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

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Participants in 2 experiments performed 2 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 2nd target when it is presented in temporal proximity of the 1st 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 postexperiment 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.

Keywords: predictive learning, attentional blink, signal validity, implicit learning

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, whereas 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, in which 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 and 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, Dosher, & 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

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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 influence 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 assume 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 unconditioned stimulus (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 to better characterize the attentional changes that occur during human predictive or category learning. These have included measures of gaze duration directed toward competing visual stimuli, which have generally shown (albeit under different task requirements and testing different hypotheses) that participants spend more time 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 that 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, 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. It is hoped that an accumulation of evidence from a range of measures that are not solely dependent on the learned response will 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, used a phenomenon commonly known as the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992). The 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 with 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 comprising 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, the participant 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, in which a conventional 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, in which 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 yields 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), whereas 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., Cleeremans, 1997; Frensch, Lin, & Buchner, 1998; 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 discussed below, these comparisons bear some resemblance to studies of the effect of voluntary selective attention on implicit learning.

Although most implicit learning studies that employ reaction time (RT) 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, and 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 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 that 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 nonpredictive 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, whereas 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 nonpredictive. Because Tp always signaled left in this experiment, only

Table 1
Trial Design for Experiment 1 Showing the Trial Sequence for Each of the Five Trial Types

Trial type	RSVP sequence	Left–right cue
Tp	# d d T1 d d d d d **T2** d # cue	100% left
Tf	# d d T1 d d d d d **T2** d # cue	50% left–50% right
Dp	# d d T1 d d d d **d** T2 d # cue	100% right
Df	# d d T1 d d d d **d** T2 d # cue	50% left–50% right
Random	# d d T1 d d d d d T2 d # cue	50% left–50% right

Note. In each rapid serial visual presentation (RSVP) sequence, d denotes a distractor presented in white, and T1 and T2 denote the two red target letters. The four bold letters (**T2** on Tp and Tf trials, **d** on Dp and Df trials) represent four preallocated 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 hash mark (#) 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).

the Tf trials on which a left response was required were used to calculate mean RTs. This avoids any issue of overall biases toward making left responses more quickly or slowly than right responses, which could produce artifactual 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 report accuracy of the targets in the RSVP sequence. A postexperiment 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 naive 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 1,000 ms on more than 20% of correct CRT responses, the participant's data were discarded. These criteria were used for both experiments. In Experiment 1, 2 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-in. (43.18-cm) cathode ray tube monitor running at 85-Hz refresh rate. Participants sat approximately 50 cm from the screen. Responses were made via 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; point 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 *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 nonpredictive target matched for frequency (Tf), a predictive distractor (Dp), and a nonpredictive 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 toward 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.

Trial order was organized in blocks of five trials, with 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 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 such that T2 occurred 5–7 serial positions after T1. This was immediately followed by a test phase comprising 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 to 7.

Procedure

On arrival, participants were told that 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 s, 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, and 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.

On completion of all 525 trials, participants were given a postexperiment 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 others, either generally throughout the experiment, specifically as the second target, or specifically as distractors near the end of the letter sequence. These questions were added, as they focus attention on those letters that appear relatively often. Pilot work suggested that verbal report of target frequency was better than report of target–response contingency, so encouraging participants to think about frequently presented letters might 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 toward the end of the letter sequence. Questions 1 and 5 were the most relevant in gauging verbalizable knowledge of the Tp–left response contingency, as were Questions 1 and 6 for the Dp–right response contingency. As discussed below, 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 RT 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

