Is implicit learning perceptually inflexible?
New evidence using a simple cued reaction-time task

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Abstract

Considerable research has been devoted to investigating learning without awareness. Burke and Roodenrys [Burke, D., & Roodenrys, S. (2000). Implicit learning in a simple cued reaction-time task. *Learning and Motivation 31*, 364–380] developed a simple learning task in which a cue shape predicts the arrival of a target shape (to which subjects respond) in a sequence of rapidly presented shapes, and found that all subjects responded faster to cued targets than to uncued targets, even those classified as unaware of the cue–target relationship. Two experiments were conducted to examine the perceptual flexibility of implicit (and explicit) learning using the paradigm developed by Burke and Roodenrys (2000). Perceptual flexibility was examined by altering the perceptual features of the cue shape. The results of the first experiment indicated the implicit, but not explicit, learning that occurs in this paradigm is perceptually inflexible. However, the second experiment indicated that perceptually flexible implicit learning can be encouraged by varying the nature of the experimental stimuli. These experiments therefore provide support for processing accounts of transfer.
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Does consciousness play a functional role in human information processing? Is it necessary for perception, memory and learning, or does it merely assist in the performing of these cognitive tasks? These complex questions have puzzled philosophers for centuries but it is only recently that researchers have begun to use empirical methods to compare

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the characteristics of conscious and unconscious processes with the aim of understanding the role that consciousness plays in cognition. This may seem difficult at first, given that when we lose consciousness, at least in the traditional sense of the word, we can no longer observe or report anything. However, it is becoming increasingly apparent that it is possible to compare conscious events that people can report accurately to unconscious ones that can be inferred and studied indirectly. Indeed, researchers in recent years have explored quite a number of cases in which conscious and unconscious conditions seem quite comparable. In particular, there is a growing body of research examining implicit versus explicit perception (see Merikle, Smilek, & Eastwood, 2001), implicit versus explicit memory (see Schacter, 1987) and the phenomena that are the focus of this article, implicit versus explicit learning (see Reber, 1989). More specifically, researchers have been interested in determining whether there are qualitative or quantitative differences between cognition that occurs with awareness and that which occurs without awareness. Importantly, the results of such experiments have profound implications for the way in which we view human information processing since evidence of significant differences may indicate that implicit and explicit cognition are underscored by independent systems that have evolved to performed different types of cognitive tasks.

Perceptual flexibility is an example of a qualitative feature that has been used to differentiate implicit and explicit learning. More specifically, a number of researchers have suggested that implicit learning is perceptually inflexible or closely tied to the surface characteristics of the input stimulus. Explicit learning, in contrast is thought to be highly flexible and easily transferred between various stimulus domains and modalities. Dienes and Berry (1997), for example, concluded that "Implicit, rather than explicit, knowledge is often relatively inflexible in transfer to different domains" (p. 3). Similar conclusions were also reached by Berry and Dienes (1991), Reber, Knowlton, and Squire (1996), Stadler, Warren, and Lesch (2000), and Squire (1992). Such a distinction raises the possibility that the explicit system evolved to perform a distinct set of more abstract cognitive tasks. That being said, evaluating the strength of the evidence for such a distinction needs to precede any theories about its potential functional importance.

There is a substantial amount of evidence that suggests implicit learning is perceptually inflexible. Berry and Broadbent (1988), for example, found that implicit learning in a computer simulated control task only transfers when the two tasks are perceptually similar (i.e. both transport tasks or both person tasks). A comparable result to this was reported by Squire and Frambach (1990). Implicit sequence learning tasks have also been used to examine perceptual flexibility. Willingham, Nissen, and Bullemer (1989), for example, performed a serial reaction-time task which involved a sequence of colours that appeared at different positions on a computer monitor. Subjects in this experiment were required to make a particular motor response based on the colour viewed, and were either placed in a condition where there was a repeating sequence of stimulus positions (perceptual learning condition) or a repeating sequence motor responses (motor learning condition). The results of this study indicated that changing the colours in the perceptual learning condition led to an elimination of the learned response (i.e. decrease in RT). In a related study, Stadler (1989) found that the learning in a matrix-scanning task is primarily a perceptual rather than motor process.

There is, however, also a substantial amount of evidence, primarily from artificial grammar learning (AG-learning) tasks, that suggests implicit learning is not *always* perceptually inflexible. The early AG-learning study performed by Reber (1969) involved three transfer

conditions. In the first condition, the letters that made up the strings were altered; in the second condition, the grammar underlying the strings was altered and in the final condition, both elements were altered. Classification performance in this study was significantly impaired by a change to the grammar, but not by a change to the letter set. This result led Reber to conclude that the subjects had implicitly learned a series of abstract rules (i.e. the rules of the grammar) that were not tied to the surface characteristics of the input stimuli. In recent years a number of researchers have replicated and advanced Reber's basic finding. Most notably, Mathews et al. (1989) demonstrated that subjects who received a new letter set every week over a four-week period performed just as well as control subjects who received the same letter set throughout the experiment.

Despite the numerous empirical demonstrations outlined above, many researchers propose that abstract rule learning has not yet been conclusively demonstrated in AG-learning experiments (e.g. Shanks, 2005). In particular, Brooks and his colleagues have convincingly argued that similarity models can explain the transfer effects observed (Brooks, 1978; see also Brooks & Vokey, 1991; Vokey & Brooks, 1992). It is also worth noting that although significant transfer has been observed in numerous artificial grammar learning experiments, including those outlined above, there has often also been evidence of transfer decrement. That is, an advantage of same domain performance over transfer performance. This suggests that at least part of the knowledge acquired by subjects is perceptually bound (see Dienes & Altman, 1997; Dienes & Berry, 1997; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Reber, Allen, & Reber, 1999).

