Human implicit memory for irrelevant dimension values is similar to rats’ incidental memory in simultaneous discrimination tasks

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Abstract

Participants completed a category-learning task in which they needed to discover which of three stimulus dimensions (shape, color, or size) was relevant. After meeting a learning criterion (nine of 10 consecutive correct responses), participants continued making categorization choices and response latencies associated with these trials were examined. In both Experiments 1 and 2, people responded reliably faster when correct responses matched the previous responses with respect to irrelevant dimension values. Thus, they demonstrated a form of incidental short-term memory analogous to that we previously reported in studies of rats. In Experiment 3, participants’ explicit memory for irrelevant dimension values was assessed after category learning was complete. The results indicated that people were unaware of the irrelevant dimension values encountered in trials preceding surprise probe trials. This indicates that memory for the irrelevant dimension values was implicit (i.e. unconscious). The findings are discussed with respect to both human and non-human studies of hippocampus-independent memory and implicit memory.

Keywords: Implicit memory; Incidental memory; Priming; Categorization; Response latencies

1. Introduction

It is well established that the hippocampus and anatomically related structures of the medial temporal lobe are critically involved with normal memory function. Numerous studies of humans, non-human primates, and non-primates have demonstrated memory impairments following damage to the hippocampal formation (Eichenbaum and Cohen, 2001; Squire and Kandel, 1999). For example, patients with damage limited to the hippocampus proper or to the hippocampal formation exhibit both impaired recall and impaired recognition memory for both verbal and non-verbal materials (Press et al., 1989; Reed and Squire, 1997; Renpel-Closter et al., 1996; Squire et al., 1990; Zola-Morgan et al., 1986). Monkeys with medial temporal lobe lesions also are impaired across a number of memory-dependent tasks including concurrent discrimination, delayed non-matching to sample, object discrimination, and spatial delayed-response tasks (Alvarez et al., 1994; Zola-Morgan and Squire, 1985). Likewise, rats with analogous lesions exhibit impaired
memory when tested in water mazes and radial arm mazes (Becker et al., 1980; Morris et al., 1982; Olton et al., 1979; Sutherland and McDonald, 1990).

It is also clear, however, that not all memory func-
tions depend upon the integrity of the hippocampus. For example, patients with hippocampal lesions exhibit normal skill, habit, and category learning, normal perceptual, repetition and semantic priming, and normal delay conditioning (Clark and Squire, 1998; Graf et al., 1985; Hamann and Squire, 1997; Knowlton and Squire, 1993; Milner et al., 1968; Reber et al., 1996; Reber and Squire, 1998; Reed et al., 1999). Monkeys with hip-
locampus lesions also can acquire new motor and cog-
nitive skills and can solve simple visual discrimination problems (Mairum et al., 1984; Orbach et al., 1982; Zola-Morgan and Squire, 1984). Rats with hippocam-
pal lesions show normal or supranormal approach and avoidance conditioning and, more often than not, per-
form simple discrimination tasks normally (Isaacsen et al., 1961; O'Keeffe and Nadel, 1978; Schmeitzl and Isaacsen, 1967).

The fact that the hippocampus is essential to nor-
mal performance on some memory tasks, but ap-
parently superfluous to performance of other mem-
ory tasks, has led to the broad distinction between hippocampus-dependent (HD) memory and hippo-
campus-independent (HI) memory. Psychologists and neuroscientists have attempted to clarify the distinction between HD memory and HI memory by distinguis-
ishing between the types of information associated with the two memorial forms (e.g. configural/elemental, Sutherland and Rudy, 1989; episodic/semantic, Olton et al., 1979; spatial/non-spatial, O'Keeffe and Nadel, 1978). A prominent means of understanding the differ-
ence between HD and HI memory that comes from studies of human amnesia is the contrast between declarative (explicit) and non-declarative (implicit) memory (Squire and Zola-Morgan, 1996). According to this view, an essential difference between HD and HI memory is that HD memory involves conscious recol-
lection, whereas HI memory does not. That is, whether or not a memory is available to conscious awareness is determined by whether or not the memory is HD, no matter if it is a memory for configural/elemental associ-
ations, episodic or semantic knowledge, or spatial/non-
spatial information.

