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Stimulus exposure effects in human associative learning

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Learning that one cue (CS) predicts a second, salient cue (US) can often be slowed by prior exposure to one or both stimuli. In animals, CS–US learning is more strongly retarded following uncorrelated exposure to both CS and US than following exposure to the US alone. In this paper we present several studies showing a similar effect in humans, using a computer-based task. Experiments 1 and 2 used a between-groups design and demonstrated a strong CS/US exposure effect, whether or not the US was signalled by a neutral cue during exposure. Experiment 3 demonstrated similar effects using a within-subjects design. Overall, these results are consistent with several theoretical interpretations and suggest that uncorrelated CS/US exposure leads to a robust retardation of subsequent CS–US learning in humans.

Some of the most interesting recent paradigms for exploring learning have exploited the fact that prior exposure to stimuli can affect the rate at which associations between those stimuli are subsequently learned. For example, learning that a previously neutral cue (the conditioned stimulus or CS) predicts a salient outcome (the unconditioned stimulus or US) is retarded by prior exposure to the CS alone; this effect has been termed "latent inhibition" (Lubow, 1973; Siddle & Remington, 1987). Such a CS exposure effect may involve attentional mechanisms, namely the loss of associability to an exposed cue that predicts no salient future events. Hence, it is disrupted in populations with attentional

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abnormalities, including individuals with schizophrenia and attention deficit disorder with hyperactivity (ADHD—see Lubow, 1997, for review). Disrupted CS exposure effects mean that unreinforced CS exposure does not retard learning in these individuals, and so they may learn the CS–US association faster than control subjects given equivalent exposure. Thus CS exposure effects have proved to be a useful means of studying learning in various clinical populations.

Other stimulus exposure effects have also been studied. For example, prior exposure to the US may retard subsequent CS–US association (e.g., Randich & LoLordo, 1979), as may prior exposure to both CS and US, uncorrelated with each other; this effect has been termed "learned irrelevance" (Mackintosh, 1973). Typically, prior exposure to both CS and US, uncorrelated, retards learning more strongly than does exposure to either CS or US alone (e.g., Mackintosh, 1973). It is a matter of great debate whether learned irrelevance reflects explicit learning of a lack of correlation between CS and US, or whether it merely reflects the sum of CS and US exposure effects (e.g., Baker & Mackintosh, 1979; Bennet, Maldonado, & Mackintosh, 1995; Bonardi & Hall, 1996; Matzel, Schachtman, & Miller, 1988). In either case, the robustness of this phenomenon makes it an attractive candidate for studying stimulus exposure effects in human learning, with particular utility in studies of clinical populations that are typically limited in terms of number of subjects available.

Although a large number of studies have considered uncorrelated CS/US exposure in animals, the paradigm has received little attention in human studies. Here, we present three experiments examining the effects of uncorrelated CS/US exposure on subsequent CS–US association in human learning using a computer-based task. The basic approach grows out of a body of prior work by Lubow and colleagues, who have used similar tasks for studying CS exposure in humans (Ginton, Urca, & Lubow, 1975; Lubow & Gewirtz, 1995; Lubow, Ingberg-Sachs, Zalstein-Orda, & Gewirtz, 1992; Zalstein-Orda & Lubow, 1994).

The procedure involves a simple prediction task: subjects see a picture of a magician together with a "magic word", which appears in a cartoon word balloon over the magician's head. Subjects are informed that the magician is trying to make a rabbit appear under his hat, and that they should guess whether he is successful on each trial. Conceptually, the appearance of the rabbit is the US—the to-be-predicted outcome. During Phase 2, a particular colour in the magician's word balloon predicts that the rabbit will appear; thus, the balloon colour is the predictive CS. This learning phase is preceded by an exposure phase in which the balloon colours and rabbit appear uncorrelated with each other. This uncorrelated exposure should slow subsequent learning of the colour–rabbit association, relative to subjects who did not receive the exposure.