There is also evidence in the invariant learning literature that suggests implicit learning may not be perceptually inflexible. More specifically, researchers in this area have shown that knowledge of an invariant feature can transfer when the perceptual characteristics of the experimental stimuli are altered between the learning and test phases. For example, in an early study performed by McGeorge and Burton (1990), it was found that subjects' preference for digit strings that contained the number 3 persisted even when the font or format (digits—words and vice versa) of the strings was altered. In a similar vein, Bright and Burton (1994) found that a preference for clocks bearing a time between 6 and 12 pm transferred when clock faces were changed from digital to analogue (and vice versa). In fact, somewhat surprisingly, the performance of subjects was actually consistently *better* when the format of the clocks was altered. These results led Burton and his colleagues to conclude that perceptually flexible, abstract rules (e.g. select strings that contain a 3) can be learned unconsciously. However, a number of more recent studies have suggested that the learning occurring in the invariant task is more specific (see for example, Churchill & Gilmore, 1998). Indeed, Stadler et al. (2000) recently proposed that implicit invariant learning produces knowledge that is *hyper*specific, or excessively sensitive to any change in form or modality.

It seems surprising, given the contradictory nature of the available evidence, that perceptual inflexibility has been proposed as a defining feature of implicit learning. This conclusion becomes even more problematic, however, when we consider that the learning occurring in these tasks may not be genuinely unconscious. Implicit learning has generally been shown by demonstrating a dissociation between a subject's performance on a task and their explicit knowledge, as measured by written or spoken tests of awareness (see Cleeremans, Destrebecqz, & Boyer, 1998). However, researchers have repeatedly pointed out that reasons, other than unconscious cognition, can account for this dissociation. Two such explanations were offered by Shanks and St. John (1994), (see also Shanks, 2005) in

their influential critique of implicit learning research. Shanks and St. John propose, firstly, that even when subjects are classified as unaware, partial or correlated explicit knowledge, not measured by awareness tests, can account for performance on implicit tasks (see also Dulany, 1961). Secondly, they propose that subjects may transmit more information in their task performance than in tests of awareness simply because performance tests are more sensitive to whatever conscious information was encoded (see also Dawson & Schell, 1985; Eriksen, 1960; Reingold & Merikle, 1988). Given these criticisms, it is possible (and even acknowledged by the researchers) that subjects classified as unaware in previous transfer experiments may have actually learned explicitly. Shanks and St. John suggest that in order to rule out alternative explanations of implicit learning, an awareness test needs to measure all and only conscious knowledge (sensitivity criteria) and the relationship that actually assisted performance on the task (information criteria).

Several researchers have responded to Shanks and St. John's (1994) criticisms by developing new implicit learning paradigms with improved awareness testing techniques (e.g. Burke & Roodenrys, 2000; Lee, 1995; Lee & Vakoch, 1996). Burke and Roodenrys (2000) developed one such paradigm, which will be utilised in the current experiment. These researchers demonstrated that subjects can implicitly learn the relationship between a cue and a target (shapes or letters), such that they respond faster to cued targets than uncued targets in a simple cued reaction-time (CRT) task. Importantly, the simplicity of the relationship learned in this paradigm allowed the researchers to develop an awareness test that was both specific (thus meeting the information criterion) and exhaustive (thus meeting the sensitivity criterion). The current experiment will examine, by altering the perceptual features of the cue, the extent to which the implicit learning occurring in the CRT task is perceptually inflexible.

Another advantage of the CRT task over previous paradigms is that it allows us to compare the relative flexibility of implicit and explicit learning. Most previous implicit learning paradigms have involved complex rules which are difficult to learn consciously and strategically. This makes sense given that the best way to acquire evidence of implicit learning is to ensure that people cannot learn explicitly. However, this situation is also problematic in that if we want to conclude that implicit, but not explicit, learning is perceptually inflexible, then surely we need to *compare* the perceptual flexibility of these two types of learning (Stadler, 1997; Willingham, 1997). In addition, this comparison should ideally occur using the same task so we can be sure that any differences in flexibility are a product of the learning, rather than the type of task being performed. The CRT task involves a simple relationship that subjects often become aware of at some point during the course of the experiment. In other words, the cue–target relationship can alter the speed of responding in subjects classified as aware of the relationship as well as those identified as unaware of the relationship, and thus allows us to compare the features of implicit and explicit learning.

General method

The procedure used in the current series of experiments very much follows that utilised by Burke and Roodenrys (2000, exp. 2). Subjects were exposed to a continuous stream of serially presented shapes that replaced each other every 250 ms in the centre of a computer monitor. Subjects were instructed to press the space bar as quickly as possible when either of two shapes appeared on the screen (square and circle, for example; the targets). The

order in which the shapes appeared was random, except one of the targets was *always* preceded by the same shape (triangle, for example; the cue). Subjects were not informed of this relationship. After a number of learning trials (pairings of the cue and the target), subjects moved into a test phase which consisted of 6 trials that contained the cue–target pairing and 3 trials that contained the uncued target. On 3 of the trials that contained the cue–target pairing, the cue was perceptually dissimilar to those viewed in the learning phase.

Experiment 1

Experiment 1 was performed to compare the perceptual flexibility of implicit and explicit learning using the simple CRT task. In this experiment, the effect of changing the cue will be measured by comparing, after a number of learning phase trials, the reaction-time (RT) of subjects to targets that are preceded by an altered cue to those either preceded by an unaltered cue or no cue. If the learning of subjects is perceptually flexible then they should respond significantly faster to cued targets than uncued targets, even when the perceptual characteristics of the cue have been altered. However, if the learning of subjects is sensitive to the perceptual alterations then they should only respond significantly faster when the cue has not been altered.