It should be apparent that determining whether or not a particular memory task is HD or HI is a relatively uncomplicated matter regardless of the species being examined. As long as histological or imaging tech-
niques can reasonably assure one of the location and extent of lesions, memory impairment is attributable to hippocampal damage in a straightforward manner. By contrast, classifying memory abilities as explicit or implicit is at best a clear-cut affair only when studying human amnesic patients. This is because we lack the means of determining the content of conscious aware-
ness for all species except our own.

Information learned implicitly by humans is often incidentally acquired. That is, participants frequently are asked to make judgments about stimuli without be-
ing instructed to remember the identity of the stimuli. Furthermore, such incidental memories are usually ir-
relevant to task performance in as much as memory of the identity of previously judged stimuli is not required in order to make additional judgments. Implicit mem-
ory in humans, therefore, can often be characterized as incidental memory for irrelevant cues. Unlike the concept of implicit memory, the concept of incidental memory for irrelevant cues lends itself to operational definitions that can be applied to both humans and non-
human species. Thus, investigations of incidental mem-
ory for irrelevant cues may provide the closest possible approximation to studies of implicit memory in non-
humans.

For example, Kesner (1998) examined running times of rats making sequences of 12 forced responses in 12-arm radial mazes. Three or four of the 12 re-
ponses involved revisiting maze arms, and for some rats food reinforcement was available on all visits. Memory for previously visited locations was consid-
ered incidental because the task situation did not “in-
struct” the animals to remember them. In addition, memory of previously visited locations was also ir-
relevant because it was not required in order to obtain food reinforcement. Despite being both incidental and irrelevant, rats demonstrated memory for previously visited maze arms in that running times were faster compared to when they visited non-repeated arms. Similarly, using two different two-alternative forced-
choice problems (delayed matching-to-sample and dis-
crimination), we found that rats made correct responses more quickly when irrelevant cues were the same as on the previous trial compared to when irrelevant cues had changed from the previous trial (Reed et al., 2003).
If tasks used with non-humans to reveal incidental memory for irrelevant cues represent the best approximations to studies of implicit memory in humans, it may be instructive to examine human performance on similar tasks. The studies described herein do just that. In particular, we employ a memory task intended to be analogous to those we previously used to examine short-term incidental memory in rats. We appraise the performance of human participants, however, and test their subsequent conscious awareness of the irrelevant dimension values. That is, we attempt to determine whether or not human short-term incidental memory for irrelevant dimension values constitutes a form of implicit memory.

2. Experiment 1

In our first study, human participants completed a task intended as an analogue to the task we examined using rats in our previous report (Reed et al., 2003, Experiment 2). The previously described task required rats to make a series of two-alternate forced choices in a T-maze. Three cues were always available in the form of a light placed over one of the choice arms, a colored and textured insert placed in one of the choice arms, and the turns (right or left) associated with the choice arms. For any one rat, only one of these cues was consistently paired with the location of reinforcement and the other two cues were irrelevant. Rats demonstrated intentional learning of the relevant cues in that they came to respond to these cues in an appropriate and consistent manner. In addition, the rats exhibited incidental memory for the values of the irrelevant di-

mensions because they responded more quickly when these values remained the same from one trial to the next.

The task used in this experiment required human participants to complete a series of categorization task trials in which they had to choose between two stim-

uls that could differ with respect to shape, color and size. After each choice participants were provided ac-

curacy feedback. In the first part of the study, partici-

pants performed this task until they reached the same learning criterion we had previously used in our stud-

ies of rats. Thereafter, participants continued the same task for a number of trials and we compared response latencies for trials on which irrelevant dimension val-

ues remained the same as on the preceding trials with response latencies for trials on which irrelevant dimen-
sion values were different compared to the preceding trials. That is, we attempted to replicate our basic finding of incidental memory for short-term memory for irrelevant cues in rats using human participants and a task that was analogous to the one used with rats.

2.1. Method

2.1.1. Participants

Twenty-four undergraduates at East Carolina Uni-

versity volunteered their participation in exchange for extra credit in psychology courses.

