

Published in *Journal of Experimental Psychology:
Animal Behavior Processes*
2009, vol 35 (2), pp 408-422

<http://www.apa.org/pubs/journals/xan/index.aspx>
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DOI: 10.1037/a0014525

Attentional Changes During Implicit Learning: Signal Validity Protects a Target Stimulus from the Attentional Blink

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Abstract

Participants in two experiments performed two simultaneous tasks: one, a dual-target detection task within a rapid sequence of target and distractor letters; the other, a cued reaction time task requiring participants to make a cued left/right response immediately after each letter sequence. Under these rapid visual presentation conditions, it is usually difficult to identify the second target when it is presented in close temporal proximity of the first target, a phenomenon known as the attentional blink. However, here, participants showed an advantage for detecting a target presented during the attentional blink if that target predicted which response cue would appear at the end of the trial. Participants also showed faster reaction times on trials with a predictive target. Both of these effects were independent of conscious knowledge of the target-response contingencies assessed by post-experiment questionnaires. The results suggest that implicit learning of the association between a predictive target and its outcome can automatically facilitate target recognition during the attentional blink, and therefore shed new light on the relationship between associative learning and attentional mechanisms.

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Author Note This research was supported by Australian Research Council (ARC) Grant DP0771154 to Justin Harris, an ARC Australian Postdoctoral Research Fellowship to Evan Livesey, and an ARC Queen Elizabeth II Research Fellowship to Irina Harris. The authors would like to thank Bob Boakes, Luis Jimenez, and Andy Wills for comments on an earlier version of this article.

Keywords: *Predictive learning, attentional blink, signal validity*

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Learning a relationship between a conditioned stimulus (CS) and an outcome that it predicts is often assumed to be accompanied by changes in attention. Some models of associative learning (e.g. Kruschke, 2001; Mackintosh, 1975) propose that changes in attention are dictated by the relative utility of the various predictive signals that one might extract from presented stimuli: Those features that are relatively good predictors of an outcome attract attention, while relatively poor predictors lose attention. Learning about the signal validity of a CS, the extent to which it signals the occurrence of a relevant outcome, thus results in a change in the processing of that CS during later learning episodes. This idea has received support from a wide variety of animal and human experiments (see Le Pelley, 2004 for a recent review). Much of the evidence in support of these proposed attentional changes has emerged from studies of predictive or discrimination learning, where the principal behavioral measure is the rate at which discrimination accuracy increases or associations between events are conditioned. Such evidence cannot easily separate changes in learning rate from other changes in performance. Thus evidence for a particular attentional mechanism, or even a general theoretical principle about attention and learning, has typically been indirect and inferred through observations that the learned behavior is generally consistent with the predictions of these models. Partly for this reason, learning theorists have conventionally adopted broad definitions of attention and attentional change, which in its most general sense simply refers to *any* change in the processing of a CS.

Learning & Attentional Change

There is a diverse range of “attentional” processes that might change as a consequence of learning about a stimulus. These include overt attentional changes, such as orienting responses (e.g. Sokolov, 1963) or changes in gaze direction (Deubel & Schneider, 1996; Kowler, Anderson, Doshier, & Blaser, 1995) in response to a CS becoming meaningful, which have a direct impact on the

physical sampling of the stimulus. Even where the locus of attention diverges from gaze direction (e.g. Posner, 1980), covert changes in spatial attention might well operate in a similar fashion, as subjects may preferentially process information from a region where a CS is expected or has recently occurred. Attentional change may also refer to changes in the relative share of limited-capacity resources allocated to processing stimulus features according to their utility, in the sense that stimuli may compete for attention even in the absence of changes in stimulus sampling at the sensory level. This form of selective attention underpins a variety of theories of discrimination learning, and assumes that there are limits on the quantity of stimulus information that can be encoded, or learned about, at any given time (e.g. Sutherland & Mackintosh, 1971). In contrast, learning the predictive validity of a stimulus may permit faster processing of that stimulus without exhausting limited resources, and this may occur in a way that is not directly driven by capacity limitations and, consequently, does not require selective processing. Models that assign *independent* parameters to each stimulus to represent their attentional weighting essentially take this view, even if the rules governing attentional change are competitive or based on a comparison with the utility of other stimuli.

The Mackintosh (1975) model can be seen as an example of this latter approach. However, these processes generally imply that attention has the opportunity to influence the extent to which a previously learned association manifests in the performance of some response, as well as influencing new learning. In contrast, Mackintosh (1975) suggested that, without any convincing evidence to the contrary, the predictive utility of a stimulus should be assumed to affect only the rate at which that stimulus is learned about (i.e. its *associability*) rather than assuming any further changes in performance that are normally associated with attention. Furthermore, there is a question of whether changes in associability are governed by the predictive validity of the CS (Mackintosh,

1975) or the predictability of the US (e.g. Pearce & Hall, 1980), both of which account for some but not all of the relevant findings in animal learning (Le Pelley, 2004). The fact that these processes are not necessarily mutually exclusive, and may have opposing or additive effects on learning in different circumstances, makes the task of determining the relationship between attention and learning all the more challenging.

Recently, researchers have begun to focus on concomitant measures of stimulus processing in order to better characterize the attentional changes that occur during human predictive or category learning. These have included measures of gaze duration directed towards competing visual stimuli, which have generally shown (albeit under different task requirements and testing different hypotheses) that participants spend longer fixating on informative stimuli that are relevant to the task outcomes than on redundant or irrelevant stimuli (Kruschke, Kappenman, & Hetrick, 2005; Rehder & Hoffman, 2005; Wills, Lavric, Croft & Hodgson, 2007). These studies demonstrate that learning about the significance of a stimulus has a directly observable effect on the overt physical sampling of that stimulus.

Studies using neurophysiological measures have also suggested that predictive learning in humans is accompanied by changes in the neural mechanisms involved in stimulus processing. For instance, Wills et al (2007) found differences in the event-related potentials evoked by the onset of stimuli which had previously been either uniquely predictive of a surprising outcome or completely redundant to the occurrence of an expected outcome. Using functional magnetic resonance imaging (fMRI), Ploghaus et al (2000; see also O'Doherty, Dayan, Friston, Critchley, & Dolan, 2003; Turner et al 2004) also found neural substrates that appeared to code absolute prediction error, that is, the mismatch between expected outcome and actual outcome regardless of whether that outcome is overpredicted or underpredicted. On the whole, these studies provide evidence

of changes in stimulus processing dictated, in some fashion, by the association between CS and US. An accumulation of evidence from a range of measures that are not solely dependent on the learned response will hopefully paint a clearer picture of the attentional processes that change as a consequence of learning in humans.

The present study investigated the relationship between predictive learning and attention but with two important differences from previous work. The first of these was to use an independent behavioral measure of stimulus processing sensitive to temporal dynamics of visual processing. The second was the use of a speeded response task in which learning is entirely incidental.

The Attentional Blink

We examined visual processing of target CSs under conditions of rapid serial visual presentation (RSVP) and in doing so, utilized a phenomenon commonly known as the attentional blink (Raymond, Shapiro & Arnell, 1992). The attentional blink (AB) refers to the observation that identification of the second of two targets in an RSVP stimulus stream is usually impaired if it appears about 200 - 500 ms after the presentation of the first target. The spacing of the two targets in terms of their serial position in the RSVP sequence is critical for the occurrence of the AB. With relatively simple and familiar visual stimuli, such as alphanumeric characters, the AB is often found to be strongest when the targets occur close together in time and when there is at least one intervening distractor between the targets (Olivers, van der Stigchel, & Hulleman, 2007).

Several studies have shown that the semantic qualities of stimuli in the AB are at least partially processed even when target detection is inaccurate (Shapiro, Driver, Ward, & Sorensen, 1997; Visser, Merikle, & Di Lollo, 2005), and some studies also indicate that the AB is sensitive to the learned significance of stimuli appearing as targets and distractors. For instance, familiar or meaningful stimuli, such as one's own name (Shapiro, Caldwell, &

Sorensen, 1997) or famous faces (Jackson & Raymond, 2006) are protected to some degree from the AB as their identification is less impaired than similar but less familiar stimuli. Smith, Most, Newsome, and Zald (2006) also showed that a stimulus recently associated with an aversive burst of white noise can automatically induce an AB-like impairment when used as a distractor in an RSVP task. Thus there is some evidence that the learned significance of a stimulus can affect the severity of, or even induce an AB, although precisely what aspects of learning result in AB changes in any given paradigm is yet to be explored systematically. Frequency of occurrence of targets within a paradigm has been explored systematically – a high probability target causes less impairment on the recognition of a subsequent target (i.e. a reduced AB) compared to a low probability target, suggesting that an expected stimulus is more easily processed (Crebolder, Jolicœur, & McIlwaine, 2002). However beyond the effects of familiarity and frequency, the influence of stimulus significance on the AB remains unclear.

Implicit Learning

We employed a speeded response task in which learning proceeded incidentally, with participants given no instruction or feedback about the to-be-learned information. Participants completed a lengthy series of dual-task trials, each comprised of an RSVP sequence of target and distractor letters followed immediately by a response cue – a circle appearing on either the left or right side of the computer screen. On each trial, the participant observed the letter sequence, trying to detect the two target letters (which were distinguishable by their color), then responded as quickly as possible to the left/right response cue with a corresponding key press. Having performed this speeded response, they then reported the two letter targets. On a proportion of trials, a particular letter appeared during the RSVP sequence, and its appearance was always followed by the same response cue. For instance, the appearance of letter P might always be followed by the left response cue. The

consistent pairing of P and left presents an opportunity for the speeded response to be performed faster than would normally be possible. That is, learning that P signals the left response should improve the speed of responding on those trials where P appears.