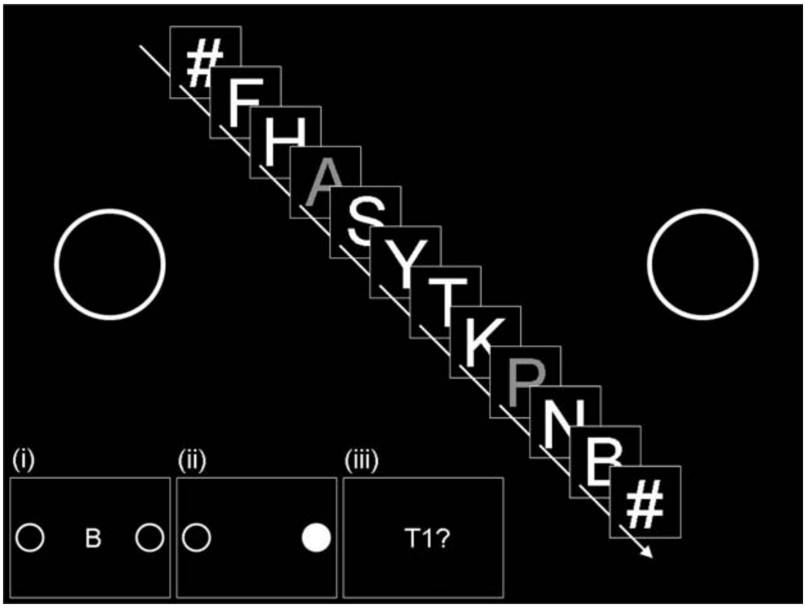

Figure 1. Diagram representing the sequence of events on each trial. The main panel shows a typical sequence of letters presented in rapid serial visual presentation (the red target letters appear in gray), with response prompts to the left and right of the screen. Smaller panels show the sequence of events: (i) Letters and masks appear serially in the center of the screen; (ii) the final mask (hash) is immediately followed 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.

for all the experiments reported here. RT and target detection accuracy data were analyzed with repeated measures analyses of variance (ANOVAs) 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 RT of less than 1,000 ms were used in calculating mean RTs for each condition. As stated, because 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 toward responding faster for left or for right (though in actual fact, calculations using left and right RTs yielded similar results to those reported below).

Figures 2A and 2B show mean RT calculated across successive 15-block bins. RT decreased with practice over the training blocks, although the introduction of shorter lag trials after Block 60 appears to have resulted in a sharp increase in RTs. Mean RTs over the last 45 blocks (test phase) were used for comparing the predictive and nonpredictive conditions. Over this test phase, RTs on Tp trials (332.1 ms) were 15.5 ms faster than RTs on Tf trials (347.6 ms), and this difference was significant, $F(1, 31) = 11.792$, $p = .002$, $\eta_p^2 = .276$. RTs on Dp trials, however, did not reliably differ from RTs 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. However, there was no evidence that anything was learned about Dp, as RTs for Dp, Df, and random trials were all closely matched. RTs on random trials did not significantly differ from RTs on either Tf or Df trials (Fs < 1), indicating that the mere frequency of the CS had little effect on response speed.

Participants performed the CRT task with a very high degree of accuracy (M 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 RT between Tp and Tf trials—Tp trials were responded to faster, but no less accurately, than Tf trials.