2.1.2 Procedure

Stimuli and instruction presentations, response recordings, and data collection were controlled by PCs connected to 17-in. color monitors and standard key-

boards. Stimuli were filled circles (C) and squares (SQ) colored red (R) or blue (B). Large (L) and small (SM) circles were 2 and 1 cm in diameter, respectively. Large and small squares had 2 and 1 cm sides, respectively. Each participant was presented with one of the six versions of the task described in Table 1. Each discrimi-
nation was randomly assigned to insure that an equal number of participants (n = 4) were exposed to each version of the task. For two versions of the task, the relevant dimension was color. For one of these, R was the correct value and for the other B was the correct value. For two other versions of the task, the relevant dimension was shape. For one of these C was the cor-

rect value and for the other SQ was the correct value. Finally, for two versions of the task, the relevant dimension was size. For one of these L was the correct value and for the other SM was the correct value. For all ver-

sions of the task, correct choices appeared on the left and on the right with equal frequency.

As in Reed et al. (2003), the values of the irrelevant dimensions covered. In particular, when irrele-
vant, L, R, and C varied together and SM, B, and SQ varied together. For example, in one version, color was the relevant dimension and R the correct value and the irrelevant dimensions of shape and size covar-

ied. Thus, L–R–C and SM–R–SQ stimuli were correct choices and L–B–C and SM–B–SQ stimuli were incor-
rect choices. See Table 1 for a complete description of the stimuli associated with each version of the task.
Table 1
Stimuli used in the six versions of the concept-learning task

<table>
<thead>
<tr>
<th>Task session</th>
<th>Relevant dimension</th>
<th>Correct value</th>
<th>Correct choices</th>
<th>Incorrect choices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Color</td>
<td>R</td>
<td>L = R, C = SM - B - SQ</td>
<td>L = B, C = SM - B - SQ</td>
</tr>
<tr>
<td>2</td>
<td>Color</td>
<td>R</td>
<td>L = C = SM - B - SQ</td>
<td>L = R, C = SM - B - SQ</td>
</tr>
<tr>
<td>3</td>
<td>Shape</td>
<td>C</td>
<td>L = R, C = SM - B - C</td>
<td>L = R, C = SM - B - SQ</td>
</tr>
<tr>
<td>4</td>
<td>Shape</td>
<td>SQ</td>
<td>L = R, C = SM - B - SQ</td>
<td>L = B, C = SM - B - C</td>
</tr>
<tr>
<td>5</td>
<td>Size</td>
<td>L</td>
<td>L = R, C = SM - B - SQ</td>
<td>L = B, C = SM - B - SQ</td>
</tr>
<tr>
<td>6</td>
<td>Size</td>
<td>M</td>
<td>SM - R, C = SM - B - SQ</td>
<td>L = B, C = SM - B - SQ</td>
</tr>
</tbody>
</table>

Colors were red (R) and blue (B). Shapes were circle (C) and square (SQ). Sizes were large (L) and small (M).

Each correct stimulus and incorrect stimulus within each discrimination task was combined to create four pairs of stimuli in which each stimulus of the pair was equally likely to be presented to the left or to the right of the other, thus creating eight different types of trials. For each block of eight trials, the order of the eight trial types was random with the constraint that each was tried only once per block.

The concept-learning task included three phases. First, participants completed concept-learning trials until a criterion of nine of 10 consecutive correct responses was met. The number of trials required to meet the criterion was calculated by counting the number of trials that preceded the criterion run. Thus, when a participant immediately started at the criterion run, the number of trials required to learn the nature of the category was zero.

Second, participants continued the concept-learning task until they completed 40 additional overtraining trials. We anticipated that human participants would learn the categories rather rapidly, whereas rats required a large number of trials to solve similar problems. In addition, we were concerned that reaction times could be especially variable during the early trials and that such variability might obscure the effect in which we were interested. We included the overtraining trials so that we could compare reactions for same and different trials when response latencies were likely to be more stable.

Finally, participants continued the task until they responded to five additional same trials and five additional different trials. Same trials were defined as those on which the correct stimulus was identical to the correct stimulus on the preceding trial. Different trials were defined as those on which the correct stimulus was not identical to the correct stimulus of the preceding trial. The three phases of the concept-learning task were continuous and indistinguishable to the participants.