A response priming paradigm of this nature can essentially be described as a form of Pavlovian conditioning, where a conventional unconditioned stimulus (US) is replaced by an imperative stimulus that requires a voluntary speeded response (Perruchet, Cleeremans & Destrebecqz, 2006). In this case, a predictive letter CS is consistently paired with a response cue US. A speeded left or right key press is made in response to the appearance of this US, so that correct responding is not contingent on learning the CS-US relationship, but responses may nonetheless be primed by the appearance of the CS if learning takes place. Pavlovian conditioning in animals has been an important test bed for attentional models of associative learning and has yielded several phenomena that strongly suggest changes in attention to the CS (e.g. in relation to *unblocking*; Dickinson, Hall & Mackintosh, 1976; Dickinson & Mackintosh, 1979; Holland, 1984, 1988; Mackintosh & Turner, 1971). Overt attentional changes during Pavlovian conditioning, such as orienting responses made by rats to the CS, also appear to conform to predicted changes in CS processing (Kaye & Pearce, 1984). However, it is not clear whether incidental learning in humans can sustain changes in attention in quite the same fashion. Attentional studies looking specifically at the effects of learning stimulus relevance have employed intentional learning, where feedback is dependent on the responses made to the CS and participants actively seek solutions to the task at hand in a trial-and-error fashion. In such studies, attending to relevant stimulus dimensions or previously predictive stimuli is of some obvious benefit to the participant, such as allowing improved performance (e.g. Rehder & Hoffman, 2005) or decreasing attentional load without sacrificing performance (e.g. the blocking studies by Kruschke et al, 2005). But should one expect to see more automatic

changes in CS processing that accompany associative learning even if those changes have no obvious or direct benefit to the human subject? A more specific and potentially more controversial variant of the same question might be to ask whether attentional changes accompany *implicit* learning of CS-US contingencies.

Implicit learning typically describes learning that occurs incidentally, in the absence of conscious hypothesis testing and conscious rule abstraction, and yielding knowledge that does not necessarily require conscious thought processes (e.g. Shanks & St John, 1994; for a recent summary, see Perruchet, 2008). To date, studies of the relationship between implicit learning and attention have been concerned with very different aspects of attention, such as attentional load and the effects of instructed selective attention. The former concerns the effect of cognitive capacity limitations on implicit learning (Frensch, Buchner, & Lin, 1994; Jiménez & Méndez, 1999; Shanks & Channon, 2002; Shanks, Rowland & Ranger, 2005), while the latter examines whether voluntary selective attention to a particular task determines what can be learned implicitly (Jiang & Chun, 2001; Jiang & Leung, 2005; Jiménez & Méndez, 1999). Indeed there is some disagreement over whether implicit learning should be defined as learning that does not load on limited attentional resources, rather than in terms of awareness or conscious intent (e.g. Frensch, Lin, & Buchner, 1998; Cleermans, 1997; Shanks & Channon, 2002). In contrast, the present experiments primarily investigated the effect of implicit learning on attentional processing of the CS, particularly in relation to the AB. Nonetheless, the effect of attentional selection of the CS on learning was also examined by comparing learning to targets and distractors. As will be discussed, these comparisons bear some resemblance to studies of the effect of voluntary selective attention on implicit learning.

While most implicit learning studies that employ reaction time as a key performance measure concern the learning of complex

sequences (e.g. Willingham, Nissen, & Bullemer, 1989), we have employed a Pavlovian conditioning approach with a simple CS-US contingency, in general agreement with the rationale outlined by Boakes, Roodenrys, & Barnes (1995). In particular, conscious knowledge of a simple CS-US relationship can be assessed with a high degree of confidence and sensitivity, and the learning of the association itself is theoretically tractable, which is particularly important in this case for relating learning to attentional change. We will return to the issue of contingency awareness in the general discussion. For the time being, it will suffice to say that we intend to demonstrate changes in attention accompanying the acquisition of associative priming in conditions that make it unlikely that participants acquire conscious knowledge of the relevant contingencies which might otherwise sustain a conscious intent to search for the predictive CSs. In this sense, the learning that accompanies the attentional changes observed in the following experiments may be considered implicit in nature.

Experiment 1

Experiment 1 investigated whether learning could be shown to a predictive target and a predictive distractor, and to gauge how learning might affect target detection accuracy across differences in serial position separating the two target letters (i.e. the *lag* between T1 and T2). A simple motor priming effect was taken as the critical evidence for learning; that is, whether participants responded faster on trials that contained a target or distractor that signaled which response would be required than on control trials with no predictive item. With this in mind, the choice of appropriate controls was extremely important because the frequency of presentation of items in RSVP has a clear effect on the ease with which an item is processed (e.g. Crebolder et al, 2002). Frequency differences could affect both target detection accuracy and the speed with which a subsequent response is executed.

Therefore, control trials contained a non-predictive target or distractor, matched in each case to the frequency of presentation (and all other temporal characteristics of presentation) of the predictive letters. As shown in Table 1, trials containing a predictive T2 target (Tp) and trials containing a predictive distractor item (Dp) each made up 20% of the overall number of trials. Trials with the control targets and distractors, referred to as Tf and Df respectively (i.e. frequency matched controls), each occurred on another 20% of trials. In Experiment 1, presentation of Tp was always followed by a left response cue on the Cued Reaction Time (CRT) task, while presentation of Dp was always followed by a right response cue. In contrast, Tf and Df were followed by left and right CRT cues 50% of the time, and as such were completely non-predictive. Since Tp always signaled left in this experiment, only the Tf trials on which a left response was required were used to calculate mean reaction times. This avoids any issue of overall biases towards making left responses more quickly or slowly than right responses, which could produce artefactual RT differences between Tp and Tf. Similarly, only Df trials with right responses were used to compare with Dp trials.

The design of the experimental trials allowed concurrent assessment of response speed on the CRT task and accuracy reporting the targets in the RSVP sequence. A post-experiment questionnaire, used to gauge the general level of conscious knowledge of the contingencies between the predictive items and responses, followed immediately after the completion of the final experimental trial.

Method

Participants

Thirty-four students at the University of Sydney participated in the experiment in return for course credit. All were naïve to the aims of the experiment. Exclusion criteria were established to rule out participants who performed very poorly on either of the target

detection or speeded response tasks. If a participant correctly reported less than 40% of T1 targets, gave the incorrect CRT response on more than 20% of trials, or failed to respond within 1000 ms on more than 20% of correct CRT responses, then their data was discarded. These criteria were used for both experiments. In Experiment 1, two participants were excluded for one or more of these criteria. All analyses were conducted on the remaining 32 participants.

Apparatus

Participants were tested individually in a dimly-lit room. The experiment was run on a Dell Optiplex desktop computer with 17 inch cathode ray tube monitor running at 85Hz refresh rate. Participants sat approximately 50 cm from the screen. Responses were made using a standard computer keyboard (the two control keys served as the left and right CRT response keys). Audio feedback for CRT responses was delivered through headphones.

Stimuli and Design

Each RSVP sequence consisted of serial presentation of 10 uppercase letters (Arial font, size 72), each appearing in the center of the computer screen. Each sequence began and ended with an additional hash (#) visual mask. Each letter appeared for approximately 106 ms and was immediately replaced by the next letter in the sequence. In each sequence, the two targets were red, and distractors were white, all against a black background. All letters of the alphabet were used in the experiment except the letters I, M, W (which were deemed to be too discriminable from the other letters), and Q (which was deemed too confusable with the letter O).

The design of the experiment involved the five trial types shown in Table 1. For each participant, four letters were randomly assigned to act as a predictive target (Tp), a non-predictive target matched for frequency (Tf), a predictive distractor (Dp), and a non-predictive distractor matched for frequency

(Df). On their respective trials, Tp and Tf always appeared as the second target in the sequence (T2). Dp and Df always appeared as a white distractor towards the end of the

letter sequence. All other distractors and targets were randomly chosen without replacement (i.e. could only appear once per trial) from the remaining letters.

Table 1. Trial design for Experiment 1, showing the trial sequence for each of the 5 trial types. In each RSVP sequence, d denotes a distractor presented in white, T1 and T2 denote the two red target letters. The 4 bold underlined letters (**T2** on Tp and Tf trials, **d** on Dp and Df trials) represent 4 pre-allocated letters that remained constant throughout the experiment. All other letters (T1, and remaining T2 and d letters) were randomly chosen on each trial (without replacement) from the pool of remaining letters. The *cue* represents the Left or Right response cue appearing immediately after the # mask at the end of the RSVP sequence. T2 appeared equally often in serial positions 8, 9 and 10 throughout the experiment (as did the meaningful distractor on Dp and Df trials). T1 appeared in position 3 for the first 60 blocks and then equally often in positions 3, 6, and 7 for the final 45 blocks. Each trial type occurred equally often (once per randomized block of trials).

| Trial Type | RSVP sequence | Left/Right cue |
|------------|---|---------------------|
| Tp | # d d T1 d d d d d T2 d # <i>cue</i> | 100% Left |
| Tf | # d d T1 d d d d d T2 d # <i>cue</i> | 50% Left/ 50% Right |
| Dp | # d d T1 d d d d d d T2 d # <i>cue</i> | 100% Right |
| Df | # d d T1 d d d d d d T2 d # <i>cue</i> | 50% Left/ 50% Right |
| Random | # d d T1 d d d d d T2 d # <i>cue</i> | 50% Left/ 50% Right |

Trial order was organized in blocks of 5 trials, each block containing one Tp, Tf, Dp and Df trial, plus one Random trial on which all targets and distractors were chosen randomly (but excluding the letters assigned as Tp, Tf, Dp, and Df). Within each block, trial order was randomized. There were 105 blocks in total (meaning 105 presentations of each of the relevant targets and distractors).

T2 appeared equally often in serial positions 8, 9, or 10 across all trials of each trial type. Dp and Df also appeared in serial positions 8, 9, or 10 so that the average interval between CS onset and response cue onset was effectively identical for all four CSs (Tp, Tf, Dp, and Df). Participants were first “trained” on the task over 60 presentations of each trial type, using relatively long lags. For this initial training phase, T1 appeared in serial position 3, meaning that T2 occurred 5-7 serial positions after T1. This was immediately followed by a “test” phase comprised of a further 45 presentations of each trial type, for which T1 appeared in positions 3, 6 or 7,

organized in such a way that the lag ranged from 1 – 7.

Procedure

On arrival, participants were told they were participating in an experiment investigating attention and changes in attention with experience. They were told that they would be completing numerous trials on which they would have to perform two attentionally demanding tasks simultaneously. Instructions and a block of 6 practice trials were first given to introduce the speeded response task and the target identification task separately. Further instructions and practice trials were then given combining the two tasks, followed by commencement of the real experimental trials. After every 75 trials, participants were given a rest break of at least 1 min. The transition from the first 60 training blocks to the final 45 test blocks was not otherwise signaled.