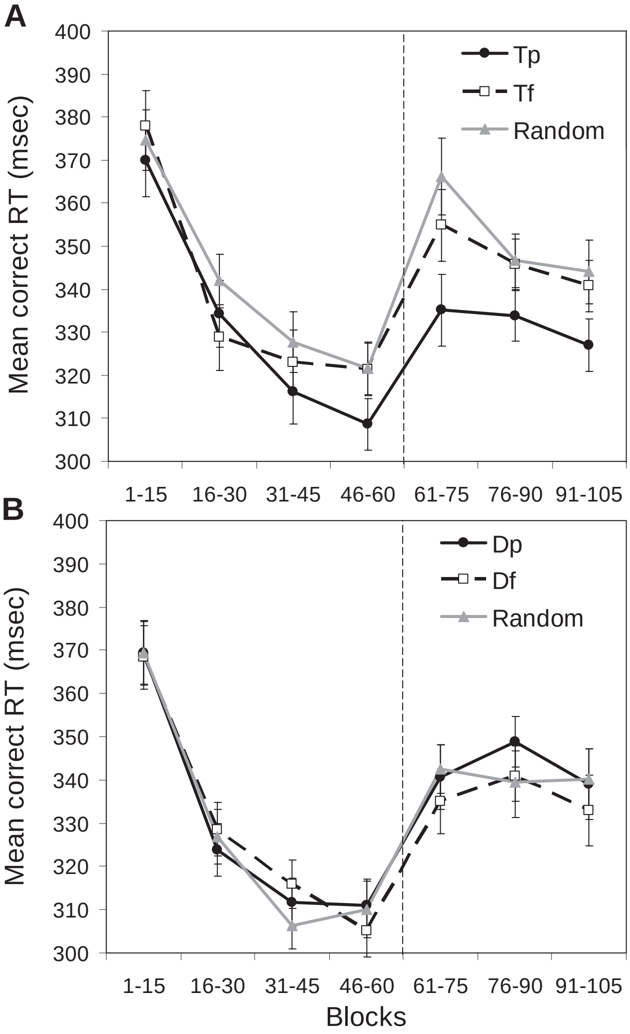

Figure 2. Mean correct response times (RTs) across blocks of Experiment 1: (A) trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), or with random T2; and (B) trials with the predictive distractor (Dp), with the control distractor matched for frequency (Df), or with random distractors. Mean RTs were calculated only for left response trials in Figure 2A (as Tp always predicted a left response) and only for right response trials in Figure 2B (as Dp always predicted a right response). Error bars display standard errors of the mean of within-subjects comparisons (Tf–Tp for Tp and Tf; Df–Dp for Dp; random–Tp/Dp for random; see, e.g., Loftus & Masson, 1994).

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 Fs < 1). Figures 3A–3C show 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 five trial types yielded poorest performance at Lag 2 and then improved across lags (with best performance at Lag 7). It is also immediately apparent, in Figure 3A, 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

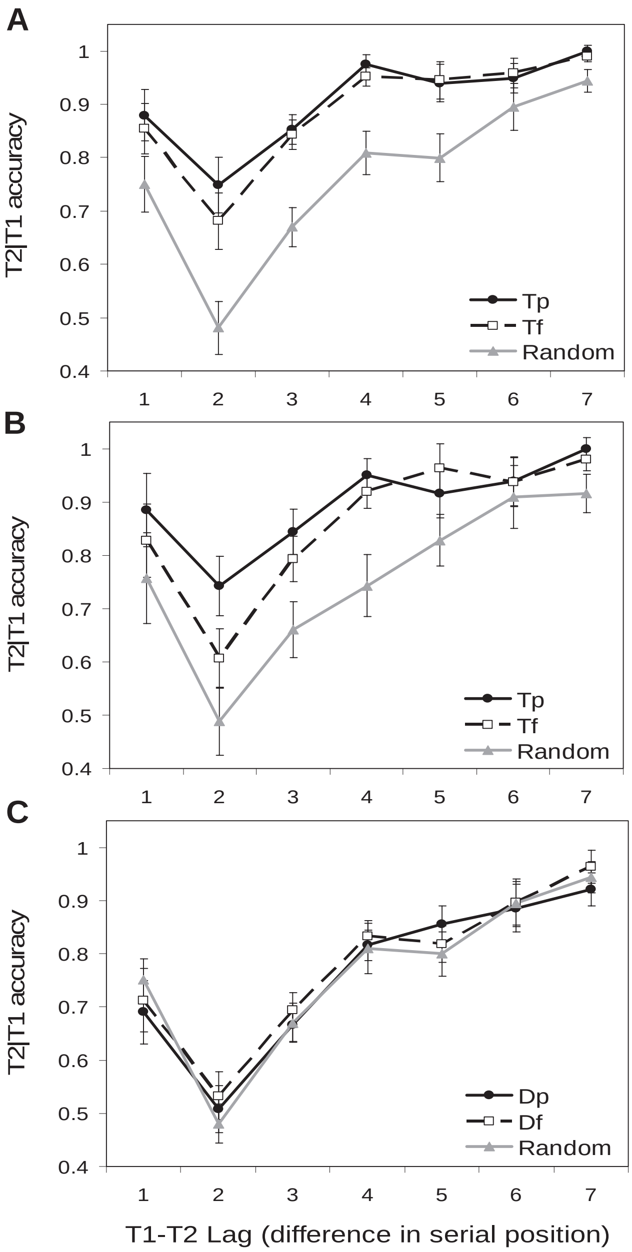

Figure 3. Target detection during test phase of Experiment 1. Figures show mean conditional T2 accuracy (T2|T1 accuracy) across different lags, expressed as the difference in serial position of the two targets: (A) mean results for all participants on Tp, Tf, and random target trials; (B) mean results of the "better learners," identified by a median split of all participants on the Tp versus Tf response time priming effect; (C) mean results for all participants on Dp, Df, and random target trials. Error bars display standard errors of the mean of within-subjects comparisons.

