings suggest, for instance, that an undesirable behaviour such as racial discrimination could be propagated by mimicry (i.e., we learn the contingency between skin colour and how each race is treated and use this information unintentionally to directly control our behaviours in accordance with this learned contingency). Research is currently underway to test whether the current results do generalize to more complex behaviours.

General Discussion

The present series of experiments provide a clear demonstration of implicit control. The results of all four experiments indicate that participants are able to learn and use contingencies between colour-unrelated words and colours without awareness. The specific mechanism by which participants use contingency information is further clarified by Experiment 4, where simple semantic association and stimulus familiarity accounts were ruled out and support for the behavioural control account was seen. This finding illuminates an inherent difference between contingency and Stroop effects. In the Stroop literature, both stimulus-stimulus effects (semantic association) and response-response effects (behavioural control) have been observed in the Stroop task (e.g., Schmidt & Cheesman, 2005, 2006; Risko, Schmidt, & Besner, in press). In contrast, only behavioural control effects were observed for the contingency task.

The fact that participants are able to learn and use contingency information to control responding even without awareness is of particular interest. Typically, control is assumed to require awareness (e.g., Kunde, 2003), whereas the present results clearly demonstrate that this need not be so (see also, Besner & Stolz, 1999). The results of the sequence analysis provide a further basis for an interpretation in terms of implicit control. Specifically, implicit control is seen in the fact that participants modulated the impact of word reading processes on colour identification based on contingencies, even though they were subjectively unaware of these contingencies in the first place. Thus, some mechanism below the level of awareness is recognizing contingencies, noticing when the word incorrectly or correctly predicts the colour response, and controlling the influence of the contingency information from the word on the following trial. These demonstrations of *implicit* control force a dissociation between control and awareness, as demonstrated in the block analysis, where the contingency effect was observed even in the first block of trials, and in Experiment 3, where the size of the contingency effect was independent of level of awareness.

Together, these results add to a growing body of research showing the various ways in which contingency information can bias responding and behaviour. For instance, Crump et al. (in press) showed an ISPC-like effect where participants were unable to guess the congruency proportions of different display locations. Implicit learning has also been observed in priming studies (Bodner & Masson, 2001, 2003; Greenwald, Abrams, Naccache, & Stanislas, 2003; Jaskowski, Skalska, & Verleger, 2003), sequential learning studies (Destrebecqz & Cleeremans, 2001; Jiménez & Méndez, 1999; Mayr, 1996; Nissen & Bullemer, 1987), and object-location learning studies (Hoffmann & Kunde, 1999; Musen, 1996). Additionally, Lewicki (1986; Lewicki et al., 1992, 1997) reported various demonstrations of implicit covariation learning (cf., Hendrickx et al., 1997a, 1997b). Given all this data, implicit learning seems to be a highly replicable and general phenomenon (although there will always be some debate over what constitutes evidence of implicit learning; see Frensch & Rünger, 2003, for a discussion of these issues).

Additionally, the account of the present findings effectively explains both the proportion congruent and ISPC effects. In these paradigms congruent words in the high proportion congruent condition have high word-response contingencies and incongruent words have low word-response contingencies. Thus, the resulting “Stroop effect” may be regarded as a combination of standard congruency effects and contingency learning effects. In contrast, in the low proportion congruent condition, congruent words have low word-response contingencies and incongruent words have high word-response contingencies. Thus, the resulting “Stroop effect” may be regarded as the standard congruency effects less contingency learning effects.

Conclusions

The received view of controlled processes is that, in contrast to automatic processes, they are effortful, require more processing resources and attention, and are conscious in nature. The present results are not consistent with this simplified view of controlled processes. In particular, we are able to learn contingency information, exert control over responding with this information, and even control the degree to which such contingency information is used on a trial-by-trial basis. All of this can be accomplished without any awareness (subjective or objective) of the contingencies present. If this analysis is correct, then control need not imply awareness.

Author Notes

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Footnotes

[1] The proportion of correct responses expected by chance = P(both correct) + P(one correct) / 2 = P(2nd correct/1st correct) + (P(1st correct) + P(2nd correct/1st incorrect) – P(2nd correct/1st correct)) / 2 = (1/6 * 2/7) + (2/7 – (1/6 * 2/7) + (1/3 * 4/7)) / 2 = .286 or 28.6%. Note: P(one correct) is divided by two because this represents only 50% accuracy.