Each trial began with the appearance of two response prompts: unfilled white circle outlines appearing on the left and right sides

of the screen. After 1 sec, an asterisk prompt appeared in the center of the screen for 250 ms, followed by the serial presentation of the letter sequence. Immediately after the presentation of the final RSVP item (the # mask), one of the circular response prompts was filled in (i.e. the response cue was the “lighting up” of one of the circles), indicating which rapid response needed to be made (see Figure 1). The participant then responded to this cue by pressing the appropriate key on the keyboard. Auditory feedback for this

response was then presented; a correct response was met with a “chime”, while an incorrect response was met with a buzzer sound. Following the speeded response, “T1?” appeared in the center of the screen, indicating that the participant should type in the first target letter. On typing in a letter, “T2?” appeared in the center of the screen, prompting a report of the second target. No feedback was given for the target detection responses.

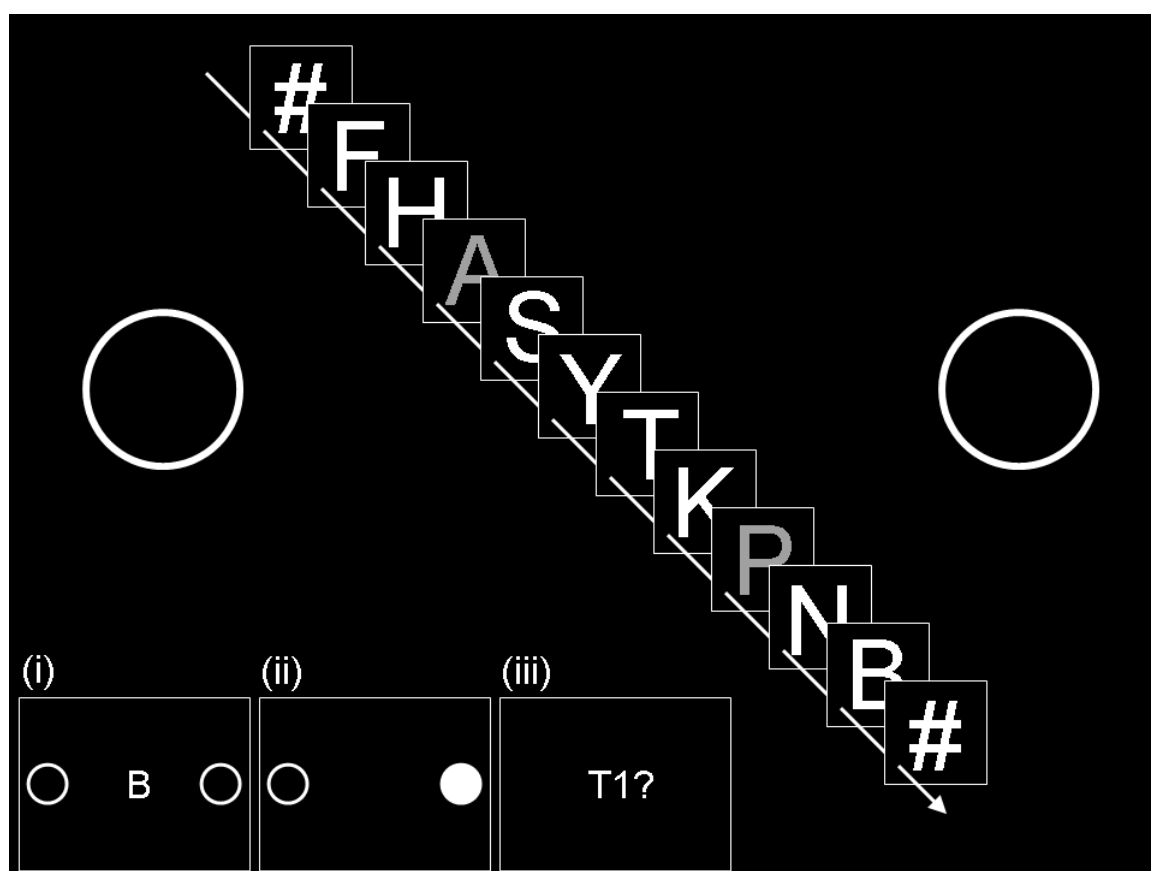


Figure 1. Diagram representing the sequence of events on each trial. Main panel shows a typical sequence of letters presented in RSVP (the red target letters appear in grey), with response prompts to the left and right of the screen. Smaller panels show the sequence of events: (i) letters and masks appear serially in the center of the screen, (ii) the final mask (hash) is followed immediately by a response cue; either the left or right circle “lighting up”, then (iii) after a rapid response is made to the response cue, participants are asked to report T1 and T2 in turn.

On completion of all 525 trials, participants were given a post-experiment questionnaire, asking them to verbalize their knowledge of the CS-US contingencies. The first question asked “Did you notice a relationship between any of the letters and the response that

followed (i.e. whether you had to press left or right more or less if certain letters appeared)? If so, please describe”. Questions 2, 3, and 4 asked if the participant had noticed certain letters occurring more frequently than the others; either generally throughout the

experiment (q2), specifically as the second target (q3), or specifically as distractors near the end of the letter sequence (q4). These questions were added as they focus attention on those letters that appear relatively often. Pilot work suggested verbal report of target frequency was better than report of target-response contingency, so encouraging participants to think about frequently presented letters may help to verbalize contingency knowledge in the subsequent questions. Question 5 asked the following: *“One letter that appeared as T2 consistently predicted one of either the left or the right responses (in other words, whenever this letter appeared as a target, it was always followed by the same response). Which letter was it and which response did it predict (guess if you are not sure)?”*. Question 6 asked essentially the same question about a white distractor letter appearing towards the end of the letter sequence. Questions 1 and 5 were the most relevant in gauging verbalizable knowledge of the Tp-left response contingency, and likewise, questions 1 and 6 for the Dp-right response contingency. As will be discussed, these questions are not the most sensitive for measuring awareness of the CS-US contingencies, but serve a valid purpose in gauging to what extent participants can verbalize whatever knowledge they may have acquired about those contingencies.

Data analysis

The critical comparisons of reaction time and target detection accuracy were based on means from the test phase. Although RT distributions are typically positively skewed, the mean of the RT distribution is a conventional measure of response speed for within subjects comparisons and is perfectly valid provided there is no reason to assume the skewness of the distributions differs appreciably between conditions. Nevertheless, it is noteworthy that median RTs yielded very similar patterns of results to mean RTs for all the experiments reported here. RT and target detection accuracy data were analyzed with repeated measures

ANOVA in this and all subsequent experiments. The alpha level for statistical significance was $p < .05$ for all analyses.

Results and Discussion

Response Times

Correct CRT responses with a reaction time of less than 1000ms were used in calculating mean reaction times for each condition. As stated, since Tp always predicted a left response and Dp always predicted a right response, only the left responses to Tf and the right responses to Df were used in the analysis. This eliminated the chance that a mean difference between conditions might be obtained merely through an overall bias towards responding faster for left or for right (though in actual fact, calculations using left and right response times yielded similar results to those reported below).

Figure 2 shows mean reaction time calculated across successive 15-block bins. Reaction time decreased with practice over the training blocks, while the introduction of shorter lag trials after block 60 appears to have resulted in a sharp increase in reaction times. Mean reaction times over the last 45 blocks (test phase) were used for comparing the predictive and non-predictive conditions. Over this test phase, response times on Tp trials (332.1 ms) were 15.5 ms faster than response times on Tf trials (347.6 ms), and this difference was significant ($F_{1,31} = 11.792$, $p = .002$, $\eta_p^2 = .276$). Response times on Dp trials, however, did not reliably differ from response times on Df trials ($F_{1,31} = 2.654$, $p = .113$, $\eta_p^2 = .079$).

Facilitation of the speeded response on Tp trials suggests that learning of the Tp-Response association occurred as predicted. On the other hand, there was no evidence that anything was learned about Dp, as reaction times for Dp, Df and random trials were all closely matched. Response times on random trials did not significantly differ from response times on either Tf or Df trials ($F_s <$

1), indicating that the mere frequency of the CS had little effect on response speed.

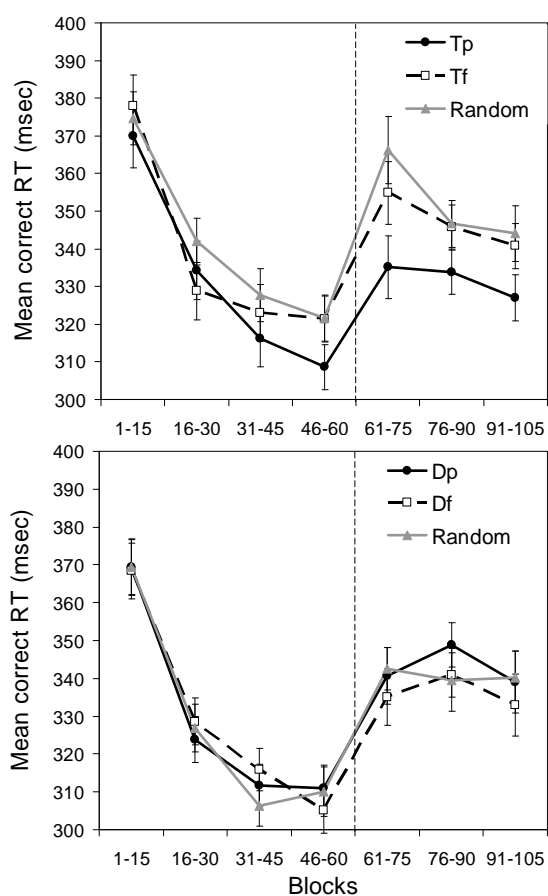


Figure 2. Mean correct response times across blocks of Experiment 1. Top panel: Trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), or with random T2 (Random). Bottom panel: Trials with the predictive distractor (Dp), with the control distractor matched for frequency (Df), or with random distractors (Random). Mean RTs were calculated only for left response trials for the top panel (as Tp always predicted a left response) and only for right response trials in the bottom panel (as Dp always predicted a right response). Error bars on all figures display SEMs for within subjects comparisons (Tf-Tp for Tp and Tf; Df-Dp for Dp; Random-Tp/Dp for Random) (e.g. see Loftus & Masson, 1994).