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 (Lags 1–7) as factors reveal only a significant effect of lag, $F(6, 186) = 22.369$, $p < .001$, $\eta_p^2 = .419$ (other Fs < 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. Figure 3B shows T2|T1 accuracy for the upper half of participants divided in this manner. Furthermore, a simplified analysis can be conducted with 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 with 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 those 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 ($F < 0.1$). 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 Figure 3C. Similar analyses as those used above (for comparisons between Tp and Tf and between Tf and random trials) were 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 1 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 4 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 5 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), $F(1, 26) = 8.58$, $p = .007$, $\eta_p^2 = .248$, and one of comparable magnitude to the overall mean. A further 6 participants, only 1 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, 7 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 (Lag 2 vs. Lag 7) and trial type (Tp vs. Tf; $F < 1$).

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 and 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 Tp and response presumably improves the ease with which that response is made, allowing for faster RTs. 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 T2 on trials in which 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 Tp and Tf 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. If we assume that the target detection effect observed in Experiment 1 is real and attributable to learning about Tp, 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 we made all trials in Experiment 2 (and most notably the RSVP-only trials) 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 Tp and Tf is strongest. This difference had more or less disappeared at lags of 4 and 5. In Experiment 2, Lag 5 was chosen to compare with Lag 2 performance. By our reducing the stimulus onset asynchrony 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 T1 and T2 as Lag 4 in Experiment 1 (i.e., approximately 410 ms). Although 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 Tp and Tf 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 Tp and Tf might therefore be attributed to the properties of the randomly assigned letters. To minimize this unwanted variability, in Experiment 2 the relevant CSs (Tp, Tf, Dp, and Df) were randomly chosen from a pool of just four 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 in Experiment 1.

In addition, the responses predicted by Tp and Dp were randomly allocated in Experiment 2, rather than fixed to Tp–Left and Dp–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 preexisting systematic group bias in left versus 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, as responses to the CSs are equivalent at a group level, even though Tp and Dp predict opposite responses for individual subjects.

The postexperiment 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 influences the priming effect. In Experiment 2, participants were given a further set of two-alternative forced-choice (2AFC) questions in which 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 that 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, under 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 five 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 94 ms (cf. 106 ms in Experiment 1) in the response phase and one every 82 ms in the target-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 preallocated 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.

Table 2
Trial Design for Experiment 2 Showing the Trial Sequence for Each of the Five Trial Types

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% Response 1–50% Response 2
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% Response 1–50% Response 2
Random	# d d d d T1 d d d d T2 d d # cue	50% Response 1–50% Response 2

Note. The four bold letters represent four preallocated letters that remained constant throughout the experiment. All other letters were randomly chosen on each trial (without replacement) from the pool of remaining letters. T2 appeared equally often in serial Positions 8, 9, and 10 throughout the experiment (as did the meaningful distractor [d] 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 left and right as Response 2 and Response 1. RSVP = rapid serial visual presentation.

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 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), the response cue and the accelerated rate of presentation.

On completion of the RSVP-only phase, participants were given a postexperiment 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 participants 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

Figures 4A and 4B show mean RT 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, whereas responses were no faster on Dp trials than on Df or random trials. Figure 5, which shows mean