The concept-learning task consisted of a series of two alternative, forced-choice trials. On each trial, two different stimuli appeared on the screen. Stimuli were centered vertically and their centers were located 9 cm from either the right or left side of the screen. Participants used the keyboard to indicate which of the two stimuli they thought was an instance of the to-be-learned concept. If they thought the right-hand stimulus was an example of the concept, they pressed the "R" key. If they thought the left-hand stimulus was an example of the concept, they pressed the "L" key. After each response, the stimulus disappeared and subjects received feedback about their accuracy. If they made the correct response, the word "CORRECT" appeared centered on the screen for 3 s. If they made the incorrect response, the word "WRONG" appeared centered on the screen for 3 s. The next trial began 3 s after the visual feedback ended.

Participants were told that response latencies were being recorded. They were instructed to make as many accurate responses as they could, but to also make their responses as quickly as possible. The entire task took each participant less than 30 min to complete. After completion, participants were debriefed, assigned extra credit, and thanked for their participation.

2.2. Results and discussion

The number of trials required for participants to meet the learning criterion ranged from 0 to 14 (M = 6.5, S.E.M. = 0.6). The numbers of trials required to meet the learning criterion were compared for the three different concepts (i.e., color, shape, and size). A one-way, between-participants ANOVA revealed that the number of trials did not differ significantly for the three con-
on the intentional task. The analysis also indicated that responses made after overtraining were significantly faster than those made immediately after meeting the learning criterion, $F(1, 23) = 14.34, P < .05$, indicating that practice allowed for faster responses. The interaction between these two factors was not statistically significant, $F(1, 23) = 1.00, P > .05$.

The five same trials and the five different trials that followed the end of the criterion run most closely were also examined using a two (same versus different) by five (trial) within-participants ANOVA. Consistent with the results reported above, this analysis indicated that responses on the same trials were faster than responses on different trials, $F(1, 92) = 6.92, P < .05$. The main effect of trial, $F(4, 92) = 2.31, P > .05$, and the interaction, $F(4, 92) = 0.82, P > .05$, were not statistically significant. This indicates that the speed advantage exhibited on same trials was stable, and did not develop with practice across these trials. This finding is consistent with the idea that the form of incidental memory exhibited by participants is similar to repetition priming, an influence of implicit memory that can be measured after only a single previous exposure to a stimulus.

3. Experiment 2

In our second study, participants were tested using a modified version of the task employed in Experiment 1. In the modified version of the task, participants' explicit memory for irrelevant dimension values was indexed at different points in time after they had met the learning criterion. We expected that the pattern of response latencies would replicate the finding of Experiment 1. In addition, we predicted that performance on the explicit memory task would be no better than one could anticipate if participants made guessing responses. Thus, we expected to find that the incidental memory for irrelevant dimension values demonstrated in Experiment 1 could also be characterized as implicit memory.

3.1. Method

3.1.1. Participants

Participants were 48 undergraduates at East Carolina University who volunteered their time in exchange for extra credit in psychology courses. Half of
the participants were assigned to the criterion condition and the others were assigned to the over-training condition. None of the Experiment 2 participants had participated in Experiment 1.

3.1.2. Procedure

The procedure was the same as for Experiment 1 with the following exceptions. For the criterion condition, the concept-learning trials ended after participants completed the post-criterion same and different trials. For the over-training condition, the concept-learning trials ended after participants completed the post-over-training same and different trials. After participants completed the same and different trials, they each completed a single surprise, two-alternative, forced-choice recognition memory trial. On this trial, the two correct stimuli were presented side by side on the monitor. The side of the screen on which any particular correct stimulus was presented was counterbalanced across participants within conditions. On-screen instructions told participants to indicate which stimulus had been presented on the penultimate concept-learning trial. The to-be-remembered stimulus was always the one participant selected on the penultimate concept-learning trial, although they were not informed about this. Participants used the same choice keys used during the concept-learning task to make responses on the recognition trial. Recognition trial responses were made approximately 30 s after the last of the timed concept-learning trials.