The experimental stimuli utilised in the current experiment were 2-dimensional shapes (see Fig. 1). The colour and size of these shapes was altered in half of the cued test phase trials. The cue was altered on two dimensions to ensure that it was clearly perceptually dissimilar to the cue that had been viewed in the learning phase. In this experiment, and also in the second experiment, the test phase consisted of only 3 uncued targets and 6 cued targets (3 preceded by an altered cue and 3 preceded by an unaltered cue). So few test phase trials were included to limit the amount of learning that could occur in this phase (see Churchill & Gilmore, 1998; Redington & Chater, 1996 for further discussion of this issue). For the same reason, there was no gap or additional instructions given between the learning and test phases. The written awareness test utilised in this experiment was almost identical to that used in Burke and Roodenrys (2000, exp. 2) except that the recognition test
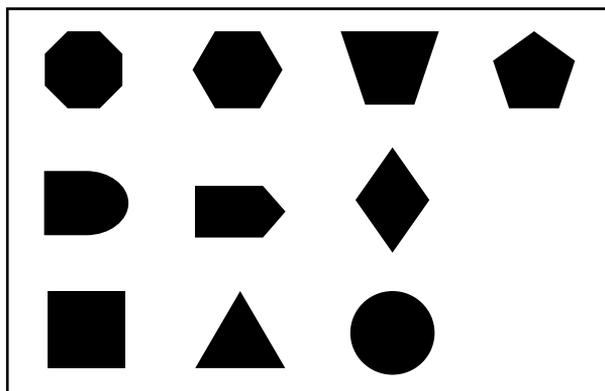

Fig. 1. The stimuli used in experiments 1 and 2. For half the subjects the square was the target (and the triangle was the cue) and for the other half the triangle was the target (and the square was the cue). The circle served as the uncued target in all conditions. All other shapes served as distractors.

included a subjective measure of confidence. The extent to which this test conclusively differentiates between aware and unaware subjects will be examined in the discussion.

Method

Subjects

Fifty-three undergraduate psychology students from Macquarie University participated in this experiment as part of a 1st year practical class. They were tested in groups of between 5 and 15 subjects. All subjects were naive with respect to the implicit learning paradigm.

Procedure

Before the commencement of the learning phase, subjects were informed that they were participating in a study designed to measure differences in left and right hand response times caused by brain hemisphere laterality. Subjects were then instructed to respond as quickly as possible by pressing the space bar with their dominant hand (hand used to write) when either a square (or triangle) or a circle appeared on the computer monitor. Subjects were finally informed that they were to fill out the questionnaire (the awareness test), which had been placed under the keyboard, as soon as they finished the computer task. Both the learning and test phases of this experiment were controlled using RSVP 3.1 [William and Tarr (no date)] running on a 15" Macintosh G3 iMac computer. Subjects sat approximately 40 cm from the computer monitor. Responses that occurred before the target, or after the end of the shape sequence for that trial, were not recorded.

Learning phase

The learning phase consisted of 108 trials. Each trial contained 8, 2-dimensional shapes (shown in Fig. 1) which replaced each other every 250 ms in the centre of the computer monitor. As in Burke and Roodenrys (2000), there was a brief pause between trials (750 ms) and thus, in order to disguise the cue–target relationship, the cue and target never appeared in the first or last position of the sequence. The shapes viewed in the learning phase were either small (2 cm × 2 cm) and green (condition 1), medium (4 cm × 4 cm) and red (condition 2) or large (6 cm × 6 cm) and blue (condition 3). Subjects were randomly assigned to one of these conditions. Six shapes in each string of 8 were randomly drawn, without replacement from the shapes, bar the diamond, shown in the top panel of Fig. 1. In 54 of the trials (cued trials) the remaining spaces in the sequence were filled by a square followed by triangle (or a triangle followed by a square). For half the subjects the square was the target (and the triangle was the cue) and for the other half the triangle was the target (and the square was the cue). The cue–target pairing appeared in a random position in each sequence. In the other 54 trials (uncued trials) the remaining spaces in the sequence were filled by a circle (uncued target) and a diamond. The circle and diamond also appeared in random positions in each trial. Subjects were randomly assigned to cues and targets. The trials appeared in a random order.

Test phase

There was no gap between the learning and test phase. The test phase consisted of 9 trials, 3 of which contained the uncued target (circle) and 6 of which contained the cued

target (square or triangle). In three of the latter trials, the target was preceded by a cue identical to that viewed in the learning phase (e.g. a green, small shape in condition 1). In the other three trials, the target was preceded by a perceptually altered cue. In condition 1, these targets were preceded by a blue, large shape (learning phase cue was green and small); in condition 2, these targets were preceded by a green, small shape (learning phase cue was red and medium), in condition 3, these targets were preceded by a red, medium shape (learning phase cue was blue and large). In order to disguise the cue–target relationship, the perceptual features of 3 (cued trials) or 4 (uncued trials) of the distractor stimuli were also altered in an identical fashion to the cue. The exact distractor stimuli altered differed randomly between subjects. The position of the uncued target or cue–target pairing in each test phase trial, like in learning phase trials, was random. In addition, the test phase trials also appeared in a random order.

Awareness test

Explicit knowledge of the cue–target relationship was assessed using a written awareness test that contained the following questions:

(1) Did you notice any way of predicting when either target shape would appear?
(2) Did you notice a relationship between any of the non-target shapes and when either target shape appeared?
(3) In this experiment it was possible to predict the arrival of one of the targets. The square was always preceded by a particular shape. Please circle which shape you think this was and guess if you are unsure.

A list of the 6 distractor and cue shape was printed horizontally below this question. The order in which the shapes appeared was randomised between subjects.

(4) Please indicate how certain you are about the shape you just picked using the scale below.

A 10 point Likert scale was printed below this question. The scale anchors were "complete guess" and "certain". In addition, "unsure" was written below the fifth point of the scale.

To be classified as unaware a subject had to respond negatively to the first two questions and incorrectly identify the cue in question 3. In contrast, to be classified as aware, subjects had to either report knowledge of cue–target relationship in question 1 or 2 or correctly identify the cue shape with some degree of certainty in the recognition test. If a subject picked the correct cue but indicated that they were unsure about their choice (less than 7 on the Likert scale), it was decided that they may have guessed correctly (or were using implicit knowledge) and therefore they were not included in the analysis.

Results

In this experiment 15 subjects were classified as being aware of the cue–target relationship and 38 subjects were classified as being unaware of the cue–target relationship. The data from 6 unaware subjects were not included in the analysis because they responded on fewer than 75% of learning phase trials. It was reasoned that these subjects either misunderstood the task or were not devoting their full attention to it. Data from an additional

2 unaware subjects were excluded because they failed to respond to any uncued targets in the test phase. This left 15 subjects classified as aware and 30 subjects classified as unaware. No subjects were removed because it was unclear whether they were unaware or aware.