EXPERIMENT 1
CS/US Exposure Effect

Experiment 1 involved three experimental conditions: No-Exposure, US-Exposure and CS/US-Exposure (Table 1). All three groups were trained on an identical discrimination: learning that one colour (CS+) predicted the appearance of a rabbit (US) whereas another colour (CS–) did not. The groups differed in prior exposure to the CS and US. Group US-Exposure received exposure to the US alone, and group CS/US-Exposure received uncorrelated exposure to both CS and US. Group No-Exposure

TABLE 1
Design for Experiment 1

Group	*Phase 1: Exposure*	*Phase 2: Training*
No-Exposure	No exposure to rabbit; no exposure to colours.	Colour CS+ → rabbit; colour CS– → no rabbit.
US-Exposure	Exposure to rabbit; no exposure to colours.	Colour CS+ → rabbit; colour CS– → no rabbit.
CS/US-Exposure	Uncorrelated exposure to colours and rabbit.	Colour CS+ → rabbit; colour CS– → no rabbit

received no exposure to CS or US in Phase 1 but proceeded directly to Phase 2. Several animal studies have suggested that US exposure should slow subsequent CS–US association, but that uncorrelated CS/US exposure should slow learning still more (e.g., Bennet et al., 1995; Mackintosh, 1973).

Methods

Subjects

Seventy-five subjects with a mean age of 20.12 years ($SE = 0.32$) were recruited from the Rutgers University community. Subjects were randomly and evenly assigned to one of three experimental groups, as shown in Table 1. There were 12 females and 13 males in group No-Exposure, 11 females and 14 males in group US-Exposure, and 15 females and 10 males in group CS/US-Exposure. Subjects received credit for an undergraduate psychology class, or payment of $5, in exchange for their participation.

Experiments were conducted on Macintosh LCII, IICi, and equivalent computers with colour monitors, using software programmed in the SuperCard language. The keyboard was masked except for two keys, labelled "yes" and "no", with which subjects made their responses. Testing took place in a dedicated testing room.

Stimuli

On each trial, the screen showed a drawing of a magician waving his wand at a large hat (Figure 1A). A "magic word" appeared in a cartoon balloon above the magician's head, taken from a set of 30 pronounceable English nonwords (see Appendix). The words were printed in large black lower-case letters. Additionally, the cartoon balloon background was red, green, or uncoloured (grey). For each subject, the two possible balloon colours red and green were randomly assigned to be CS+ and CS–. At the end of each trial, the magician's hat was raised to reveal whether the rabbit had appeared (Figure 1B).

Procedure

For each subject, the list of "magic words" was randomly divided into two 15-element sublists L1 and L2. Words from L1 were used in Phase 1, and words from L2 were used in Phase 2.