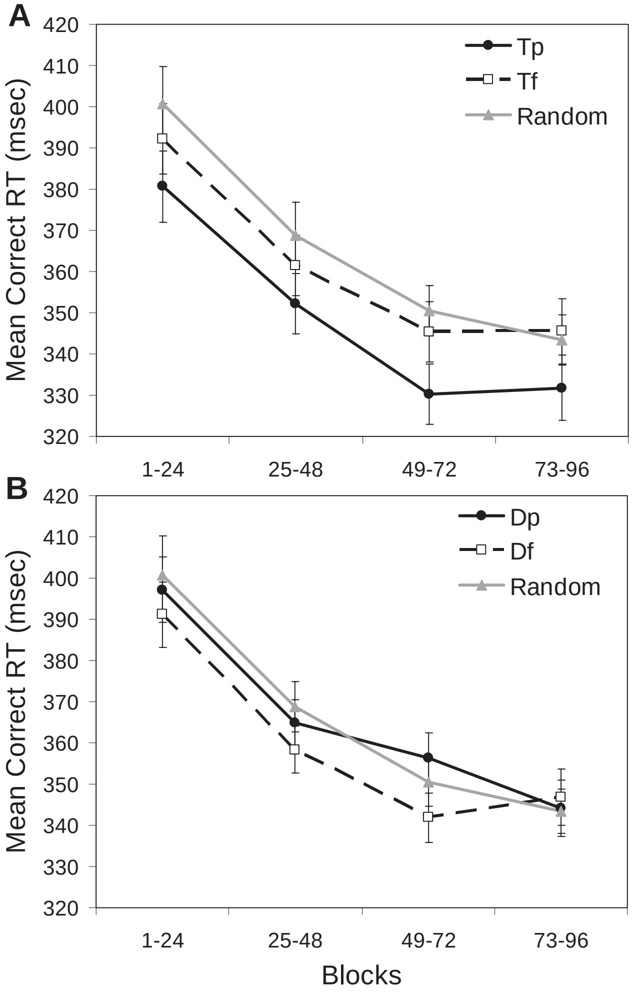

Figure 4. Mean correct response times (RTs) across blocks of Experiment 2: (A) trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), or with random T2; (B) trials with the predictive distractor (Dp), with the control distractor matched for frequency (Df), or with random distractors. Error bars display standard errors of the mean of within-subjects comparisons.

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 nonpredictive 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, $F(1, 25) = 1.351$, $p = .256$, $\eta_p^2 = .051$ (largest). The significant interaction suggests that the difference in RT between predictive and nonpredictive trials depends on whether the CSs were targets (Tp–Tf) or distractors (Dp–Df). Further analyses of solely 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 RTs 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, $F(1, 25) = 1.437$, $p = .242$, $\eta_p^2 = .054$ (larger).

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 confirm 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 in Experiment 1, was still high (*M* 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, $F(1, 25) = 1.397$ (largest). Over the second half of the CRT trials, participants made on average 1.76 errors on Tp trials (out of 48), compared with 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, whereas Dp and Df trials were responded to with equivalent speed and accuracy.

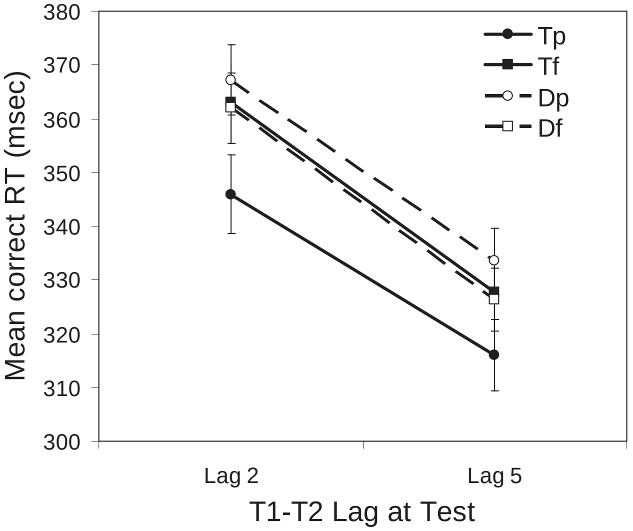

Figure 5. Mean correct response times (RTs) over the second half of cued reaction time trials in Experiment 2, separated according to the lag on each trial (Lag 2 or Lag 5): trials with the predictive T2 (Tp), with the control T2 matched for frequency (Tf), with the predictive distractor (Dp), or with the control distractor matched for frequency (Df). Error bars display standard errors of the mean of within-subjects comparisons.

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). Figures 6A and 6B plot conditional T2 accuracy (T2|T1) for the different trial types. As revealed in Figure 6A, which shows performance in the last 24 blocks (i.e., the RSVP-only trials) for each of the five trial types, a frequency effect is again evident, with accuracy for Tp and Tf generally higher than for the other trial types. In comparing Tf and random trials, a 2 × 2 ANOVA with T2 frequency (Tf vs. random) and lag (Lag 2 vs. Lag 5) as factors yielded significant main effects of T2 frequency and lag, $F(1, 25) = 13.145$, $p = .001$, $\eta_p^2 = .345$ (smaller), 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. In comparing Tp and Tf, a 2 × 2 ANOVA with trial type (Tp vs. Tf) and lag (Lag 2 vs. Lag 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 ($F < 1$). 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 versus random and Dp versus Df trials again failed to yield any significant effects (all *F*s < 1) other than main effects of lag in each analysis, $F(1, 25) = 13.11$, $p = .001$, $\eta_p^2 = .344$ (smaller).