3.2. Results and discussion

The number of trials required to meet the learning criterion ranged from 0 to 45 (M = 4.75, S.E.M. = 1.56). The number of trials required to meet the learning criterion were examined using a two (condition) by three (concept type) between-participants ANOVA. The main effect of condition, F(1, 42) = 2.20, P > .05, the main effect of concept type, F(2, 42) = 2.00, P > .05, and the interaction, F(2, 42) = 0.77, P > .05, were all statistically insignificant. Thus, the three different concepts were learned with about equal ease.

Participants made errors on only 1.25% of the response latency trials. Two participants in the criterion condition each made one error and four participants in the overtraining condition made one from to three errors. Response latencies were always based on only times from trials on which participants responded correctly.

Mean response latencies for same and different trials from participants in the criterion condition are presented in Fig. 2. For trials completed immediately after the learning criterion was met, response latencies were significantly faster for same trials (M = 645.33 ms, S.E.M. = 75.84) compared to different trials (M = 645.33 ms, S.E.M. = 75.84), t(23) = 2.06, P < .05. In addition, criterion condition participants responded correctly equally often on same trials (M = 4.96, S.E.M. = .04) and different trials (M = 4.96, S.E.M. = .04) for which response latencies were examined. As was the case in Experiment 1, the five same trials and the five different trials that followed the end of the criterion run most closely were also examined using a two (same versus different) by five (trial) within-participants ANOVA. Consistent with the results reported above, this analysis indicated response times on the same trials were faster than responses on different trials, F(1, 92) = 4.68, P < .05. The main effect of trial, F(4, 92) = 0.94, P > .05, and the interaction, F(4, 92) = 1.04, P > .05, were not statistically significant. Taken together, these results replicate the findings of Experiment 1 in that they provide a demonstration of incidental memory for irrelevant dimension values and indicate that the same trial advantage is stable across trials.

Mean response latencies for same and different trials from participants in the over-training condition are presented in Fig. 3. Response latencies were examined using a two (same versus different) by two (post-
criterion versus post-overtraining) within-participants ANOVA. The analysis indicated that responses on same trials \(M = 513.02\) ms, S.E.M. = 45.62) were significantly faster compared to different trials \(M = 589.61\) ms, S.E.M. = 68.62), \(F(1, 23) = 14.34, P < 0.05\). Thus, the basic finding from the previously reported rat experiments was replicated in this study of human category learning. That is, incidental memory for irrelevant dimension values enhanced speed of responding on the intentional task. The analysis also indicated that responses made after overtraining \(M = 512.23\) ms, S.E.M. = 42.90) were significantly faster than those made immediately after meeting the learning criterion \(M = 590.40\) ms, S.E.M. = 69.90), \(F(1, 23) = 15.12, P < 0.05\), indicating that practice allowed for faster responses. The interaction between these two factors was not statistically significant, \(F(1, 23) = 1.00, P > 0.05\).

The five same trials and the five different trials that followed the end of the criterion run most closely were also examined using a two (same versus different) by five (trial) within-participants ANOVA. The analysis indicated responses on the same trials were faster than responses on different trials, \(F(1, 92) = 27.44, P < 0.05\). The main effect of trial, \(F(4, 92) = 2.35, P > 0.05\), and the interaction, \(F(4, 92) = 0.61, P > 0.05\), were not statistically significant. Consistent with the finding from the criterion condition, these results replicate the findings of Experiment 1 in that incidental memory for irrelevant dimension values was demonstrated and it was found to be stable across trials.

The question of whether or not the incidental memory for irrelevant dimension values can also be considered a form of implicit memory was addressed by examining responses on the recognition memory task. Recall that each participant received only one two-alternative, forced-choice recognition trial. If participants had too explicit memory for the to-be-remembered stimulus and were forced to guess, one would expect that the number of participants who responded correctly would be the same as the number of participants who responded incorrectly. For the criterion condition, the number of participants who responded correctly to the two-alternative, forced-choice, explicit memory question (13 of 24) was not significantly greater than expected based on chance guessing, \(X^2(1) = .017, P > 0.05\). Likewise, for the overtraining condition, the number of participants who responded correctly (14 of 24) was not significantly greater than expected based on chance guessing, \(X^2(1) = .667, P > 0.05\).