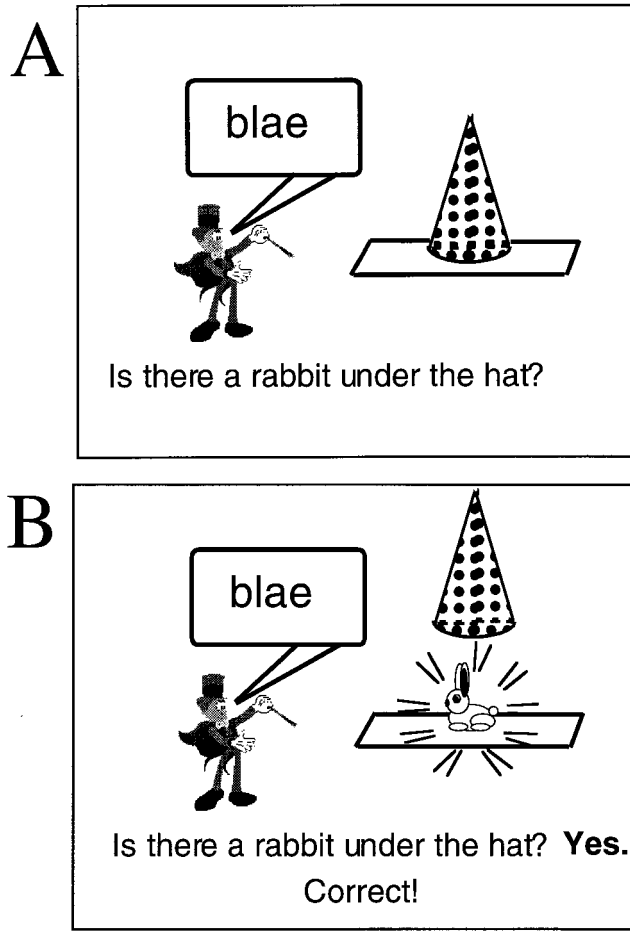

FIG. 1. Screen events. (A) On each trial, the magician appears, together with a "magic word" printed on a background, which may be red, green, or uncoloured (grey). The subject is asked to predict whether the rabbit will appear on this trial. (B) The hat is then raised to show whether the rabbit is present, and corrective feedback is given.

There were 30 trials in Phase 1; on each trial, a word from L1 was randomly chosen to appear, with the constraint that each word from L1 should appear twice during this phase. The rabbit was randomly scheduled to appear on 12 trials in Phase 1.

For subjects in group US-Exposure, the cartoon balloon was always uncoloured (grey) in Phase 1. For subjects in group CS/US-Exposure, colour CS+ occurred on 10 trials and colour CS– occurred on the remaining 20 trials; the rabbit (US) and colour CS+ co-occurred on exactly four trials. Thus, for subjects in group CS/US-Exposure, the probability of the US given CS+ was 4/10 = 0.4—exactly the same as the probability of the US given CS–: 8/20 = 0.4.

Subjects in group No-Exposure received no Phase-1 trials but proceeded directly to Phase 2.

For Phase 2, there were 60 trials, with each word from L2 appearing on exactly 4 trials. Colour CS+ occurred on one-third of the trials and the rabbit always appeared on these trials; colour CS– occurred on the remaining two-thirds of the trials and the rabbit never appeared on these trials.

There was no correlation between magic words and rabbit in Phase 2, and no magic word appeared together with the rabbit more than once in Phase 2.

To initiate testing, each subject was seated in the experimental room in front of the computer and shown the following instructions on the screen: "*Welcome. You will hear a magician using magic words, trying to make a rabbit appear under the hat. Some of the magic words will work and some will not. Try and predict when the rabbit appears*!" The experimenter read these instructions through with the subject and indicated the "yes" and "no" keys and "button" that were to be used.

On each Phase-1 trial, the subject saw the magician and hat, together with the balloon colour and the corresponding magic word from wordlist L1. A prompt, "*Is there a rabbit under the hat?*" appeared in black letters at the bottom of the screen (Figure 1A). The subject then pressed either the "yes" or "no" key to respond, and the hat was moved upward to reveal whether there was a rabbit underneath (Figure 1B). If the subject's response was correct, the word "Correct" appeared; otherwise, the word "Incorrect" appeared, and a beep was sounded through the computer speakers. At the end of Phase 1, subjects saw the following instructions: "*Good! Now the rules may have changed. Listen to the magic words and try to predict when the rabbit appears.*"

The screen events in Phase 2 were identical to those in Phase 1, except that colour $CS+$ always predicted that the rabbit would appear, whereas colour CS– always predicted that the rabbit would not appear. Phase 2 was terminated early if the subject reached criterion performance, defined as 15 consecutive correct responses. Total Phase-2 errors were recorded for each subject.

Results

Mean total Phase-2 errors for all groups are shown in Figure 2. Subjects in group CS/US-Exposure made more errors than did subjects in group No-Exposure, whereas subjects in group US-Exposure made somewhat fewer errors. A three-way analysis of variance (ANOVA) with significance level set at .05 probability revealed a significant group difference $F(2, 68) = 5.13$, $p = .005$; there were no significant effects of subject age, $F < 1$, or subject gender $F(1, 68) = 2.68$, $p = .106$, nor any interaction between gender and group, $F(2, 68) = 1.97$, $p = .147$. Planned post-hoc Tukey HSD pairwise comparisons showed a significant difference between groups US-Exposure and CS/US-Exposure, $p = 0.005$; the difference between groups No-Exposure and CS/US-Exposure approached