RT data from the learning phase of experiment 1 were examined using a 2 (cueing: cued, uncued) 5 × 2 (awareness: aware, unaware) 5 × 9 (blocks: 1–9) mixed factorial analysis of variance (ANOVA), with awareness as a between subjects factor and block and cueing as within subjects factors. Blocks are simply the median RT of 6 trials. Thus, the first cued block is the median RT of subjects to the first 6 cued targets, the first uncued block is the median RT of subjects to the first 6 uncued targets and so on. The results of this analysis revealed a significant main effect of cueing, $F(1, 43) = 84.65$, $p < .001$, and a significant main effect of awareness, $F(1, 43) = 5.52$, $p < .05$. It also revealed a significant interaction between cueing and awareness, $F(1, 43) = 7.431$, $p < .05$, and a significant interaction between cueing and block, $F(8, 344) = 5.101$, $p < .001$. All other main effects and interactions were insignificant.

Fig. 2 shows the way in which RT changed as a function of trial block in the learning phase of this experiment. These plots suggest, firstly, that the main effect of cueing was caused by aware and unaware subjects responding faster to cued targets than uncued targets. Interestingly, this effect was present from the first block. This suggests that both groups of subjects were able to learn something of the cue–target relationship in fewer than 6 pairings of the cue and target. However, additional analysis revealed that the difference in RT to the first block of cued targets and the first block of uncued targets was not significant in either aware, $t(14) = 1.533$, $p > .146$, or unaware, $t(29) = .844$, $p > .405$ subjects. The plots additionally suggest that the significant interaction between cueing and block is being caused by both aware and unaware subjects getting faster at responding to cued targets, but not uncued targets, as the experiment progressed. It also appears that both the main affect of awareness and the interaction between cueing and awareness are caused by cueing having a much greater affect on the RT of aware subjects. Importantly, the main effect of cueing remained significant, $F(1, 29) = 30.674$, $p < .001$, when the learn-
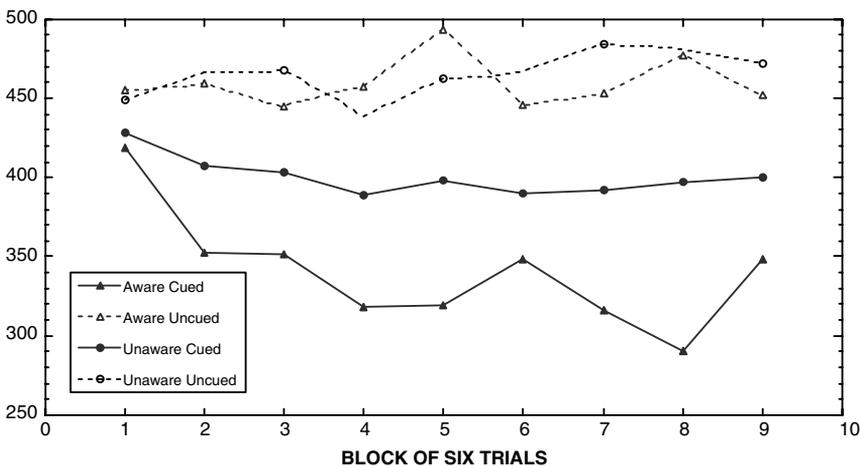

Fig. 2. Mean median RT for aware and unaware subjects as a function of target cueing in learning phase of experiment 1.

ing phase data from unaware subjects were analysed separately using a 2 (cueing: cued, uncued) 5×9 (block: 1-9) factorial ANOVA.

For each subject, the median RT to each kind (cued by unaltered cue, cued by altered cue and uncued) of test phase target was computed. Fig. 3 shows the means and standard errors of these medians for aware and unaware subjects. Median RT's from the test phase were analysed using a 2 (awareness: aware, unaware) 5×3 (cueing: altered cue, unaltered cue, no cue) mixed factorial ANOVA. The results of this analysis revealed a significant main effect of cueing, $F(2, 86) = 22.595$, $p < .001$, and a significant interaction between cueing and awareness, $F(2, 86) = 4.826$, $p < .05$. Fig. 3 shows that the main affect of cueing is most likely caused by aware and unaware subjects responding faster to both kinds of cued targets while the significant interaction is a product of the fact that unaware, but not aware subjects, were slower at responding to cued targets preceded by an altered cue.

Further analysis revealed that the difference between the RT of unaware subjects to unaltered cued targets and uncued targets was significant, $t(29) = 4.147$, $p < .001$, while the difference between their RT to altered cued targets and uncued targets was not significant, $t(29) = 1.86$, $p = .073$. Alpha for these analyses was set at .025 to control for the familywise error rate. The difference between the RT of aware subjects to unaltered cued targets and uncued targets was similarly significant $t(14) = 4.660$, $p < .001$. Unlike in unaware subjects, the difference between the RT of aware subjects to altered cued targets and uncued targets was also significant, $t(14) = 5.708$, $p < .001$. Alpha for these analyses was also set at .025 to control for the familywise error rate.

Discussion

There was a decrease in the RT of aware and unaware subjects to cued targets in the learning phase of the current experiment. This effect was far more marked in aware subjects, but clearly present in both groups. In contrast, there was no decrease in the RT of
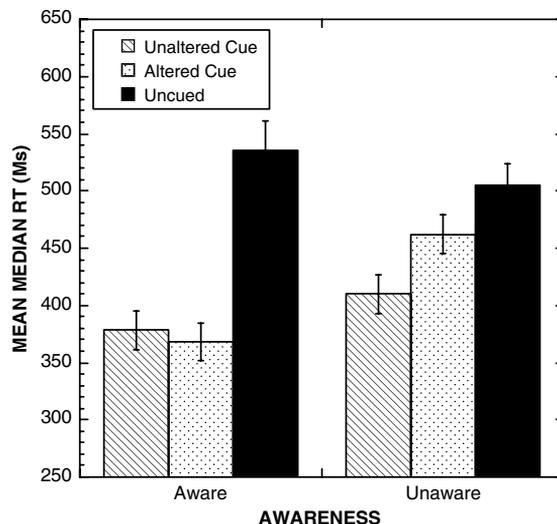