Although these results are consistent with the idea that participants did not exhibit explicit memory for the test stimuli, the number of participants who responded correctly on the recognition trial was numerically greater than the number who responded incorrectly. Thus, it is possible that the group of participants who responded correctly was made up of a mixture of those who guessed correctly and some who actually had explicit memory for the test stimuli. It is furthermore possible that the same trial response latency advantage was driven entirely by those participants that had explicit memory for the test stimuli.

In order to explore this issue further, we adopted the logic ana method used by Clark and Squire (1998) to examine explicit awareness of CS-US relationships in their examination of human delay and trace conditioning. If the same trial response latency advantage truly reflects the influence of implicit memory for the irrelevant dimension values, then the advantage should be the same for participants who responded correctly on the recognition trial and those who responded incorrectly on the recognition trial. Conversely, if the same trial advantage reflects the influence of explicit memory for the irrelevant dimension values, then the advantage should be exhibited by participants that responded correctly.
on the recognition trial but by those who responded incorrectly. This line of reasoning led us to compare response latencies for same and different trials for participants who responded correctly to the recognition test trial and those who responded incorrectly on the recognition trial. Thus, we conducted two, two (same versus different, within-participants) by two (correct versus incorrect, between-participants) ANOVAs. For the criterion condition the analysis indicated a significant advantage for same trials, $F(1, 22) = 5.17, P < .05$, whereas there was no group difference, $F(1, 22) = 0.57, P > .05$, and no interaction, $F(1, 22) = 2.79, P > .05$. The results of the analysis for the overt training condition were the same in that a significant advantage for same trials was found, $F(1, 22) = 4.34, P < .05$, whereas there was no group difference, $F(1, 22) = 1.54, P > .05$, and no interaction, $F(1, 22) = 1.00, P > .05$. The results of both of these analyses are consistent with the conclusion that the same trial advantage is based on implicit memory of irrelevant dimension values rather than on explicit memory.

4. General discussion

Participants demonstrated short-term incidental memory for irrelevant dimension values in both Experiments 1 and 2, as indicated by an indirect memory measure within the context of a category-learning task. Response latencies to relevant dimension values were faster when irrelevant dimensions maintained the value associated with the preceding trial (same trials) compared to when the value of the irrelevant dimension had changed (different trials). The difference in response times between the two types of trials is not attributable to a difference in categorization accuracy because participants were making completely accurate responses for both trial types. This finding represents a replication of a previously reported results obtained from studies of rats tested on delayed matching-to-sample and discrimination tasks (Reed et al., 2003).

Although the indirect measure (response latencies) indicated that participants remembered the values of the irrelevant dimension values, the direct test of awareness used in Experiment 2 indicated that such memory was implicit. Surprise probe trials revealed that participants could not reliably identify the value of irrelevant dimension values when asked about them after only a single categorization trial had intervened between the presentation of the stimulus and the query about its qualities. In addition, participants who responded incorrectly on the recognition task exhibited the same trial advantage as participants who responded correctly on the recognition task. Thus, we conclude that participants exhibited implicit memory for irrelevant dimension values.

The implicit memory for irrelevant dimension values exhibited by our participants is similar to priming effects observed in many studies of humans (e.g., Poldrack and Gabrieli, 2001; Schott et al., 2002; Tulving et al., 1991). Priming reflects the influence of implicit memory and is in evidence when stimulus processing is enhanced due to prior exposure to identical, similar or related stimuli. For example, Cooper et al., 1992 found that structural possibility judgments of line drawings of three-dimensional figures was enhanced when the participants previously viewed size transformed or reflections of the to-be-judged figures. In our experiments responses were enhanced when stimuli maintained the same irrelevant characteristics as previously judged stimuli. Furthermore, this influence did not appear to increase across task trials as some forms of implicit memory do (e.g., habit learning). Instead, the effect appeared to be rather stable, similar to repetition priming effects. Thus, the implicit memory for irrelevant dimension values demonstrated in the current study is very similar to a well-established form of implicit memory.