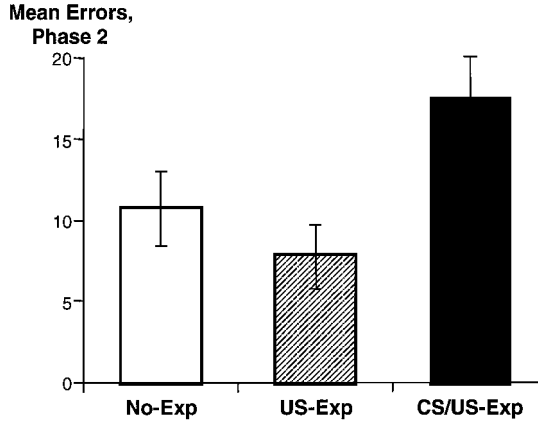

FIG. 2. Mean number of Phase-2 errors made by each group in Experiment 1.

but did not reach significance, $p = 0.055$, and there was no difference between groups No-Exposure and US-Exposure, $p = 0.638$. In summary, uncorrelated CS/US exposure slowed subsequent CS-US learning relative to subjects who received exposure to the rabbit alone. Exposure to the rabbit alone did not slow learning relative to a control condition that received no Phase-1 trials.

Discussion

This experiment involved a simple computer-based task, in which subjects learned that a screen event—the appearance of a magician's rabbit—was predicted by one balloon colour CS+ but not by a second colour CS–. Subjects who had previously received uncorrelated exposure to colours and the rabbit (CS/US-Exposure) were slower to learn the colour–rabbit association than were subjects previously exposed to the rabbit alone (US-Exposure). This finding is consistent with prior animal conditioning studies, which show that prior uncorrelated exposure to CS and US can slow learning more than exposure to the US alone (Bennet et al., 1995).

Animal studies also suggest that prior exposure to the US alone slows learning relative to a control condition with no exposure (e.g., Overmier & Wielkiewicz, 1983; Randich & LoLordo, 1979; Rescorla, 1967). Lubow, Caspy, and Schnur (1982) demonstrated a similar effect of US exposure in children using a visual discrimination task. By contrast, the current study showed no evidence that US exposure slowed learning; subjects in group US-Exposure actually averaged fewer Phase-2 errors than did subjects in group No-Exposure, although this difference did not reach statistical significance. Of course, the No-Exposure condition corresponds only roughly to the proper control condition in animals: normally, while one or more groups are exposed to stimuli, non-exposed animals might be given equivalent time in the experimental context (conditioning chamber) without exposure to any CS or US.

However, the slightly facilitated learning in group US-Exposure may reflect the fact that these subjects were learning about the task demands in Phase 1 and also learning to ignore the presence of the magic words. At the start of Phase 2, then, these subjects may have found it relatively easier to attend to the novel coloured balloons. By contrast, at the start of Phase 2, subjects in group No-Exposure were confronted with all the experimental stimuli (balloon colours, rabbit, magic words) and may accordingly have been slower to learn the correct colour–rabbit association. Thus, the apparent absence of a US-exposure effect in the current experiment may be due to the presence of other stimuli in addition to the designated CS and US.

Another possible factor contributing to the absence of a US-exposure effect may be contextual blocking (Baker, Mercier, Gabel, & Baker, 1981; Randich & LoLordo, 1979). According to this account, associations formed between the context and US in Phase 1 might block or reduce the ability to form subsequent associations between CS and US in Phase 2. In the current paradigm, Phase 1 was followed by a short break, where a change in instructions warned the subject that a phase change was taking place. This might have acted as a kind of context shift, which, in turn, could have ameliorated the US exposure effect. An explicit change of context does eliminate the US exposure effect in animals (Dess & Overmier, 1989; Hinson, 1982). Such a context shift does not eliminate the effect

of uncorrelated CS/US exposure in animals (Matzel et al., 1988). This would be consistent with the current findings of retarded learning in group CS/US-Exposure but not in group US-Exposure.