Fig. 3. Mean median RT of unaware and aware subjects to test phase targets preceded by an unaltered cue, an altered cue and no cue in experiment 1. Error bars represent ±1 standard error.

aware or unaware subjects to uncued targets. In fact, the latter subjects actually got slightly slower at responding to these targets as the experiment progressed. Taken together, these results provide further evidence in support of the view that, at least in certain circumstances, learning can occur without conscious awareness. This conclusion of course assumes that subjects classified as unaware genuinely possess no explicit knowledge of the cue–target relationship - an issue that is discussed at length below. The decrease in RT observed in unaware subjects was small in magnitude (approximately 28 ms from blocks 1–9), however, the size of this effect may have been influenced by the fact that this group most likely included a number of subjects who were either not motivated or not devoting their full attention to the task. The possibility of such subjects existing in this experiment is probably greater than in Burke and Roodenrys (2000) because testing took place in larger groups and in a less formal setting. It is also feasible that the implicit learning occurring in this task renders subjects both faster at responding to cued targets and slower at responding to uncued targets.

In the test phase, aware subjects responded significantly faster to cued targets than uncued targets, even when the perceptual features (size and colour) of the cue were altered. In fact, these subjects were actually slightly faster at responding to cued targets preceded by a perceptually altered cue. Unaware subjects, in contrast, were only significantly faster at responding to cued targets in the test phase when the perceptual features of the cue were not altered. Collectively, these results suggest that while the learning of the aware subjects in this experiment was perceptually flexible, in that it transferred perfectly when the perceptual features of the cue were altered, the learning of unaware subjects was perceptually inflexible, in that it did not transfer when the perceptual features of the cue were altered. It is, however, worth noting that the unaware subjects were in fact faster at responding to altered cued targets than uncued targets and that this difference was close to significant before the Bonferroni adjustment was made. This suggests that implicitly acquired knowledge may have some, admittedly weak, perceptual flexibility. This issue is explored in the second experiment.

Despite the difference between the RT of unaware subjects to altered cued targets and uncued targets, the test phase results generally provide further evidence that implicit learning is indeed, as was suggested by Dienes and Berry (1997), perceptually inflexible. Significantly, very few recent implicit learning experiments have failed to show at least some evidence in support of this view, however, there are notable exceptions. Manza and Reber (1997), for example, found no evidence of transfer decrement when subjects performing an AG-experiment transferred between a sequence of tones and lights (see also Bright and Burton; 1994; Newell & Bright, 2002). It is also possible that perceptual inflexibility was observed in the current experiment, but not in those outlined above, because the learning occurring is genuinely implicit. That is, it is possible, as argued by Gomez (1997) and Stadler et al. (2000), that successful transfer in the past has been based on explicit knowledge, not captured by the awareness test. It is also possible that the learning phase of the current experiment, in which subjects viewed 106 trials in which all shapes were the same size and colour, encouraged unaware subjects to be sensitive to particular perceptual characteristics of the stimuli. The latter possibility is explored further in the next experiment.

At this point, it is worth briefly recalling that Stadler et al. (2000) suggest, based primarily on evidence from a series of invariant learning experiments, that implicit learning is best characterised as *hyper*specific, or excessively sensitive to any change in form of modality. In support of this proposal, however, Stadler et al. only cite experiments in which fairly

large perceptual alterations were made to the experimental stimuli (digits to words). These experiments, therefore, were not, in a sense, actually testing whether implicit learning is sensitive to *minor* format changes. The alterations made in the current experiment (size and colour), in contrast, were much smaller, and thus can be considered a test of *hyper*specificity. Importantly, based on the results we can conclude that implicit learning may indeed be *hyper*specific, a suggestion that has also been made about implicit memory (see Crowder, 1993; Tulving & Schacter, 1990).

The conclusions reached using the results of this experiment, as mentioned previously, very much rest on the assumption that the learning occurring in subjects classified as unaware is genuinely implicit. The awareness test utilised in this experiment is very similar to the measure used in Burke and Roodenrys (2000), and like this measure seems to meet both the sensitivity and information criterion set by Shanks and St. John (1994). More specifically, the simplicity of the relationship between the cue and the target makes it unlikely that any conscious information, besides knowledge of the cue, could have assisted performance (information criterion). It also seems unlikely that subjects who were unable identify the cue, directly after performing the task, had any conscious knowledge of the cue–target relationship while performing the task (sensitivity criterion).

The subjective measure of confidence (question 4) was primarily included to determine whether subjects who correctly identified the cue in question 3, but failed to report any relevant information in question 1 or 2, were using explicit knowledge. Based on experiments that have utilised the zero-correlation criterion and guessing criterion (see Dienes & Berry, 1997), it was reasoned that subjects who correctly identified the cue with high confidence (7–10 on the Likert scale) possessed explicit knowledge of the cue–target relationship. In contrast, it was reasoned that subjects who correctly identified the cue with low confidence (below 7 on the Likert scale) may have possessed explicit knowledge but may also have either guessed or used implicit knowledge to perform the task. As such, subjects who correctly identified the cued with low confidence were removed from the analysis. No subject was removed from the analysis for this reason in experiment 1.

In conclusion, the results of the current experiment generally support the view that implicit, but not explicit, learning is perceptually inflexible. However, it is unclear whether this inflexibility is present in all conditions or rather is influenced, as has been suggested in processing accounts of transfer, by factors such as the experimental stimuli and encoding task (see Whittlesea & Dorken, 1997 for example). Put another way, it is unclear whether implicit learning is *always* perceptually inflexible. This possibility is examined in experiment 2. Importantly, the fact that there was some weak evidence of transfer in the current experiment suggests that there may be situations in which we can encourage a significant amount of perceptual flexibility.