Participants performed the CRT task with a very high degree of accuracy (mean across all trials = 97.4%) and generally made equally few

errors for each trial type. On average, participants made a total of 3.13 (out of 105) CRT errors for Tf trials versus 2.56 errors for Tp trials, though this difference did not approach significance ($F_{1,31} = 1.172$). Thus there is no evidence of a speed-accuracy trade-off that could explain the difference in reaction time between Tp and Tf trials - Tp trials were responded to faster, but no less accurately, than Tf trials.

Target Detection

On each trial, report of a target letter was considered correct if it was reported as either T1 or T2 (regardless of the actual order). Overall mean report accuracy for T1 was 87.4% and did not differ appreciably according to the type of trial or the lag between T1 and T2 (all F s < 1). Figure 3 shows conditional T2 report accuracy, calculated from those trials on which T1 was correctly reported, as a function of the lag separating T1 and T2. Conditional T2 accuracy (T2|T1) is conventionally used in the AB literature as it restricts analyses to those trials on which we can assume processing of T1 has occurred. As expected, lag was clearly an important factor in T2|T1 accuracy, as all 5 trial types yielded poorest performance at lag 2 and then improved across lags (with best performance at lag 7). It is also immediately apparent, looking at the top panel of Figure 3, that both Tp and Tf were more accurately reported than Random trial targets. This difference in T2|T1 accuracy between Tf and Random trials would suggest an effect of T2 frequency alone because, on both these trial types, targets do not predict the CRT outcome. Analyses with T2 frequency (Tf vs Random) and lag (lags 1-7) as factors yielded strongly significant effects of lag ($F_{6,186} = 26.095$, $p < .001$, $\eta_p^2 = .457$) and T2 frequency ($F_{1,31} = 36.471$, $p < .001$, $\eta_p^2 = .541$), and a significant interaction ($F_{6,186} = 2.30$, $p = .036$, $\eta_p^2 = .069$), which reflects the fact that the difference between Tf and Random targets was less pronounced at longer lags, where accuracy was generally higher. This confirms a strong effect of the frequency of occurrence of T2 on report accuracy, and highlights the importance of

using a control cue that is matched for frequency.

Of greater interest in this case, however, is the difference in report accuracy between Tp and Tf, which occurred equally often throughout the experiment. At short lags, particularly lag 2, Tp appears to be more accurately reported than Tf. However, analyses with trial type (Tp vs Tf) and lag (1-7) as factors reveal only a significant effect of lag ($F_{6,186} = 22.369, p < .001, \eta_p^2 = .419$; other $F_s < 1$).

One should only see a difference in target detection between Tp and Tf if participants actually learned about Tp. Thus it is reasonable to expect that a target detection effect might be more evident in those participants who displayed stronger priming of Tp, relative to Tf. Therefore, further analyses of the Tp and Tf trials were conducted by splitting the participants into equal groups according to whether they displayed relatively good or relatively poor evidence of learning in terms of RT differences between Tp and Tf trials. A median split of the participants was performed, based on the difference in RT during the test phase between Tp and Tf. The middle panel of Figure 3 shows T2|T1 accuracy for the upper half of participants divided in this manner. Furthermore, a simplified analysis can be conducted using only lags 2 and 7, which assays the extent of the AB. As discussed, the typical AB function for relatively simple dual-target tasks such as this one tends to display the strongest impairment in T2 processing at Lag 2, with performance improving to an asymptotic level at longer lags. We therefore have a strong *a priori* reason for focusing particularly on Lag 2 and comparing it to the longest lag tested (i.e. lag 7 in this case), which is confirmed by the data, showing a very pronounced impairment, specifically at Lag 2. For the upper half of participants (split on RT priming of Tp), the simplified analyses using lags 2 and 7 now yielded a significant main effect of trial type ($F_{1,15} = 7.289, p = .016, \eta_p^2 = .327$) and marginal interaction between trial type and lag ($F_{1,15} = 3.596, p = .077, \eta_p^2 =$

.193). A planned comparison of Tp and Tf at lag 2 was also significant for these participants who showed better evidence of learning ($F_{1,15} = 5.971, p = .027, \eta_p^2 = .285$). There was no such effect for the lower half of participants who showed relatively poor evidence of learning ($F_{1,15} < 0.1$). This provides some evidence that learning about Tp improves that target's detectability at the point where the AB is expected to be strongest.

In comparison, target detection accuracy on Dp and Df trials very closely resembles accuracy on Random trials, as can be seen in the bottom panel of Figure 3. Similar analyses as those used above (for comparisons between Tp and Tf and between Tf and Random trials) were also used to compare Dp with Df trials, and Df with Random trials. None of these analyses yielded any significant effects or interactions other than a main effect of lag. Given the absence of a priming effect for Dp trials, it is not surprising that Dp and Df trials were closely matched for target report accuracy. Recall that both Dp and Df trials used random targets for T2, and merely involved the systematic presentation of a white distractor letter (predictive of the CRT outcome in the case of Dp) near T2 in the sequence. This manipulation (i.e. frequently seeing a particular distractor either immediately before or after T2) also appears to have had no effect on T2 report accuracy.

Awareness Questionnaire

The overall level of verbal report of the predictive relationships was very low. Only one out of 32 participants reported noticing a relationship between a particular letter and response (the participant also correctly reported the letter and response when prompted). A further four participants were able to guess the correct letter (Tp) and the response that it predicted (left) when told that such a relationship did exist. Three out of these five participants who displayed at least some knowledge of the contingencies also yielded priming effects (Tf vs Tp) greater than the overall mean. However, the remaining 27 participants still showed a significant priming effect (Tf vs Tp: $F_{1,26} = 8.58, p = .007, \eta_p^2 =$

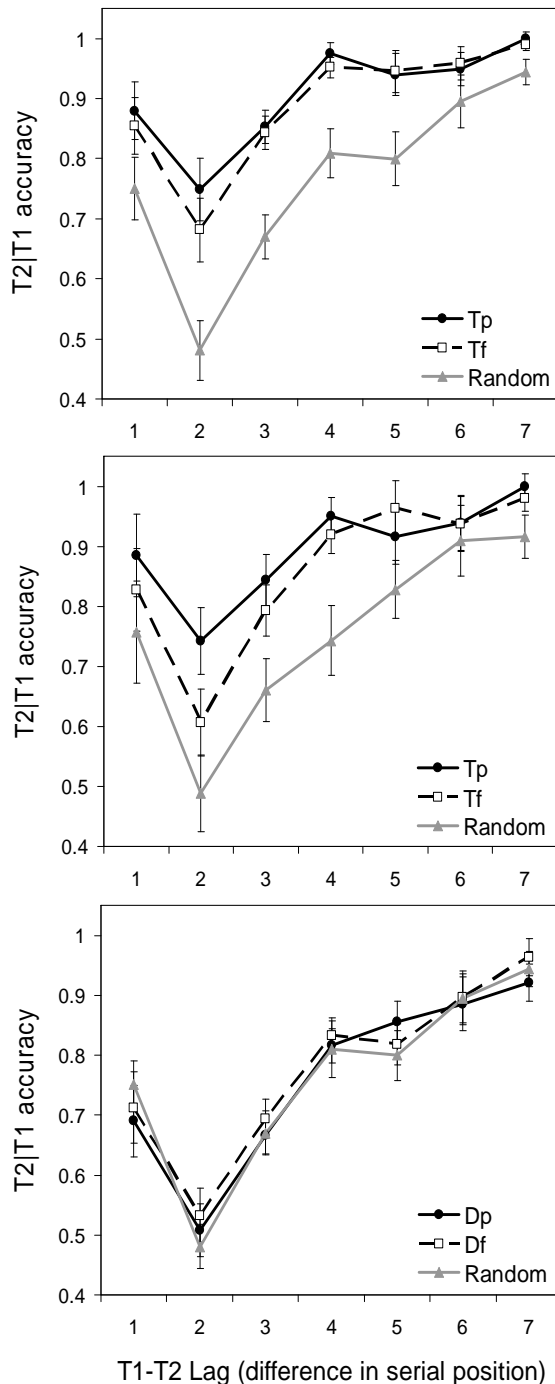


Figure 3. Target detection during test phase of Experiment 1: figures show mean conditional T2 accuracy (T2|T1 accuracy) across different lags, expressed as the difference in serial position of the two targets. Top panel: Mean results for all participants on Tp, Tf and Random target trials; Middle panel: Mean results of the “better learners”, identified by a median split of all participants on the Tp vs Tf RT priming effect; Bottom panel: Mean results for all participants on Dp, Df and Random target trials.

.248) and one of comparable magnitude to the overall mean. A further 6 participants, only one of whom showed a priming effect greater than the mean, reported the Tp letter but failed to report the correct response that Tp predicted. Thus 11 participants in total reported Tp as being predictive at some stage in the questionnaire (in comparison, seven participants reported Tf as a predictive letter). Excluding these participants, the remaining 21 still showed a significant priming effect of around 19 ms (Tf vs Tp: $F_{1,20} = 13.37$, $p = .002$, $\eta_p^2 = .401$). Five of these excluded participants fell in the top half of participants split on RT priming of Tp (i.e. the group that showed clearest evidence of a target recognition advantage for Tp). For the remaining 11 participants in the top half, the Tp advantage at lag 2 was still numerically evident (63.4% accuracy for Tp vs 54.4% accuracy for Tf) but with the reduced sample size, the difference between Tp and Tf was no longer significant ($F_{1,10} = 3.08$, $p = .11$, $\eta_p^2 = .236$), nor was the interaction between lag (2 vs 7) and trial type (Tp vs Tf) ($F_{1,10} < 1$).

Experiment 2

Following the evidence in Experiment 1 for learning of the target-response relationship and for a target detection advantage for Tp during the AB, Experiment 2 examined target detection performance in more depth, particularly with a short lag between T1 and T2. This time, only two lags (T2 occurring 2 & 5 serial positions after T1) were used throughout the experiment. If learning the signal validity of a target facilitates recognition of that target during the AB, then Tp should be more accurately recognized than Tf, especially at Lag 2.