Finally, under many conditions, prior exposure to stimuli can facilitate, rather than retard, subsequent learning (e.g., Gibson & Walk, 1956; Graham & McLaren, 1988; Hall, 1980). Many variables may influence whether exposure facilitates or retards subsequent learning, including exposure duration, physical placement of exposed stimuli, and whether the stimuli are to be associated or discriminated. It may well be the case that a small perceptual learning effect occurred in the current experiment, in which prior exposure to the rabbit in particular, and task demands in general, produced a slight facilitation in subsequent learning relative to subjects in group No-Exposure, who had no prior exposure to the task. Even if this is so, there was still a strong and significant retardation in learning among subjects exposed to both colour (CS) and rabbit (US), uncorrelated, compared with those given exposure to the rabbit alone.

EXPERIMENT 2
CS/US Exposure With Signalled US

In animals studies, the effect of uncorrelated CS/US exposure is not eliminated when the US is signalled by a novel cue during CS/US exposure (Baker & Mackintosh, 1979; Matzel et al., 1988). That is, subjects given uncorrelated exposure to the CS and the US, where the US is signalled by a Cue A (Group CS/A-US) learn a subsequent CS–US association more slowly than do subjects given signalled exposure to the US alone (Group A-US).

Experiment 2 attempted to introduce the same manipulation into the human computer-based paradigm. The same basic task was employed as in Experiment 1. Table 2 shows the experimental design. One group of subjects (group A-US) was exposed to the rabbit (US) in Phase 1, but the appearance of the rabbit was always signalled by a particular "magic word" A appearing in the magician's word balloon. A second group (group CS/A-US) received the same signalled exposure to the rabbit, and also received exposure to the balloon colours CS+ and CS–, uncorrelated with the appearance of the rabbit. All subjects were then transferred to Phase 2, in which the rabbit was always predicted by colour CS+ and not by colour CS–. By analogy with the animal data, we expected to see slower Phase-2 learning in the subjects given prior exposure to the colours (Group CS/A-US), even though the US was signalled in Phase 1.

TABLE 2
Design for Experiment 2

Group	*Phase 1: Exposure*	*Phase 2: Training*
A-US	Rabbit predicted by magic word A; no exposure to colours CS+, CS–.	Colour CS+ → rabbit; colour CS– → no rabbit.
CS/A-US	Rabbit predicted by magic word A; uncorrelated exposure to colours CS+, CS–.	Colour CS+ → rabbit; colour CS– → no rabbit.

Methods

Subjects

Forty subjects with a mean age of 20.13 years (SE = 0.81) were recruited from the Rutgers University community. Subjects were assigned randomly and evenly to two experimental groups, as shown in Table 2, with the constraint of equal gender distribution between groups. In both groups, there were 11 females and 9 males. Subjects received credit for an undergraduate psychology class, or payment of $5, in exchange for their participation.

Apparatus, Stimuli, and Procedure

Apparatus and stimuli were the same as described in Experiment 1. Procedures were also the same as in Experiment 1, with the following exceptions. Once the set of "magic words" had been divided into two sublists, L1 and L2, one element of sublist L1 was selected randomly to be the "magic word" A, which would signal the rabbit in Phase 1. For all subjects, the rabbit occurred on 12 trials in Phase 1, and word A occurred on these same trials; other words from L1 occurred on the remaining trials. For subjects in group A-US, the word balloon was always uncoloured in Phase 1; for subjects in group CS/A-US, balloon colours $CS+$ and $CS-$ occurred uncorrelated with the rabbit, as in Experiment 1.

In Phase 2, as in Experiment 1, balloon colour $CS+$ predicted the appearance of the rabbit. Note that neither word A nor any other word from L1 recurred in Phase 2, which used words from sublist L2.

Criterion performance in Phase 1 was defined as 10 or more consecutive correct responses; criterion in Phase 2 was defined as 15 or more consecutive correct responses. Total errors were recorded for each subject in both Phase 1 and Phase 2.