Experiment 2

Processing accounts of implicit learning assume that the expression of learning, independently of whether it is implicit or explicit, depends on the match between the operations that were engaged during the learning and test phases. Such accounts claim that the more congruency between the operations, the greater the expression of the learning (Newell & Bright, 2002). In terms of transfer across domains, this theory predicts that perceptual inflexibility will be observed in situations where the learning of subjects is focused on the surface characteristics of the experimental stimuli. If, in contrast, the subjects are

encouraged to encode conceptual or semantic features then their learning should be less sensitive to structural alterations (Whittlesea & Dorken, 1997 provide an especially clear processing account of transfer). In the last decade processing accounts of transfer have grown in popularity (see Manza & Reber, 1997; Stadler, 1997; Whittlesea & Dorken, 1993, 1997; Willingham, 1997). This increased support is primarily due to the fact that there is a growing number of studies that suggest that the amount of transfer in implicit, like explicit, learning episodes depends on factors such as task demands, instructions, experimental stimuli and intention.

Whittlesea and Dorken (1993), for example, performed an AG-learning experiment in which two groups of subjects were exposed to identical learning phase strings. The first of these groups was required to memorise each string while to second group was required to indicate whether particular letters were repeated. The results of this study indicated that both groups of subjects were able to successfully classify new strings that were constructed using letters viewed in the learning phase. However, only subjects in the second group were able to classify strings that were constructed from a novel letter set. The researchers, thus, suggested that the analysis of repetitions had provided these subjects with abstract knowledge that could be applied regardless of the surface structure of the stimuli. In contrast, the instructions given to the memorisation subjects had prompted them to focus on the perceptual properties of individual items. Based on these findings, Whittlesea and Dorken concluded that the narrow transfer often observed in implicit learning experiments is not due the operation of an independent learning mechanism that produces qualitatively different representations. Rather task instructions, primarily aimed at distracting subjects from the rules, leads to perceptually focused learning (see also Whittlesea & Dorken, 1997).

Manza and Reber (1997), (see also Reber & Allen, 1978) found that variations in experimental stimuli can also have a significant effect on the perceptual flexibility of AG-learning. In the learning phase of this experiment, subjects were required to memorise grammatical strings that were constructed using either one (letter set A) or two letter sets (letter set A and B). They were then asked to classify strings that were constructed from letter set A, B and a third, novel letter set (letter set C). All subjects in this experiment showed transfer to the novel letter set. However, this effect was far more pronounced in the subjects who were exposed to both instantiations in the learning phase. This suggests that exposing the subjects to two letter sets in AG-learning experiments encourages the establishment of abstract representations. Manza and Reber additionally found that the presentation of simple bigrams during the learning phase promotes the build up of fragmentary representations.

Invariant learning studies, such as Bright and Burton (1994), have also provided evidence that supports processing accounts. In Bright and Burton, subjects were shown a series of analogue clock faces and either asked to write out the time displayed (experiment 2) or judge the "quality" of the clock (experiment 3). The results of these experiments indicated that although all subjects performed significantly above chance when asked to classify digital clock faces, classification performance was superior in experiment 2. Importantly, the awareness test indicated that explicit knowledge, unlike performance, was not influenced by task instructions. Bright and Burton, thus, concluded that the perceptual flexibility of implicit invariant knowledge, differs depending on whether attention is focused on superficial or semantic aspects of the stimuli viewed in the learning phase. In a similar vein, Newell and Bright (2002) found that subjects were better able to transfer

(digits to words and vice versa) knowledge of an invariant ''3'' when the orienting task encouraged semantic encoding of learning phase number strings.

The current experiment aimed to further examine processing accounts of transfer by looking at whether the relative flexibility of the implicit and explicit learning occurring in the CRT task is affected by the stimuli viewed in the learning phase. More specifically, in this experiment the same perceptual alterations will be made to the cue (i.e. the altered cue will be a novel colour and size), but all learning phase stimuli will appear in three colours and sizes, except the cue which will appear in two colours and sizes. It is hoped that the viewing of different coloured and sized shapes will encourage unaware subjects to encode the experimental stimuli at a level that is not sensitive to surface characteristics.

If the learning of unaware (or aware) subjects in the current experiment, as in experiment 1, is perceptually flexible then they should, in the test phase, respond significantly faster to cued targets than uncued targets, even when the perceptual characteristics of the cue have been altered. However, if the learning of unaware (or aware) is sensitive to the perceptual alterations then they should only respond significantly faster when the cue has not been altered.

Method

Subjects

Sixty-three new, naive undergraduate psychology students from Macquarie University participated in this experiment as part of a 1st year practical class. They were tested in groups of between 10 and 22 subjects. English was the first language of all subjects.

Procedure

The experiment 2 procedure was the same as the experiment 1 procedure with the following exceptions:

Learning phase

The learning phase was identical to the experiment 1 learning phase, except all shapes (shown in Fig. 1), bar the cue but including the target, appeared in three colour-size combinations: blue, large (6 cm²); red, medium (4 cm²) and green, small (2 cm²). Each of these combinations was shown an equal number of times (36×) and the particular combination shown in each trial was random. The cue appeared in two colour-size combinations. In condition 1, the cue was small and green on 50% of the cued trials and red and medium on 50% of the cued trials; in condition 2, the cue was red and medium on 50% of the cued trials and blue and large on 50% of the cued trials; in condition 3 the cue was green and small on 50% of the cued trials and blue and large on 50% of the cued trials. The particular size and colour of the cue viewed in each trial was random.

Test phase

The cues viewed in the test phase of this experiment were the same as those viewed in the test phase of experiment 1. That is, the familiar cued target was preceded by a green, small shape in condition 1; a medium, red shape in condition 2 and a large, blue shape in condition 3. In contrast, the altered cued target was preceded by a blue, large shape in con-

dition 1; a green, small shape in condition 2 and a red medium shape in condition 3. All other shapes, like in the learning phase, appeared in one of three different colour/size combinations. The particular combination used for each of the distractor shapes was chosen randomly. The position of the uncued target or cue–target pairing in each test phase trial, like in learning phase trials, was also random. In addition, the test phase trials also appeared in a random order.

Awareness test

The awareness tests were identical to those used in experiment 1. In addition, the same criteria were used to classify subjects as aware or unaware.