As in Experiment 1, trials combining RSVP and CRT tasks were used to establish a predictive relationship between one target letter (Tp), appearing on one in every five trials, and a cued response, as well as a predictive relationship between one distractor letter (Dp), also appearing on one in five trials, and the opposite cued response. In Experiment 2, however, a final test phase of RSVP-only trials was added, during which no speeded

left/right responses were required. The rationale for this was to eliminate the effect of interference from the CRT task on target detection and report. Performing the speeded response as quickly as possible is attentionally demanding, and probably interferes with target retention to some degree. This means that the CRT task could potentially mask any differences in target accuracy as it adds an extra source of variability. Moreover, it raises the possibility that target detection differences may actually be a direct result of performing the CRT task. Learning the predictive relationship between T_p and response presumably improves the ease with which that response is made, allowing for faster reaction times. It follows that, if the response is made more easily, then it also requires less limited capacity resources to perform and thus interferes less with the retention of targets in working memory, affording better target report. Increased accuracy for T_2 on trials where the response is signaled could thus be an artifact of making that response easier to execute. However, if target detection differences should persist when the speeded responses are removed then it would point to a more persistent change in stimulus processing.

The rate of presentation of distractors and targets was also increased in Experiment 2. Target detection performance for T_p and T_f was near ceiling at most lags in Experiment 1, and indeed some participants showed perfect performance for these targets even at lags where an AB was expected. Assuming that the target detection effect observed in Experiment 1 is real and attributable to learning about T_p , it is not entirely clear whether the effect is specific to the AB or more general and potentially observable at all lags, but masked by ceiling accuracy levels. Thus all trials in Experiment 2 (and most notably the RSVP-only trials) were made considerably more difficult by increasing the rate of presentation of the RSVP sequence.

Results from Experiment 1 suggested that a lag of 2 represents the point at which the AB should be strongest and also where the

difference in detection accuracy between T_p and T_f is strongest. This difference had more or less disappeared at lags of 4 or 5. In Experiment 2, Lag 5 was chosen to compare with Lag 2 performance. By reducing the SOA between each letter to 82 ms in the final phase, performance at this lag should be well below ceiling, and have similar temporal offset between T_1 and T_2 as Lag 4 in Experiment 1 (i.e. approximately 410 ms). While this means that the Lag 5 condition also falls within the temporal bounds in which one might expect an AB, this is of little concern if a clear interaction between stimulus validity and lag is demonstrated. If the effect of signal validity on target detection is specific to short lags, then the difference in detection accuracy between T_p and T_f should be greater at lag 2 than lag 5.

It became evident in Experiment 1 and in a series of unrelated RSVP experiments that we have also conducted, that accuracy for identifying target letters on any given trial is largely dictated by the distinctiveness of the letters themselves. Although some letters had been excluded on the basis of their distinctiveness (namely M, W, I and Q), it was also clear that others were either relatively easy to detect at all lags, or difficult to detect at most lags. A large proportion of the variance in target detection differences comparing T_p and T_f might therefore be attributed to the properties of the randomly assigned letters. To minimize this unwanted variability, in Experiment 2 the relevant CSs (T_p , T_f , D_p , and D_f) were randomly chosen from a pool of just 4 letters selected for their intermediate and roughly equivalent levels of detectability. On the basis of accuracy levels measured over a series of very similar RSVP experiments, the letters C, D, P, and U were chosen, and represented the four CSs for all subjects. All other targets and distractors were chosen randomly from the remaining letters in the same fashion as Experiment 1.

In addition, the responses predicted by T_p and D_p were randomly allocated in Experiment 2, rather than being fixed to T_p -Left and D_p -Right, as in Experiment 1. This eliminates the

reason for using only half the Tf and Df trials (i.e. the half on which the same response was made) because there is no longer a reason for suspecting that a pre-existing systematic group bias in left vs right response speed might favor or hinder responses to either Tp or Dp. Using the full set of data for Tf and Df permits a more reliable estimate of RT for the control conditions. The change is also advantageous because it permits a direct comparison of priming effects for Tp and Dp, since responses to the CSs are equivalent at a group level, even though Tp and Dp predict opposite responses for individual subjects.

The post-experiment questionnaire used in Experiment 1 was useful for ruling out conscious rule-abstraction or intentional strategies as a source of learning, given the lack of contingency knowledge that participants were able to express. However, a more sensitive measure of contingency awareness may be desirable to determine whether, say, poorly retrieved contingency knowledge or vague awareness influence the priming effect. In Experiment 2, participants were given a further set of two-alternative forced choice (2AFC) questions, where the CS was provided and participants were asked to guess which response (out of left and right) was predicted by that CS. This measure gives an indication of whether the sample as a whole showed above-chance accuracy on a sensitive measure of contingency awareness, and was also used to compare priming effects from the groups who reported the correct and

incorrect responses. The absence of any influence of awareness, as assessed by this measure, would help to confirm that learning in this case was entirely incidental.

Method

Participants and Apparatus

Thirty undergraduate psychology students at the University of Sydney participated in the experiment in return for course credit. Four participants were excluded from the final analyses because they performed very poorly on one or both of the target detection and CRT tasks, using the criteria from Experiment 1. All analyses were conducted on the remaining 26 participants. Apparatus and testing conditions were the same as in Experiment 1.

Design and Stimuli

Trial design, as shown in Table 2, again consisted of 5 trial types, with one predictive target trial type (Tp), one predictive distractor trial type (Dp), corresponding control trials matched for frequency (Tf and Df), and random trials. The individual trial sequence was identical in appearance to that used in Experiment 1, except for the following changes. Each RSVP sequence consisted of 12 (rather than 10) uppercase letters, flanked by # masks. In Experiment 2, the letters and masks were presented at a rate of one every 94ms (cf. 106 ms in Experiment 1) in the response phase and one every 82ms in the target -

Table 2. Trial design for Experiment 2, showing the trial sequence for each of the 5 trial types. T2 appeared equally often in serial positions 8, 9, and 10 throughout the experiment (as did the meaningful distractor on Dp and Df trials). T1 always preceded T2 by either 2 or 5 serial positions (equally often for each trial type). Participants were randomly allocated Left and Right as Response 1 and Response 2 or vice versa.

| Trial Type | RSVP sequence | Left/Right cue |
|------------|--|-----------------|
| Tp | # d d d d T1 d d d d T2 d d # cue | 100% Response 1 |
| Tf | # d d d d T1 d d d d T2 d d # cue | 50% R1/ 50% R2 |
| Dp | # d d d d T1 d d d d T2 d d # cue | 100% Response 2 |
| Df | # d d d d T1 d d d d T2 d d # cue | 50% R1/ 50% R2 |
| Random | # d d d d T1 d d d d T2 d d # cue | 50% R1/ 50% R2 |

-detection only phase. The serial position of T2 varied from trial to trial, appearing at positions 8, 9, and 10 equally often for each trial type. The position of the pre-allocated distractor letter on Dp and Df trials also varied between positions 8, 9, and 10 throughout the experiment. For each trial type, T1 was presented 2 serial positions before T2 on half of the trials and 5 serial positions before T2 on the other half of trials. This time, audio feedback for the CRT task was accompanied by visual feedback; the response prompt corresponding to the response made by the participant lit up green if correct or red if incorrect. As with the audio feedback, this was mainly to assist in maintaining accurate responding and concentration on the CRT task.

Procedure

On arrival, participants were given instructions and practice trials as in Experiment 1. Each participant was randomly allocated to a response condition such that Tp predicted either left or right and Dp predicted the opposite, and the letters C, D, P, and U were randomly allocated to the roles of Tp, Tf, Dp, and Df. Each participant completed 96 blocks (480 trials) of the combined RSVP-CRT task, with a rest break of at least 1 min every 24 blocks. On completion of the CRT trials, a further 1 min break was given, followed by instructions for the final RSVP-only phase. Participants were instructed that they would no longer be required to make speeded left/right responses, but that they should continue to perform the target recognition task as they had been doing. The 24 blocks of RSVP-only trials were identical in appearance to the CRT trials except for the omission of the response prompts (the empty circles appearing on either side of the screen at the start of the trial) and the response cue, and the accelerated rate of presentation.

On completion of the RSVP-only phase, participants were given a post-experiment questionnaire assessing awareness of the letter-response contingencies and letter frequencies. The same questions were asked as in Experiment 1, but a further set of

questions was added asking the participant to judge which response (out of left and right) was more likely to follow a given letter when it appeared in a sequence. Participants were asked in turn about the letters P, U, D, and C, two of which were actually predictive of a response. Note that for each of the Tp and Dp letters, participants had a 0.5 probability of correctly guessing the answer to this 2AFC question.

Results and Discussion

Response Times

Figure 4 shows mean reaction time for each of the trial types across the course of the CRT trials. It is evident that responses were faster on Tp trials than on Tf trials, particularly over the second half of the experiment, while responses were no faster on Dp trials than on Df or Random trials. Figure 5, which shows mean correct RT over the second half of the CRT trials (blocks 49-96), indicates that Tp trials were generally met with faster responses regardless of whether they were presented with a lag of 2 or 5 serial positions between T1 and T2. A repeated measures ANOVA of mean correct RT over the second half of the Tp, Tf, Dp, and Df trials was conducted with lag (lag of 2 or 5), CS identity (target or distractor), and trial type (predictive or non-predictive control) as within-subjects factors. This yielded significant main effects of lag ($F_{1,25} = 26.416, p < .001, \eta_p^2 = .514$) and CS identity ($F_{1,25} = 4.401, p = .046, \eta_p^2 = .150$), and a significant interaction between CS identity and trial type ($F_{1,25} = 5.682, p = .025, \eta_p^2 = .185$). No other main effects and interactions approached significance (largest $F_{1,25} = 1.351, p = .256, \eta_p^2 = .051$). The significant interaction suggests that the difference in RT between predictive and non-predictive trials depends on whether the CSs were targets (Tp/Tf) or distractors (Dp/Df). Further analyses looking solely at Tp and Tf yielded significant main effects of lag ($F_{1,25} = 28.570, p < .001, \eta_p^2 = .533$) and trial type ($F_{1,25} = 5.850, p = .023, \eta_p^2 = .190$), but no interaction ($F < 1$), confirming that reaction times to Tp (345.9 ms at lag 2; 316.0 ms at lag 5) were significantly faster than to Tf (363.0

ms at lag 2; 327.7 ms at lag 5), and that this priming effect (17.0 ms at lag 2; 11.7 ms at lag 5) was not significantly affected by the lag at test. Further analyses of Dp and Df reveal a significant effect of lag ($F_{1,25} = 19.256$, $p < .001$, $\eta_p^2 = .435$) but no main effect of trial type or interaction (larger $F_{1,25} = 1.437$, $p = .242$, $\eta_p^2 = .054$).