Results

In Phase 1, subjects in both groups learned that the rabbit was predicted by the "magic word" A. Two subjects in group A-US and one in group CS/A-US failed to reach criterion in this phase. Overall, subjects in group A-US averaged 5.40 errors (SE 0.61), and subjects in group CS/A-US averaged 4.95 errors (SE 0.87). A two-way ANOVA revealed no significant difference in average errors between the two groups, $F < 1$, no significant effect of subject age, $F(1, 35) = 1.30$, $p = .262$, or gender, $F(1, 35) = 3.44$, $p = .072$, and no significant Group $\times$ Gender interaction, $F < 1$.

By contrast, there was a strong group difference between groups in terms of total Phase-2 errors, as shown in Figure 3. Subjects in group A-US averaged nearly three times as many errors as did subjects in group CS/A-US. A two-way ANOVA confirmed a significant effect of group, $F(1, 35) = 6.08$, $p = .019$, with no significant effects of subject age, $F(1, 35) = 1.18$, $p = .285$, or gender, $F(1, 35) = 1.53$, $p = .224$, and no Group $\times$ Gender interaction $F < 1$. One subject in group A-US and three in group CS/A-US failed to reach criterion performance in Phase 2; none of these was among the subjects who failed to reach criterion performance in Phase 1. Overall, the effect of Phase-1 performance on Phase-2 errors failed to reach statistical significance, ANOVA, $F(11, 28) = 2.04$, $p = .063$.

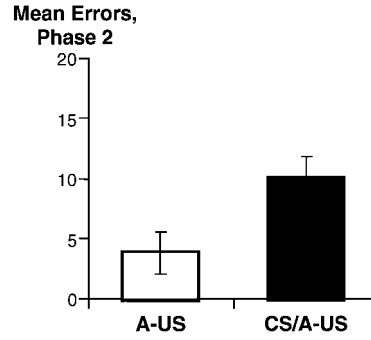

FIG. 3. Mean number of Phase-2 errors made by each group in Experiment 2.

In summary, even with the US signalled in Phase 1, uncorrelated exposure to CS and US slowed subsequent CS–US association more than exposure to the US alone.

Discussion

Experiment 2 again demonstrated that uncorrelated exposure to the balloon colours and rabbit retarded subsequent association between them. This effect was obtained even though the rabbit was signalled by a "magic word" in Phase 1. These results were broadly consistent with animal studies demonstrating that the retardative effect of uncorrelated exposure to the CS and US survives even if the to-be-predicted outcome is signalled by a neutral warning stimulus during the exposure phase (Baker & Mackintosh, 1979; Matzel et al., 1988).

Together, Experiments 1 and 2 demonstrate that uncorrelated exposure to CS and US slows subsequent CS–US association more than does exposure to the US alone. This is true regardless of whether the US was signalled by a neutral cue in Phase 1.

EXPERIMENT 3
Within-subjects CS/US Exposure

Several nonassociative factors may have influenced the demonstration of the effect of CS/US exposure in Experiments 1 and 2. First, the subject groups were exposed to different numbers of stimuli in Phase 1: some subjects saw two balloon colours CS+ and CS–, whereas others only saw an uncoloured (grey) balloon. Increasing the number of stimuli presented during the exposure phase may have introduced additional sources of interference that retarded subsequent learning.

Second, the use of a between-subjects design meant that individual variations might have influenced performance. This was especially important given that Phase 2 was arbitrarily terminated after 60 trials; subjects who failed to reach criterion performance in this time may have been incapable of mastering the task or might simply have needed additional trials to acquire the CS–US association. The latter may reflect exposure-related retardation, but the former does not. In principle, this problem should have been minimized by randomly assigning subjects to experimental groups—but with small

TABLE 3
Design for Experiment 3

Group	*Phase 1: Exposure*	*Phase 2: Training*
Visual-Exposure	Uncorrelated exposure to rabbit and red balloon; no exposure to tone.	Red balloon CS → rabbit; tone CS → rabbit; neither → no rabbit.
Auditory-Exposure	Uncorrelated exposure to rabbit and tone; no exposure to red balloon	Red balloon CS → rabbit; tone CS → rabbit; neither → no rabbit.

sample sizes minor variations can still produce large effects. A within-subject design can eliminate some of these concerns.