Results

In this experiment 12 subjects were classified as being aware of the cue–target relationship, 44 subjects were classified as being unaware of the cue–target relationship and in 7 subjects it was unclear. Data from the third group were removed from the analysis. The data from an additional 6 unaware subjects and 2 aware subjects were removed because they responded on fewer than 75% of learning phase trials. It was, again, reasoned that these subjects either misunderstood the task or were not devoting their full attention to it. Data from a final unaware subject were not included in the analysis because they failed to respond to any cued targets in the test phase. This left 10 subjects classified as aware and 37 subjects classified as unaware. Rates of awareness were fairly low in this experiment, possibly because the varied colours and sizes made the task slightly more difficult, but as the aware group showed fairly consistent, significant effects, it did not seem necessary to run additional subjects.

RT data from the learning phase of experiment 2 were examined using a 2 (cueing: cued, uncued) 5×2 (awareness: aware, unaware) 5×9 (blocks: 1–9) mixed factorial ANOVA, with awareness as a between subjects factor and block and cueing as within subjects factors. The results of this analysis revealed a significant main effect of cueing, $F(1, 44) = 94.294$, $p < .001$, and a significant main effect of awareness, $F(1, 44) = 4.985$, $p < .05$. It also revealed a significant interaction between cueing and awareness, $F(1, 44) = 14.402$, $p < .001$, and a significant interaction between cueing and block, $F(8, 352) = 5.653$, $p < .001$. All other main effects and interactions were insignificant.

Fig. 4 shows the way in which RT changed as a function of trial block in the learning phase of this experiment. These plots suggest, firstly, that the main effect of cueing is being caused by aware and unaware subjects responding, on average, faster to cued targets than uncued targets. The plots also suggest that the significant interaction between cueing and block is being caused by the fact that both aware and unaware subjects got faster at responding to cued targets and slower at responding to uncued targets as the experiment progressed. This effect was particularly marked in unaware subjects whose increase in RT to uncued targets was greater than their decrease in RT to cued targets. Once again, it is possible that this effect is either being caused by subjects losing motivation or by the learning rendering subjects both faster to respond the cued targets and slower to respond to uncued targets. Aware subjects did not get slower at responding to uncued targets in the previous experiment but this may simply be due to individual differences in the motivation levels of these subjects. The fact that the aware subjects in the previous experiment
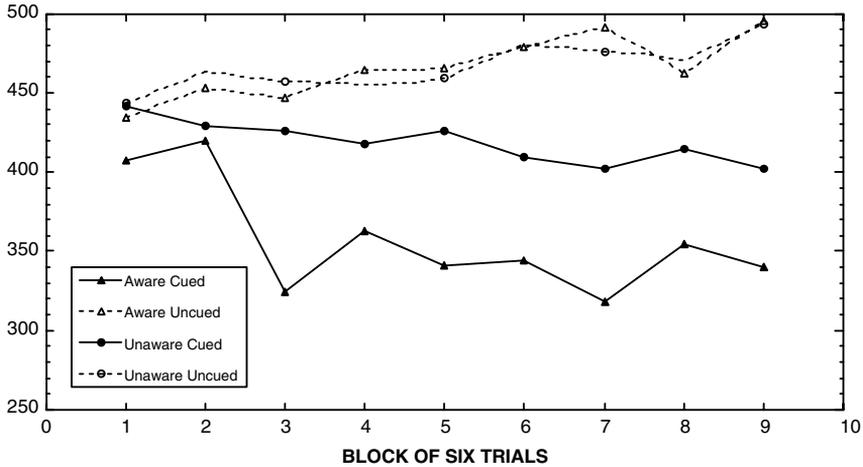
Fig. 4. Mean median RT for both aware and unaware subjects as a function of target cueing in learning phase of experiment 2.

showed a greater decrease in RT (lowest RT to cued target is 289 ms in experiment 1 compared to 318 ms in experiment 2) supports possibility.

Returning to the plots, it appears, like in experiment 1, that the main effect of awareness and the significant interaction between cueing and awareness was caused by cueing having a much greater affect on the RT of aware subjects. Importantly, when the learning phase data from unaware subjects were analysed separately, both the main effect of cueing, $F(1, 35) = 52.371$, $p < .001$, and the interaction between cueing and block, remained significant, $F(8, 280) = 3.701$, $p < .001$.
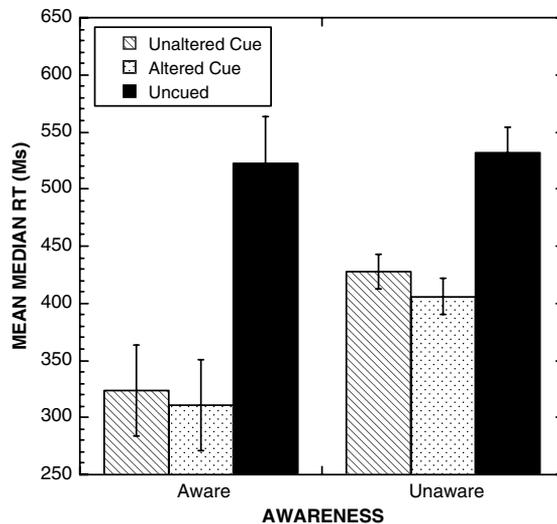

Fig. 5. Mean median RT of unaware and aware subjects to test phase targets preceded by an unaltered cue, an altered cue and no cue in experiment 2. Error bars represent ±1 standard error.

For each subject, the median RT to each kind (cued by unaltered cue, cued by altered cue and uncued) of test phase target was computed. Fig. 5 shows the group means and standard errors of these medians for aware and unaware subjects. Median RT's from the test phase were analysed using a 2 (awareness: aware, unaware) 5 × 3 (cueing: altered cue, unaltered cue, no cue) mixed factorial ANOVA. The results of this analysis revealed a significant main effect of cueing, $F(2, 88) = 21.124$, $p < .001$, and a significant main effect of awareness, $F(1, 44) = 9.437$, $p < .01$. Unlike in the previous experiment, the interaction between cueing and awareness was insignificant, $F(2, 88) = 1.667$, $p > .190$. Fig. 5 suggests that the main effect of cueing is being caused by aware and unaware subjects responding faster to (altered and unaltered) cued targets than uncued targets. This figure also suggests that the main effect of awareness is due to the effect of cueing being much stronger in aware subjects.