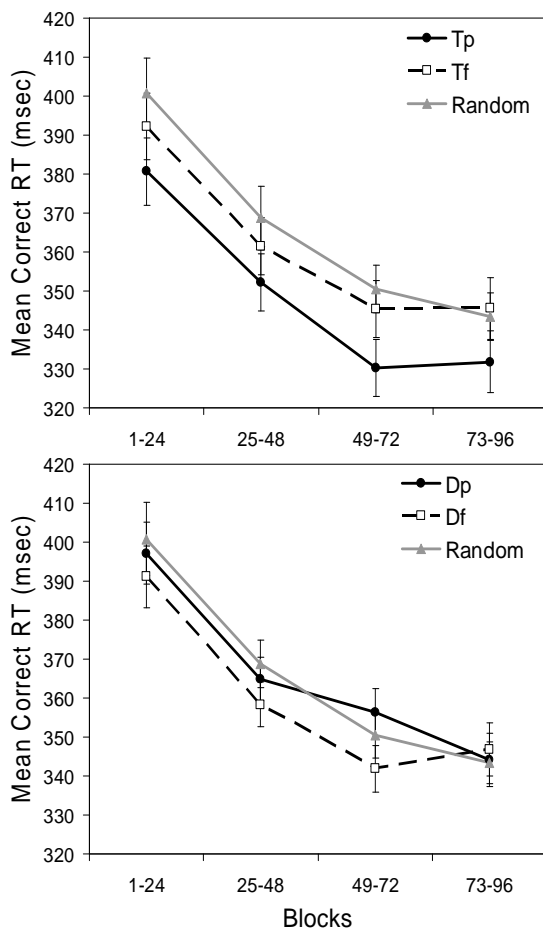


Figure 4. Mean correct response times across blocks of Experiment 2. Top panel: Trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), or with random T2 (Random). Bottom panel: Trials with the predictive distractor (Dp), with the control distractor matched for frequency (Df), or with random distractors (Random).

These analyses reveal a significant priming effect for the predictive target Tp, and significantly more priming for Tp than the predictive distractor Dp (for which we have no evidence of any priming). The main effects of lag in each of these analyses confirms that RTs were significantly faster on trials with the

longer lag, which suggests that difficulty of target detection has an effect on the speed of performing the subsequent CRT task. However, lag did not appear to influence the expression of priming on Tp trials, as the difference between Tp and Tf did not significantly differ as a function of test lag.

Accuracy of CRT responses in Experiment 2, though slightly lower than Experiment 1, was still high (mean over all trial types = 92.9%). Again, error rates for each trial type were very closely matched. Repeated measures analyses with test lag, CS identity, and trial type as factors failed to yield any significant main effects or interactions (largest $F_{1,25} = 1.397$). Over the second half of the CRT trials, participants made on average 1.76 errors on Tp trials (out of 48) compared to 1.65 errors on Tf trials. Neither this difference, nor the difference in errors between Dp and Df trials approached significance ($F_s < 1$). Thus, in Experiment 2, it seems that Tp trials were responded to faster but no less accurately than Tf trials, while Dp and Df trials were responded with equivalent speed and accuracy.

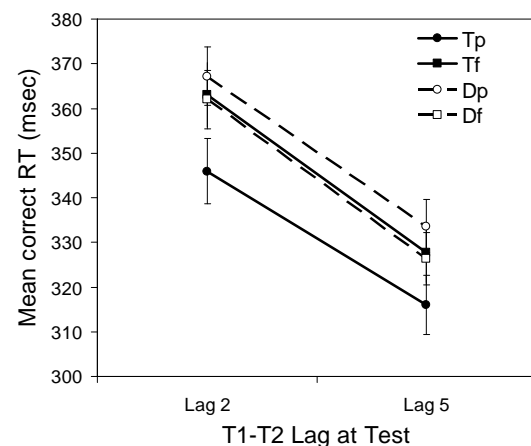


Figure 5. Mean correct response times over the second half of CRT trials in Experiment 2, separated according to the lag on each trial (lag 2 or lag 5). Trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), with the predictive distractor (Dp), or with the control distractor matched for frequency (Df).

Target Detection

Overall mean accuracy for T1 during the RSVP-only phase was 70.6% and did not noticeably

vary according to either trial type or lag (all $F_s < 1$). Figure 6 plots conditional T2 accuracy (T2|T1) for the different trial types. Looking at the top panel, which shows the performance in the last 24 blocks (i.e. the RSVP-only trials) for each of the 5 trial types, a frequency effect is again evident, with accuracy for Tp and Tf generally higher than the other trial types. Comparing Tf and Random trials, a 2 x 2 ANOVA with T2 frequency (Tf vs Random) and lag (2 vs 5) as factors yielded significant main effects of T2 frequency and lag (smaller $F_{1,25} = 13.145$, $p = .001$, $\eta_p^2 = .345$) but no interaction ($F < 1$), suggesting the difference between Tf and Random trials was irrespective of lag. As predicted, a large difference in target accuracy between Tp and Tf is also evident at lag 2. Comparing Tp and Tf, a 2 x 2 ANOVA with trial type (Tp vs Tf) and lag (2 vs 5) as factors revealed a significant main effect of lag ($F_{1,25} = 14.708$, $p = .001$, $\eta_p^2 = .370$) and significant interaction between lag and trial type ($F_{1,25} = 7.439$, $p = .012$, $\eta_p^2 = .229$), but no main effect of trial type ($F_{1,25} = 1.695$, $p = .205$, $\eta_p^2 = .063$). Planned contrasts reveal a significant effect of trial type at lag 2 ($F_{1,25} = 9.156$, $p = .006$, $\eta_p^2 = .268$), but not at lag 5 ($F_{1,25} < 1$). As in Experiment 1, Dp and Df trials were very closely matched to Random trials in terms of target accuracy and similar analyses of Df vs Random, and Dp vs Df trials again failed to yield any significant effects (all $F_s < 1$) other than main effects of lag in each analysis (smaller $F_{1,25} = 13.11$, $p = .001$, $\eta_p^2 = .344$).

The bottom panel of Figure 6 shows the progression of target detection accuracy across the course of the experiment. A lag 2 detection advantage for Tp over Tf emerges gradually throughout the experiment, but is only statistically robust in the final blocks when the CRT responses were removed. The detection advantage for Tp is thus clearly not dependent on making the CRT responses and cannot be explained in terms of different levels of interference from those speeded responses. It is also evident that accuracy for lag 5 trials drops substantially in the last phase, for each trial type. This is not surprising, given that the rate of presentation was increased in this last phase so that lag 5

trials probably fell within the temporal window in which one might expect to see an AB effect. It is thus noteworthy that lag 5 performance was well below ceiling in the final phase of the experiment, and still displayed no difference in accuracy between Tp and Tf. This indicates that the advantage for processing Tp appears to be specific to very short lags, rather than being a general effect that is not modulated by lag but is nevertheless only observable at low accuracy. It seems reasonable to assume then that this is a modulation specific to the AB rather than a change in general target detectability.

Awareness Questionnaire

Verbal reporting of the predictive relationships was again very low in Experiment 2. No participants reported having identified a relationship between a letter and response. Three participants reported the correct letter for Tp when told about the relationship between a target letter and response, but of these only one correctly reported the response that Tp predicted (in comparison, six participants reported Tf as a predictive letter). Analyses excluding these three participants still yield a significant difference in RT between Tp and Tf ($F_{1,22} = 6.422$, $p = .019$, $\eta_p^2 = .226$), a significant difference in lag 2 target accuracy between Tp and Tf ($F_{1,22} = 8.715$, $p = .007$, $\eta_p^2 = .284$), and significant interaction in target accuracy between lag and trial type ($F_{1,22} = 8.858$, $p = .007$, $\eta_p^2 = .287$). No participants accurately reported the correct letter for Dp. For the 2AFC questions, 11 out of 26 correctly chose the response predicted by Tp, and 12 out of 26 correctly chose the response predicted by Dp, indicating that overall ability to answer the forced-choice questions did not differ from chance. Using accuracy on the 2AFC question for Tp as a between subjects factor, the previously reported analysis of RT with trial type (Tp vs Tf) and lag (2 vs 5) as within subjects factors yielded no significant main effect nor interactions with 2AFC accuracy (all $F_s < 0.5$), while the Tp vs Tf main effect remained significant ($F_{1,24} = 5.409$). This suggests that the priming effect for Tp was equally strong for the group that failed the

most sensitive of the awareness questions as it was for the group that correctly answered this question. Turning to target accuracy, the 2AFC question also yielded no interaction with trial type (Tp vs Tf) at lag 2, nor a 3 way interaction with lag and trial type (both $F_s < 1$). It therefore appears that the target recognition advantage for Tp was equally strong for the groups that answered the 2AFC question correctly and incorrectly. In fact,

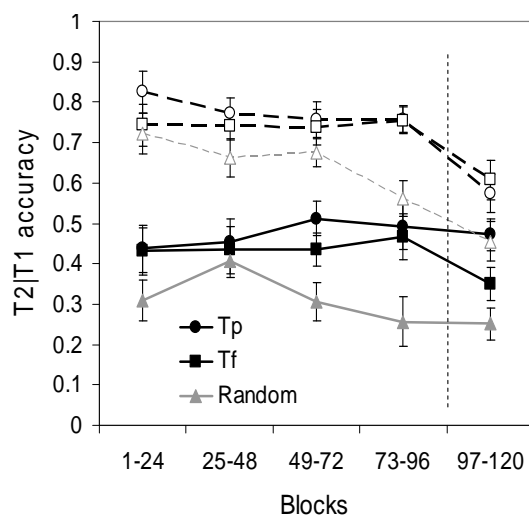
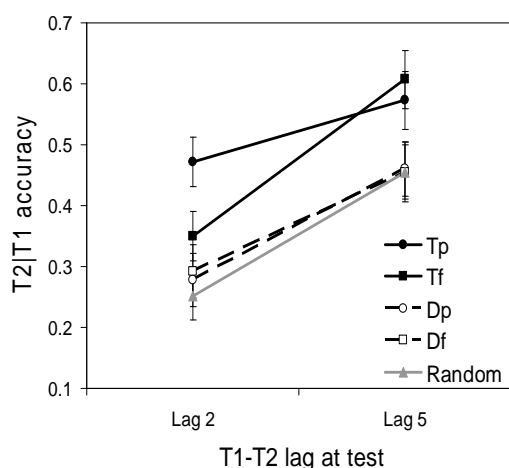


Figure 6. Mean conditional T2 accuracy ($T2|T1$) during Experiment 2. Top panel shows accuracy during the RSVP-only blocks (blocks 97-120), for each trial type and at each of the two lags. Bottom panel shows accuracy on Tp, Tf and random trials, across the course of the experiment, separated into lag 2 trials (solid lines) and lag 5 trials (dashed lines). The dotted line indicates the point at which the task changed to RSVP-only test phase; blocks 1-96 involved RSVP at 94 msec per letter in combination with speeded left/right responses, while blocks 97-120 involved RSVP at 82 msec per letter and no speeded responses.

looking solely at the 15 participants who answered the 2AFC question incorrectly, target accuracy at lag 2 was still significantly higher for Tp than Tf ($F_{1,14} = 8.010$, $p = .013$, $\eta_p^2 = .364$).