Accordingly, Experiment 3 was designed as a within-subjects version of the exposure paradigm used in Experiments 1 and 2. Table 3 shows the experimental design. In Phase 1, some subjects were exposed to a red balloon CS, uncorrelated with the rabbit, and other subjects were exposed to an auditory tone CS, likewise uncorrelated with the rabbit. To ensure that all subjects received some auditory as well as visual stimulation, audio recordings of the "magic word" were also played on each trial. In Phase 2, both the red balloon CS and the tone CS predicted that the rabbit would appear. It was expected that subjects would be slower to learn the association between the rabbit and the cue to which they had been exposed in Phase 1 than between the rabbit and the non-exposed cue.

Methods

Subjects

Twenty-four subjects were recruited from the Rutgers University Psychology Department undergraduate subject pool; subjects received class credit in exchange for their participation. Of this group, 18 subjects were female and 6 were male, with mean age 18.8 years ($SE = 0.35$). Subjects were assigned randomly to two groups, as shown in Table 3, with the constraint that males and females should be approximately equally distributed among groups.

Apparatus

Apparatus was the same as in Experiment 1.

Stimuli

The visual stimuli were the same as in Experiment 1, with the exception that the word balloon above the magician's head could be red or uncoloured (white, matching the screen background). Additionally, each "magic word" was recorded by a male native speaker of English, using the computer microphone. Of these words, 15 were used in Phase 1 and 15 in Phase 2. The auditory CS consisted of a pure tone, 1000 Hz, 500 ms in duration, also played through the computer speaker.

Procedure

The procedure was similar to that described in Experiment 1, with the following exceptions.

On each Phase-1 trial, subjects in both groups saw the magician and a "magic word" in the word balloon. For both groups, the appearance of the magician was accompanied by a recording of the magic word, played through the computer speakers. There was no delay between the appearance of the visual stimuli and the onset of the recording.

The rabbit appeared randomly on six of the 30 Phase-1 trials. For subjects in group Visual-Exposure, the word balloon was coloured red on 10 trials and uncoloured on the remaining trials; these trials occurred randomly, with the constraint that the red balloon CS and rabbit should co-occur on exactly two trials. For subjects in group Auditory-Exposure, the red balloon CS never appeared, but the tone CS was played immediately following pronunciation of the magic word on 10 trials; these trials occurred randomly, with the constraint that the tone CS and rabbit should co-occur on exactly two trials. Thus, for each group, the probability of the rabbit's appearance was exactly the same whether or not the exposed cue was present.

In Phase 2, the rabbit was scheduled to appear on a random 40% of trials; on half of these trials it was predicted by the auditory tone, and on half it was predicted by the red balloon, with the constraint that the tone and red balloon never co-occur. Again, the recording of the magic word was played aloud on each trial. Phase 2 continued to a maximum of 75 trials but was terminated if the subject reached criterion performance of 15 consecutive correct responses.

Data Collection

An error in Phase 2 was recorded if the subject failed to predict the rabbit on a trial where either the red balloon CS or tone CS was present, or if the subject mistakenly predicted the rabbit would appear on any other trial. These three types of error were scored separately, along with the total errors for each subject.

Results

Overall, subjects seemed to solve this task relatively easily: all but three subjects reached criterion performance within the maximum 75 trials, indicating that they had mastered both the auditory and visual associations. Figure 4A shows that learning of the exposed cue was slower than learning of the non-exposed cue in terms of total errors on each kind of trial. A repeated-measures ANOVA revealed this effect to be significant, $F(1, 22) = 7.24$, $p = .013$. There were no significant effects of subject group, $F < 1$, nor a significant interaction between subject group and trial type (exposed vs. non-exposed cue, $F < 1$).