[2] One of the reviewers expressed concern that our measure of subjective awareness may have been subject to demand characteristics, leading participants to deny their actual awareness of contingencies. However, our interaction with the participants suggests this to be unlikely, as contingency-unaware participants seemed to have the reverse bias. Many seemed slightly anxious to “discover” what we were asking them to say and would often claim that they “thought” they might have been aware, but when probed for examples gave clearly inappropriate responses (e.g., “I think I saw blue most often,” with no reference to a word), thus demonstrating their complete lack of awareness even when motivated to demonstrate awareness.

[3] However, there were some contingency-aware participants in Experiment 3, which also used a 50% contingency. In fact, subjective awareness was higher in all of our University of Waterloo samples, likely resulting from the fact that University of Waterloo participants were given some information on the actual purpose of the experiments during recruiting, whereas University of Saskatchewan participants were not. There may have also been differences in level of motivation between summer session University of Saskatchewan students and regular session University of Waterloo students.

[4] A reviewer of an earlier version of this manuscript pointed out that the constraint put on the presentation order of print colours (viz., that no colour can be repeated) makes it such that word repetitions occur on a differential proportion of trials in the various conditions. For instance, a

word repetition cannot occur on a high contingency trial if the preceding trial was also a high contingency trial. However, the interaction remains after removing word repetitions, only it falls short of significance, $F(1,49) = 2.382$, $MSE = 1513$, $p = .129$, due to the fact that removing word repetitions entails discarding 25% of the data (most of which is lost from the cells which already have very few observations), which increases the error term. In addition, this reviewer's account actually predicts an interaction of the *reverse direction* observed. On trial n-1 high contingency trials, trial n low contingency trials should be speeded due to 33% word repetitions and trial n high contingency trials should be unaffected due to 0% word repetitions. Thus, the contingency effect should be *decreased* where it actually increased. On trial n-1 low contingency trials, trial n low contingency trials should be speeded due to 22% word repetitions, but trial n high contingency trials should be even more speeded due to 33% word repetitions. Thus, the contingency effect should be *increased* where it actually decreased.

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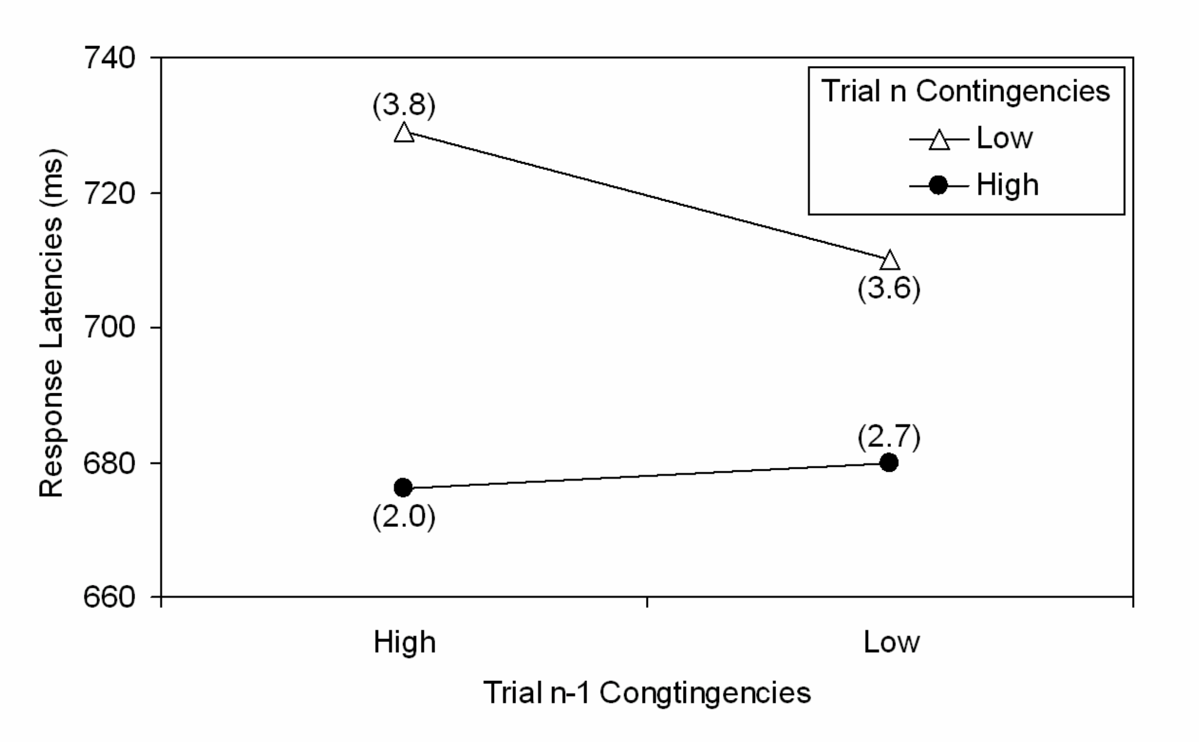
Figure Captions

Figure 1. Experiment 1 and 2 response latencies in milliseconds for trial n high and low contingency and trial n-1 high and low contingency trials. Percentage errors appear in brackets.