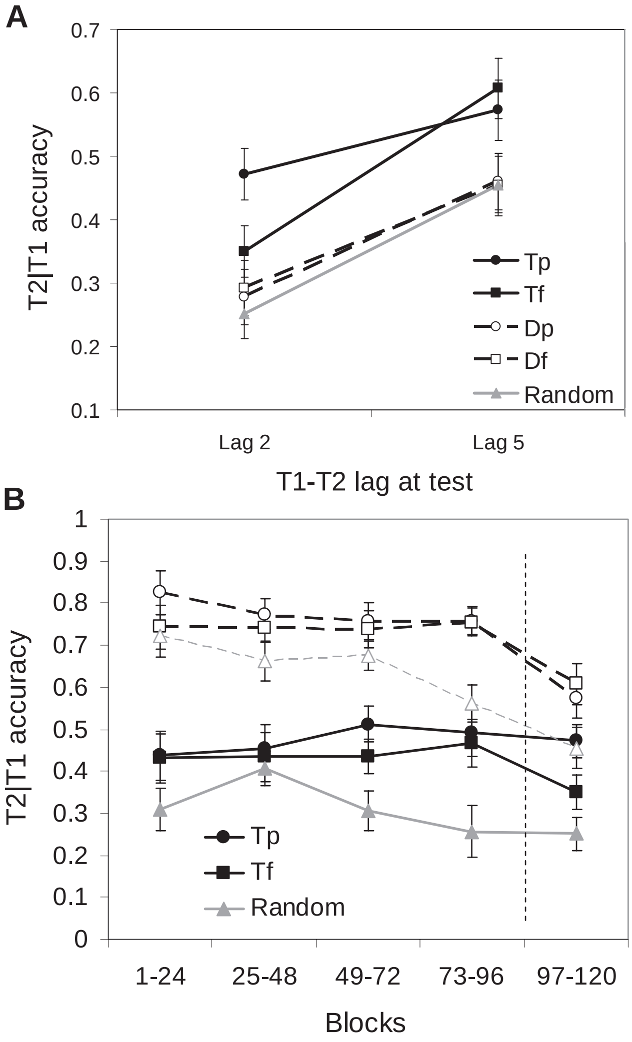

Figure 6. Mean conditional T2 accuracy (T2|T1) during Experiment 2. Figure 6A shows accuracy during the rapid-serial-visual-presentation-(RSVP)-only blocks (Blocks 97–120), for each trial type and at each of the two lags. Figure 6B shows accuracy on Tp, Tf, and random trials, across the course of the 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 ms per letter in combination with speeded left–right responses, and Blocks 97–120 involved RSVP at 82 ms per letter and no speeded responses. Error bars display standard errors of the mean of within-subjects comparisons.

Figure 6B 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 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 1 correctly reported the response that Tp predicted (in comparison, 6 participants reported Tf as a predictive letter). Analyses excluding these 3 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. With 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 (Lag 2 vs. Lag 5) as within-subjects factors yielded no significant main effect or interactions with 2AFC accuracy (all Fs < 0.5), although the Tp versus 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. For target accuracy, the 2AFC question also yielded no interaction with trial type (Tp vs. Tf) at Lag 2, nor a three-way interaction with lag and trial type (both Fs < 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, for 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. Whereas the equivalent effect in Experiment 1 was evident only 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, RTs 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, postexperiment 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 postexperiment 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 with a nonpredictive 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 Tp during the AB persisted. As with the AB itself, the target detectability effect was observed only at very short lags and was not simply related to level of performance. Although the difficulty in identifying targets was varied across the two experiments when we changed the rate of letter presentation, the same result was observed—better performance for Tp than Tf 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, in which 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 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.

Although 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 (e.g., white letter targets among white single-digit distractors) may yield quite different results, as preliminary investigations from our own laboratory suggest (Pincham, Livesey, & Harris, 2009). Thus, although 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 (see, e.g., 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 RTs, 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 those of 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, in which 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, 2008). 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 among 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 among 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 which 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 because of 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, in which 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 unpredictive 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 signal validity, which is a specific aspect of the significance of a stimulus. This suggests that stimuli that have been useful because they predict an outcome of some significance to the subject will be more easily processed among 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.

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