The implicit memory demonstrated by the humans in the current study is also highly similar to the incidental memory exhibited by rats in the study we reported previously (Reed et al., 2003) as well as other animal studies (Bloogh, 1989; Langley et al., 1996). Thus, it is tempting to conclude that the rats that demonstrated incidental short-term memory for irrelevant cues were exhibiting implicit memory. The difficulty, of course, is that it is not possible to directly assess the conscious recollection of rats in order to firmly establish the memories as implicit. The finding, however, suggests that future studies may reveal that rats’ incidental memory for irrelevant cues may be H1 and thus similar to implicit memory in a neuroanatomical sense. Studies of another form of implicit learning, trace eye-blink conditioning, might anticipate how additional research could more firmly establish rats’ incidental short-term
memory for irrelevant cues as a form of implicit memory.

For example, eye-blink conditioning can be either HD and explicit or H and implicit, depending on whether a delay conditioning paradigm or a trace condition- ing paradigm is used. In delay conditioning, the CS onset precedes the US onset but both stimuli tempo- rally overlap for a period. The fact that rabbits with hippocampal lesions (Schmidl and Ticuio, 1972) and amnesic patients (Clark and Squire, 1998; Dauam and Ackerman, 1994; Daum et al., 1989; Gabrielli et al., 1999; Weiskrautz and Warrington, 1979) exhibit nor- mal delay eye-blink conditioning indicates that this form of learning is HD. In trace conditioning, the CS onset and offset both precede the US onset. In contrast with delay conditioning, the fact that rabbits with hippocampal lesions (Moyer et al., 1990; Solomon et al., 1986) and amnesic patients (Clark and Squire, 1998; McGilhoney-Berreth et al., 1997; Woodruff-Pak, 1993) exhibit impaired trace eye-blink conditioning demon- strates that this form of learning is HD.

Several related observations indicate that delay condition- ing does not require conscious awareness of the relationship between the CS and US. First, people ex- hibit normal delay eye-blink conditioning regardless of whether or not they are able to demonstrate explicit knowledge of the predictive value of a CS (Clark and Squire, 1998). Furthermore, delay conditioning is not impaired when a distracting secondary task interferes with awareness of the CS-US relationship (Clark and Squire, 1999). Similarly, the strength of conditioned responses in the delay conditioning paradigm is unre- lated to participants’ conscious expectations of a US following a CS (Clark et al., 2001). Thus, HD delay eye-blink conditioning is an implicit memory process. By contrast with delay conditioning, several lines of evidence indicate that trace conditioning appears to re- quire conscious awareness of the relationship between the CS and US. First, people only exhibit trace condi- tioning if they are aware of the CS-US relationship (Clark and Squire, 1998). Furthermore, trace condi- tioning is disrupted when a distracting secondary task interferes with awareness of the CS-US relationship whereas it is facilitated when people are made aware of the CS-US relationship by a description of the pre- dictive nature of the CS (Clark and Squire, 1999). Similarly, the strength of conditioned responses in the trace conditioning paradigm is directly related to par- participants’ expectations of a US following a CS (Clark et al., 2001). Thus, HD trace eye-blink conditioning is an explicit memory process.

Future studies, like those that investigated delay eye-blink conditioning, may reveal that implicit hu- man memory for irrelevant dimension values and re- dent short-term memory for irrelevant cues are forms of HI memory. Towards this end, three lines of research are clearly indicated. First, rats need to be tested in order to determine whether or not incidental memory for irrelevant cues remains intact after hippocampal les- sions are created. Second, human patients that exhibit impaired explicit memory but spared perceptual prim- ing (e.g. patients with hippocampal amnesia (Hannan and Squire, 1997), Parkinson’s disease (Kivisto et al., 1996) and, perhaps, Alzheimer’s disease (Willems and Adam, 2002)) need to be similarly assessed in order to determine whether or not implicit memory for irrele- vant dimension values is intact. Finally, the influence of drug treatments known to influence forms of implicit memory should be examined to determine whether or not implicit memory for irrelevant dimension values is similarly impaired. For example, scopolamine chal- lenge (Thiel et al., 2002) and chronic low doses of clomipramine (Caldeira de Carvalho et al., 2002) imp- pair priming and therefore may also influence implicit memory for irrelevant dimension values in a similar manner.

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References