In Experiment 2, the target detection advantage for Tp is very distinct across the participant sample as a whole. While the equivalent effect in Experiment 1 was only evident in the top half of participants (i.e. those who showed an RT priming effect), Experiment 2 confirms the effect more clearly. The detection advantage for Tp during the AB does not appear to be sustained by any clearly explicit or verbalizable knowledge of the contingency between Tp and the response that it predicts.

General Discussion

In both experiments, response times were significantly faster on trials containing a target that signaled the required response, even though reported awareness of the target-response contingency was poor. In both experiments, this priming effect was associated with a target detection advantage for the predictive target when presented under parameters conducive to an AB. The results of the two experiments together demonstrate that learning the signal validity of a stimulus has a replicable effect on the attentional processes governing recognition of that stimulus in RSVP.

In both experiments, post-experiment recall of the predictive target letter was very poor, and in Experiment 2 the magnitude of the priming effect did not differ according to whether participants could correctly answer a 2AFC question about which response was more likely to follow the predictive target letter. Therefore, given how little contingency knowledge participants were able to express in the context of the post-experiment questionnaire, we argue that the priming effects observed in these experiments can be classified as examples of implicit learning.

Implicit change to target recognition during the attentional blink

Changes in the accurate identification and report of T2 were consistent across both experiments, and mirrored learning of the target's signal validity. In each case, the predictive target letter for which participants showed an RT priming effect was also reported more accurately when it was presented in the depth of the AB (at lag 2), compared to a non-predictive target letter that appeared equally frequently. Thus the predictive target appears to be somewhat protected from the AB. The effect is not an artifact of the CRT response being easier to execute on signaled trials – in Experiment 2, when the speeded responses were removed, the target detectability advantage for T_p during the AB persisted. As with the AB itself, the target detectability effect was only observed at very short lags, and was not simply related to level of performance. While the difficulty in identifying targets was varied across the two experiments by varying the rate of letter presentation, the same result was observed – better performance for T_p than T_f at lag 2, but no difference at longer lags (e.g. 5, 6, or 7 serial positions after T1). Notably, this pattern was observed in Experiment 2, where target accuracy at lag 5 was well below ceiling.

Learning to targets but not distractors

In this particular task, learning about a target is clearly easier than learning about a distractor. In fact, we found no evidence of priming from a predictive distractor in either experiment, and in Experiment 2 significantly more priming was observed to the predictive target than to a comparable distractor. The failure to see priming from a distractor may be due to a number of reasons. For instance, the white distractor CSs may be physically less salient than the red target CSs. Alternatively, perhaps learning requires selection of the CS for consolidation in short-term memory, in preparation for reporting at the end of the trial. This would imply that even if the CS-US contingency is not consciously identified, attending to the CS may be necessary for learning or expressing the learned

relationship. Even if learning does not rely on consolidation of the CS in memory, attentional processes during RSVP may still disfavor learning about distractors. The process of attending to targets during RSVP may well involve some degree of active inhibition of the distractors (Dux, Coltheart, & Harris, 2006; Dux & Harris, 2007; Olivers & Watson, 2006), and indeed Raymond et al's (1992) original *attentional gating* account of the AB assumed this was the case. Thus, failure to learn about the distractors, or to express anything that had been learned about the distractors, might be due to this active distractor suppression. At the very least, acquisition of these priming effects seems to require a basic level of processing above and beyond the minimal levels needed to identify and selectively ignore distractor items, which in this task, could be achieved on the basis of processing color alone.

While the failure to see learning about a distractor could be due to a number of factors, the difference in priming from a predictive target and distractor suggests an influence of volitional attentional mechanisms on incidental learning, which agrees with existing evidence that selective attention to the relevant stimulus information facilitates implicit learning (Jiang & Chun, 2001; Jiménez & Méndez, 1999). Whether learning of this sort *necessarily* requires attention to the CS, in terms of its selection for short term memory, may depend in part on subtle procedural variables. For instance, an RSVP task in which semantic qualities of the distractors must be processed to some degree in order to ignore them (for instance, white letter targets amongst white single-digit distractors) may yield quite different results, as preliminary investigations from our own laboratory suggest (Pincham et al, 2008). Thus, while it is not clear from the present results alone that conscious identification or selection of the CS is necessary for learning in this paradigm, attention to the CS certainly seems to increase the level of acquired associative priming.

Implicit learning and contingency awareness

Several controversies over the methods used to assay explicit contingency knowledge in the study of implicit learning are well documented and highlight the difficulty of establishing clear evidence of learning in the absence of awareness (e.g. see Lovibond & Shanks, 2002; Shanks & St John, 1994). One could be forgiven for concluding that several of the enduring problems regarding awareness assessment such as immediacy and sensitivity will never be satisfactorily resolved. With respect to the present study, we see the level of awareness of the participant as rather less important than the automaticity of the learning that takes place, as we are asking whether attentional changes occur in the absence of any clear intent from the participant to search for or concentrate on a particular CS. Learning in the presence of vague or momentary contingency awareness, but in the absence of an actively maintained hypothesis about the CS, might be considered just as automatic as learning in the complete absence of awareness. Perruchet et al (2006) have recently demonstrated that motor priming attributable to consistent pairings of a tone CS with a response cue can be dissociated from conscious expectancy of the response cue in a situation where those pairings are obvious and unconcealed. Their result suggests that associative priming occurs automatically, even where it changes performance in a manner that seems to contradict conscious expectation. The acquisition of response priming from a CS, as measured by differences in cued response times, thus appears to be a viable method for studying automatic associative processes in humans. The current experiments examined whether those same automatic associative processes are accompanied by attentional changes that can be attributed to learning the signal validity of the CS. In this case, the clearest way to confirm that learning occurred relatively automatically was to demonstrate a paucity of reportable contingency knowledge and a general absence of conscious rule abstraction. To this extent, the learning observed here can be described as entirely incidental, and indeed implicit in nature.

Attentional change, learning and associability

The attentional changes observed here are consistent with several models of associative learning that predict a CS with signal validity (i.e. a relatively good predictor of an outcome) will be attended to more than a CS with no or less signal validity (Kruschke, 2001; Mackintosh, 1975). They are also generally consistent with stimulus *associability* changes observed in intentional human learning tasks, where attentional change is gauged by variations in the rate of learning about stimuli presented in compound (e.g. Le Pelley & McLaren, 2003; Livesey & McLaren, 2007; Lochmann & Wills, 2003; Mitchell, Harris, Westbrook, & Griffiths, in press). It is worth noting that the effects of attentional change on the *expression* of the learned association are not addressed in this study. The effect of attentional change on performance has been a point of some contention amongst proponents of attentional learning models (e.g. Kruschke, 2001; Le Pelley & McLaren, 2003). For instance, attentional change might have a further influence on the performance of the learned response, purely because the representation of the CS has become more salient, which could increase the extent to which it primes other representations with which it is associated, as is assumed by some recent models of associative learning (Harris, 2006; McLaren & Mackintosh, 2000). Such a hypothesis was not tested in these experiments, and even if it were, faster recognition of a predictive target could lead to greater priming through less direct routes (e.g. a reduction in interference between identifying T2 and executing the speeded response).

The use of the concept of attention in the study of learning has been characterized by an abundance of proposed mechanisms and a dearth of clear distinctions amongst those mechanisms and the terms used to describe them (Mackintosh, 1975). What is actually meant by attention is still fairly ambiguous, at least 80 years after its introduction into formal learning theory. As with other concomitant measures of stimulus processing,

studies using RSVP tasks like those reported here might be useful in helping to characterize the changes that take place during learning. For instance, at this point we can make some confident assertions about what processes do *not* explain these attentional changes. This particular effect of signal validity on CS recognition during the AB cannot be due to the affective consequences of the outcome that is signaled. Studies have previously shown that stimuli associated with aversive outcomes (or aversive stimuli) cause an AB due to their significance (Smith et al, 2006). However, in the current paradigm, equivalent outcomes occur on every trial, and could hardly be considered to have significant (or differential) aversive or affective properties. The result is also not due to a change in the expectancy or salience of the CS brought about simply by its frequency of occurrence, as control conditions were carefully matched for frequency of occurrence. The result also suggests that learning the predictive validity of a CS does more than just change its associability, the rate at which further learning to the CS occurs. Processing of the CS is clearly affected in a way that is independent of the learned response, particularly in Experiment 2 where the response was removed altogether.

There is little evidence from these experiments to suggest that the advantage for Tp processing comes at the expense of processing other stimuli. A selective attention account might predict, for instance, worse T1 report accuracy on Tp trials because learning favors the processing of the predictive T2 over the unpredictable T1 when the targets are consolidated in working memory. There is no evidence that the advantage for Tp comes at the expense of processing T1. T1 report accuracy was completely unaffected by any of the manipulations of signal validity. This suggests that the attentional change is not well characterized as a product of the predictive stimulus seizing a greater share of some limited-capacity attentional or memory resource. Rather, it might indicate that the processing of the predictive stimulus occurs faster or more easily, in a fashion that could

actually alleviate constraints on the processing of other information occurring at about the same time. Nevertheless, T1 may be insensitive to competition from a blinked T2 because of its privileged position in the temporal allocation of attention. Even in the absence of an effect on T1, the advantage for reporting Tp may act through selective attention by facilitating suppression of neighboring distractors. In future studies, manipulations specifically designed to test this hypothesis might yield evidence of stimulus competition.