The analysis of the test phase data suggests that the learning of unaware subjects in experiment 2, unlike in experiment 1, is in no way perceptually bound. Because all the groups in experiment 1 and experiment 2 were tested in identical conditions during the same period of the academic year, it seemed reasonable to conduct a 2 (experiment: experiment 1, experiment 2) 5 × 3 (cueing: altered cue, unaltered cue, no cue) mixed factorial ANOVA on the test phase data from unaware subjects. The results of this analysis revealed a significant main effect of cueing, $F(1, 64) = 17.100$, $p < .001$, and significant interaction between cueing and experiment, $F(1, 64) = 3.121$, $p < .05$. Fig. 6 shows the test phase data of unaware subjects from experiments 1 and 2.

This figure suggests, firstly, that the main effect of cueing is being caused by both groups of unaware subjects responded faster to (altered and unaltered) cued targets than uncued targets. This figure also suggests that the significant interaction between cueing and experiments is a product of unaware subjects in experiment 1, but not experiment 2, responding slower to the altered cued target than the unaltered cued target. Unaware subjects in experiment 2 were actually slightly faster to respond to altered cued targets. Further anal-
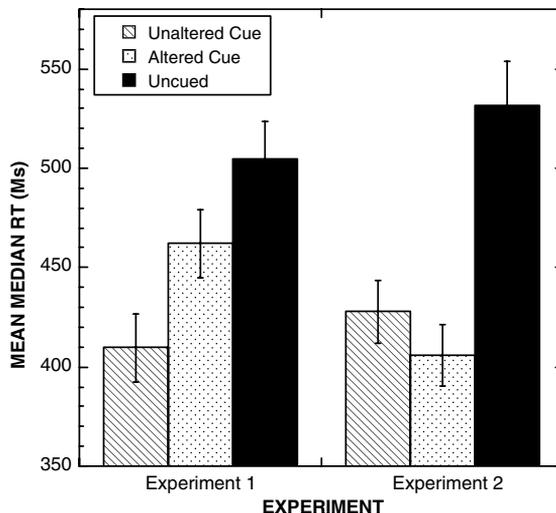

Fig. 6. Mean median RT of unaware subjects to test phase targets preceded by an unaltered cue, an altered cue and no cue in experiments 1 and 2. Error bars represent ±1 standard error.

ysis revealed that the difference between the RT of unaware subjects to altered cued targets in experiments 1 and 2 was significant, $t(64) = 2.191$, $p < .05$.

Experiment 2 and general discussion

There was a decrease in the RT of aware and unaware subjects to cued targets in the learning phase of experiment 2. Both groups of subjects also showed an increase in RT to uncued targets. It is possible, as suggested above, that the latter effect is being caused either by subjects losing motivation. It is also possible that the learning renders them both faster at responding to cued targets and slower at responding to uncued targets. The positive effect of cueing (decrease in RT to cued targets) was once again much stronger in subjects classified as aware.

Aware and unaware subjects responded significantly faster to both unaltered and altered (colour and size) cued targets than uncued targets in the test phase of experiment 2. Unaware subjects in the previous experiment, in contrast, only responded significantly faster to cued targets than uncued targets when the perceptual features of the cue were not altered. In addition, it was found that unaware subjects responded significantly faster to altered cued targets in the second experiment than in the first experiment. These results suggest, firstly, that neither the learning of aware nor, more importantly, unaware subjects in the current experiment was perceptually inflexible and that the learning of unaware subjects was significantly more flexible in the second experiment than in the first. Importantly, these findings, coupled with those from the previous experiment, provide support for processing accounts of implicit learning (see for example Whittlesea & Dorken, 1997). That is, the results suggest that the perceptual flexibility of implicit, like explicit, learning can be influenced by whether or not subjects focus on perceptual, or higher order, aspects of the experimental stimuli. More specifically, it appears that the inclusion of different coloured and sized stimuli in the learning phase encouraged the unaware subjects to encode the cue at a conceptual, or at least perceptually flexible, level.

It is, of course, possible that subjects in the second experiment simultaneously learned two distinct cue–target relationships. Such a possibility would account for slower initial acquisition of the cue–target relationship, and might be able to explain greater transfer to novel cues, since the new cue might be more similar to an average of the training exemplars than it would be to a particular training exemplar (as was used in experiment 1). If we ignore the colour of the cues, and concentrate on their sizes, then this explanation predicts that in experiment 2 transfer should be best in condition 3 (in which subjects learned with a big and a small cue and were tested with a medium sized cue) next best in condition 1 (in which they learned with small and medium and transferred to large) and worst in condition 2 (in which training was with a medium and a large cue, and test was with a small cue). In fact, for the unaware subjects, the cueing × condition interaction was not near significance, $F(4, 68) = 0.463$, $p = 0.763$, effectively ruling this explanation out.

It was suggested above that the current experiment provides evidence that the flexibility of implicit, like explicit, learning can differ depending on whether or not subjects are encouraged to focus on perceptual aspects of the learning phase stimuli. While this does not necessarily mean that implicit and explicit learning cannot be differentiated based on their perceptual flexibility, as has been suggested in the past (see Dienes & Berry, 1997), it is much more consistent with the idea that the underlying learning processes are similar. Previous experiments that have claimed to show the perceptual inflexibility

of implicit learning may simply have used conditions that encouraged inflexibility. It appears that both implicit and explicit learning can be flexible or inflexible, depending on the learning conditions, but flexibility is easier to encourage in aware subjects. This may be because in experiment 1, in which a single exemplar of the cue was used, aware subjects, who had learned enough about the cue to answer written questions about it, had therefore learned a relationship between the stimulus category (e.g. triangle) and the target, and so transferred this learning to new cue exemplars. Unaware subjects, on the other hand, may have learned only that a particular exemplar predicted the target in this experiment, and so showed less transfer to new exemplars. When they were trained with multiple exemplars, in experiment 2, they too may have learned the category–target relationship, and so showed as much transfer as aware subjects.

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