Figure 2. Experiment 1 and 2 (a) response latencies in milliseconds and (b) percentage error for contingency and block.

Figure 3. Experiment 3 response latencies in milliseconds for contingency and level of awareness. Percentage errors appear in brackets.

Figure 4. Experiment 4 response latencies in milliseconds according to trial type. Percentage errors appear in brackets.


740
720
700
680
660
Response Latencies (ms)
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(3.6)
(2.7)
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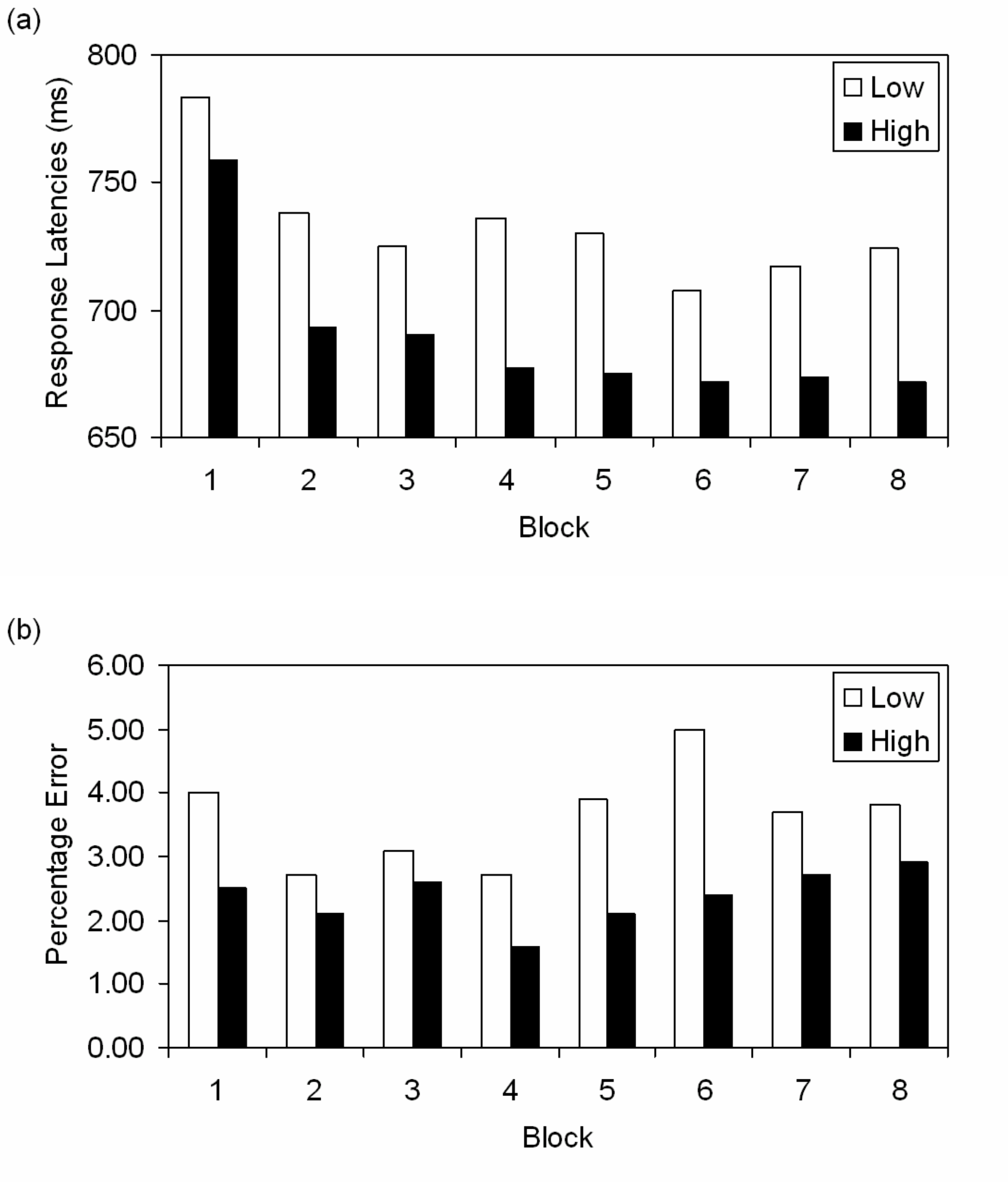
Trial n Contingencies
Low
High
High
Low
Trial n-1 Congtingencies