In conclusion, implicit learning of a CS-US association facilitates the recognition of that CS when it appears as a target in the AB. This result is in agreement with theoretical predictions that attentional processing of the CS is related to its validity in predicting an associated outcome. It also suggests that the AB, which has been shown to be affected by the general meaningfulness and familiarity of the “blinked” target, is also sensitive to the signal validity, which is a very specific aspect of the significance of a stimulus. This suggests that stimuli which have previously been useful because they predict an outcome of some significance to the subject will be more easily processed amongst a background of changing and confusable stimuli. The effect may have important and advantageous behavioral consequences in an environment that is rich in visual stimulation, especially where attention is necessary to identify meaningful objects and events.

References

- Boakes, R. A., Roodenrys, S., & Barnes, B. W. (1995). Implicit Learning in a Cued Reaction Time Task. In P. Slezak, T. Caelli & R. Clark (Eds.), *Perspectives on cognitive science* (pp. 1-17). Norwood, NJ: Ablex.
- Cleeremans, A. (1997). Sequence learning in a dual-stimulus setting. *Psychological Research*, *60*, 72-86.
- Crebolder, J. M., Jolicœur, P., & Mcllwaine, J. D. (2002). Loci of Signal Probability Effects and of the Attentional Blink Bottleneck. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 695-716.

- Deubel, H., & Schneider, W. X. (1996). Saccade Target Selection and Object Recognition: Evidence for a Common Attentional Mechanism. *Vision Research*, *36*, 1827-1837.
- Dickinson, A., Hall, G., & Mackintosh, N. J. (1976). Surprise and the Attenuation of Blocking. *Journal of Experimental Psychology: Animal Behavior Processes*, *2*, 313-322.
- Dickinson, A., & Mackintosh, N. J. (1979). Reinforcer specificity in the enhancement of conditioning by posttrial surprise. *Journal of Experimental Psychology: Animal Behavior Processes*, *5*, 162-177.
- Dux, P. E., Coltheart, V., & Harris, I. M. (2006). On the fate of distractor stimuli in rapid serial visual presentation. *Cognition*, *99*, 355-382.
- Dux, P. E., & Harris, I. M. (2007). On the failure of distractor inhibition in the attentional blink. *Psychonomic Bulletin & Review*, *14*, 723-728.
- Frensch, P. A., Buchner, A., & Lin, J. (1994). Implicit Learning of Unique and Ambiguous Serial Transitions in the Presence and Absence of a Distractor Task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *20*, 567-584.
- Frensch, P. A., Lin, J., & Buchner, A. (1998). Learning versus behavioral expression of the learned: The effects of a secondary tone-counting task on implicit learning in the serial reaction task. *Psychological Research*, *61*, 83-98.
- Harris, J. A. (2006). Elemental Representations of Stimuli in Associative Learning. *Psychological Review*, *113*, 584-605.
- Holland, P. C. (1984). Unblocking in Pavlovian Appetitive Conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*, 476-497.
- Holland, P. C. (1988). Excitation and Inhibition in Unblocking. *Journal of Experimental Psychology: Animal Behavior Processes*, *14*, 261-279.
- Jackson, M. C., & Raymond, J. E. (2006). The role of attention and familiarity in face identification. *Perception & Psychophysics*, *68*, 543-557.
- Jiang, Y., & Chun, M. M. (2001). Selective attention modulates implicit learning. *Quarterly Journal of Experimental Psychology*, *54A*, 1105-1124.
- Jiang, Y., & Leung, A. W. (2005). Implicit learning of ignored visual context. *Psychonomic Bulletin & Review*, *12*, 100-106.
- Jiménez, L., & Méndez, C. (1999). Which Attention Is Needed for Implicit Sequential Learning? *Journal of Experimental Psychology: Learning, Memory and Cognition*, *25*, 236-259.
- Kaye, H., & Pearce, J. M. (1984). The Strength of the Orienting Response During Pavlovian Conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*, 90-109.
- Kowler, E., Anderson, E., Doshier, B., & Blaser, E. (1995). The Role of Attention in the Programming of Saccades. *Vision Research*, *35*, 1897-1916.
- Kruschke, J. K. (2001). Toward a Unified Model of Attention in Associative Learning. *Journal of Mathematical Psychology*, *45*, 812-863.
- Kruschke, J. K., Kappenman, E. S., & Hetrick, W. P. (2005). Eye Gaze and Individual Differences Consistent With Learned Attention in Associative Blocking and Highlighting. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *31*, 830-845.
- Le Pelley, M. E. (2004). The role of associative history in models of associative learning: A selective review and a hybrid model. *Quarterly Journal of Experimental Psychology*, *57B*, 193-243.
- Le Pelley, M. E., & McLaren, I. P. L. (2003). Learned associability and associative change in human causal learning. *Quarterly Journal of Experimental Psychology Section B- Comparative and Physiological Psychology*, *56*, 68-79.
- Livesey, E. J., & McLaren, I. P. L. (2007). Elemental Associability Changes in Human Discrimination Learning. *Journal of Experimental Psychology: Animal Behavior Processes*, *33*, 148-159.
- Lochmann, T., & Wills, A. J. (2003). Predictive history in an allergy prediction task. In *Proceedings of EuroCogSci 03: The European Conference of the Cognitive Science Society* (pp. 217-222). Mahwah, NJ: Lawrence Erlbaum Associates.
- Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, *1*, 476-490.
- Lovibond, P. F., & Shanks, D. R. (2002). The Role of Awareness in Pavlovian Conditioning: Empirical Evidence and Theoretical Implications. *Journal of Experimental Psychology: Animal Behavior Processes*, *28*, 3-26.
- Mackintosh, N. J. (1975). A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review*, *82*, 276-298.
- Mackintosh, N. J., & Turner, C. (1971). Blocking as a function of novelty of CS and predictability of UCS. *Quarterly Journal of Experimental Psychology*, *23*, 359-366.

- McLaren, I. P. L., & Mackintosh, N. J. (2000). An elemental model of associative learning: I. Latent inhibition and perceptual learning. *Animal Learning & Behavior*, *28*, 211-246.
- Mitchell, C. J., Harris, J. A., Westbrook, R. F., & Griffiths, O. (in press). Changes in cue associability across training in human causal learning. *Journal of Experimental Psychology: Animal Behavior Processes*.
- O'Doherty, J. P., Dayan, P., Friston, K., Critchley, H., & Dolan, R. J. (2003). Temporal Difference Models and Reward-Related Learning in the Human Brain. *Neuron*, *28*, 329-337.
- Olivers, C. N. L., van der Stigchel, S., & Hulleman, J. (2007). Spreading the sparing: against a limited-capacity account of the attentional blink. *Psychological Research-Psychologische Forschung*, *71*, 126-139.
- Olivers, C. N. L., & Watson, D. G. (2006). Input control processes in rapid serial visual presentations: Target selection and distractor inhibition. *Journal of Experimental Psychology-Human Perception and Performance*, *32*, 1083-1092.
- Pearce, J. M., & Hall, G. (1980). A model of Pavlovian conditioning: Variations in the effectiveness of conditioned but not unconditioned stimuli. *Psychological Review*, *87*, 332-352.
- Perruchet, P. (2008). Implicit Learning. In H. L. Roediger (Ed.), *Cognitive psychology of memory* (Vol. 2). Oxford: Elsevier.
- Perruchet, P., Cleeremans, A., & Destrebecqz, A. (2006). Dissociating the Effects of Automatic Activation and Explicit Expectancy on Reaction Times in a Simple Associative Learning Task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *32*, 955-965.
- Pincham, H. L., Livesey, E. J., & Harris, J. A. (2008). Conditioning in humans requires neither conscious awareness nor selective attention: Evidence from a cued reaction time task. *Manuscript in preparation*.
- Ploghaus, A., Tracey, I., Clare, S., Gati, J. S., Rawlins, J. N. P., & Matthews, P. M. (2000). Learning about pain: The neural substrate of the prediction error for aversive events. *Proceedings of the National Academy of Sciences*, *97*, 9281-9286.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3-25.
- Rehder, B., & Hoffman, A. B. (2005). Eyetracking and selective attention in category learning. *Cognitive Psychology*, *51*, 1-41.
- Shanks, D. R., & Channon, S. (2002). Effects of a secondary task on "implicit" sequence learning: learning or performance? *Psychological Research*, *66*, 99-109.
- Shanks, D. R., Rowland, L. A., & Ranger, M. S. (2005). Attentional load and implicit sequence learning. *Psychological Research*, *69*, 369-382.
- Shanks, D. R., & St John, M. F. (1994). Characteristics of dissociable human learning systems. *Behavioral & Brain Sciences*, *17*, 367-447.
- Shapiro, K. L., Caldwell, J., & Sorensen, R. E. (1997). Personal Names and the Attentional Blink: A Visual "Cocktail Party" Effect. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 504-514.
- Shapiro, K. L., Driver, J., Ward, R., & Sorensen, R. E. (1997). Priming from the Attentional Blink: A Failure to Extract Visual Tokens but Not Visual Types. *Psychological Science*, *8*, 95-100.
- Smith, S. D., Most, S. B., Newsome, L. A., & Zald, D. H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion*, *6*, 523-527.
- Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology*, *25*, 545-580.
- Sutherland, N. S., & Mackintosh, N. J. (1971). *Mechanisms of animal discrimination learning*. New York: Academic Press.
- Turner, D. C., Aitken, M. R. F., Shanks, D. R., Sahakian, B. J., Robbins, T. W., Schwarzbauer, C., et al. (2004). The Role of the Lateral Frontal Cortex in Causal Associative Learning: Exploring Preventative and Super-learning. *Cerebral Cortex*, *14*, 872-880.
- Visser, T. A. W., Merikle, P. M., & Di Lollo, V. (2005). Priming in the attentional blink: Perception without awareness? *Visual Cognition*, *12*, 1362-1372.
- Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the Development of Procedural Knowledge. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *15*, 1047-1060.
- Wills, A. J., Lavric, A., Croft, G. S., & Hodgson, T. L. (2007). Predictive learning, prediction errors, and attention: Evidence from event-related potentials and eye tracking. *Journal of Cognitive Neuroscience*, *19*, 843-854.