(a)
Response Latencies (ms)
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750
700
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Low
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1
2
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5
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Block
(b)
Percentage Error
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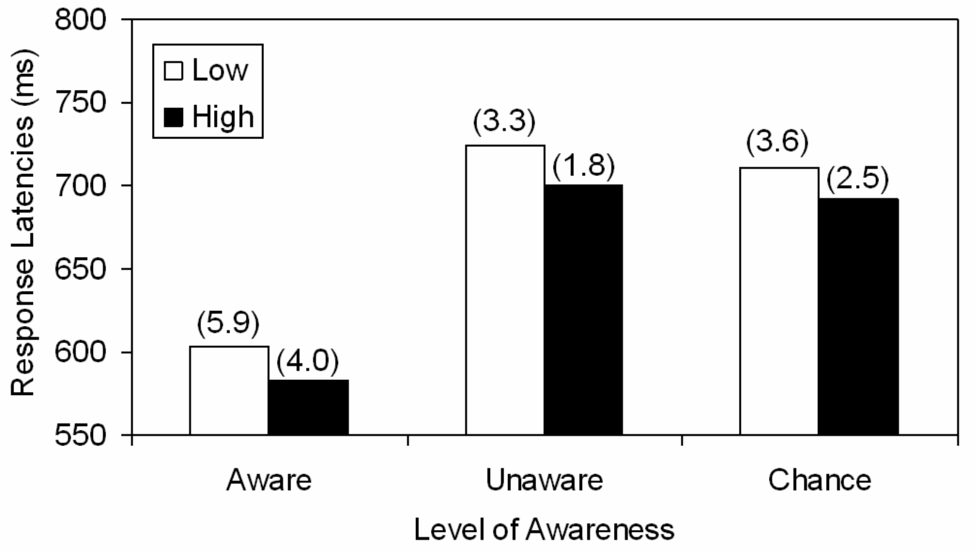
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750
700
650
600
550
Response Latencies (ms)
Low
High
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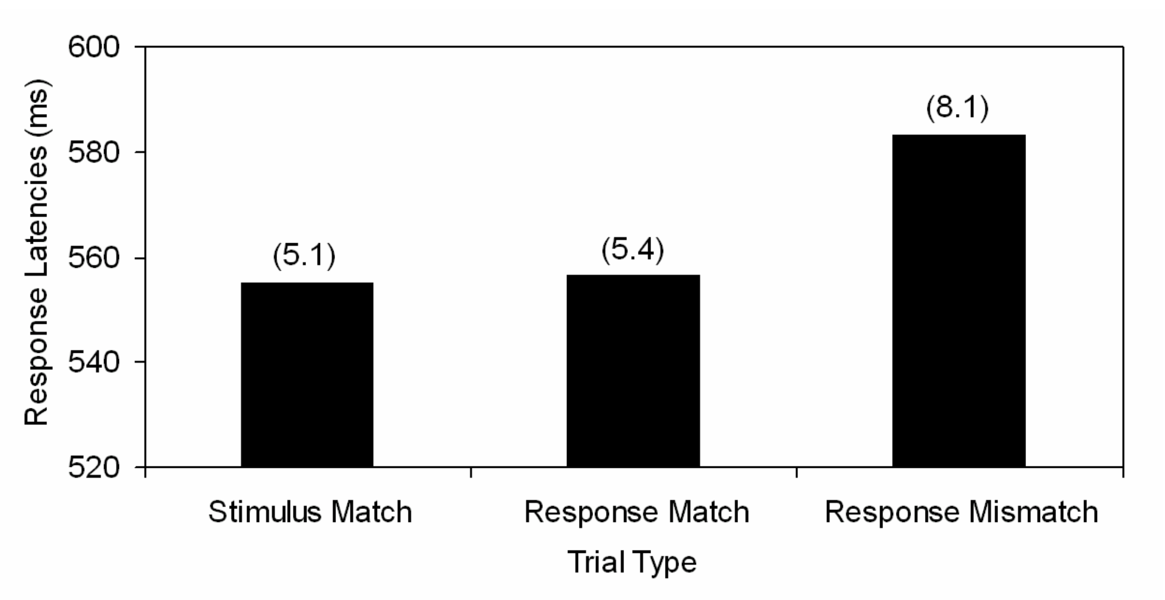
(2.5)
Aware
Unaware
Chance
Level of Awareness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580
560
540
520
Response Latencies (ms)
(5.1)
(5.4)
(8.1)
Stimulus Match
Response Match
Response Mismatch
Trial Type