Three subjects, one in group Auditory-Exp and two in group Visual-Exp, failed to reach criterion performance. If the Phase-2 data from these subjects are excluded, the basic effect remains: subjects averaged 5.0 errors on trials involving the exposed cue ($SE = 0.59$) but only 2.19 errors on trials involving the non-exposed cue ($SE = 0.36$).

Figure 4B shows the data for these 21 subjects broken down by exposure condition. Subjects given prior exposure to the tone CS were slower to learn that it predicted the rabbit than to learn an association involving a novel visual CS. Conversely, subjects given prior exposure to a red balloon CS were slower to learn about it than a novel auditory CS. Thus, the exposure effect was demonstrated regardless of which stimulus was exposed in Phase 1. A repeated-measures ANOVA revealed no significant differences between

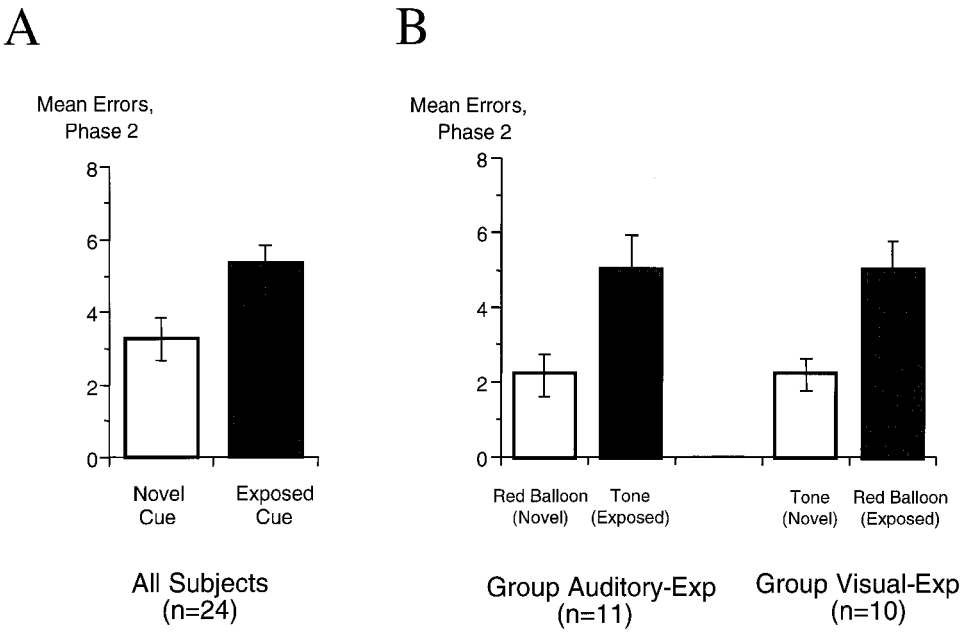

FIG. 4. Mean number of Phase-2 errors made in Experiment 3 to the previously-exposed CS and a novel CS, (A) averaged across all subjects, and (B) within Group Auditory-Exp and Group Visual-Exp, for those subjects who reached criterion on both associations.

groups, $F < 1$, a significant effect of trial type (exposed vs. non-exposed cue, $F(1, 19) = 18.56$, $p < .001$) and no interaction between these variables, $F < 1$.

Discussion

Like Experiments 1 and 2, Experiment 3 demonstrated that exposure to CS and US, uncorrelated, retarded subsequent learning to associate CS and US. Subjects were exposed to either an auditory or a visual CS, uncorrelated with the rabbit, and then given training in which both the auditory and visual CSs predicted the appearance of the rabbit. Subjects were slower to learn the association involving the exposed than the non-exposed CS, regardless of modality.

This experiment avoided several difficulties inherent in Experiments 1 and 2. Most importantly, it reduced the high failure rates, as 88% of subjects reached criterion performance in Phase 2. Additionally, it suggested that the exposure effects were specific to the exposed CS rather than retarding all CS–US learning, as learning was selectively retarded in the case of the exposed but not novel CS.

GENERAL DISCUSSION

The purpose of the experiments reported here was to determine whether a CS/US exposure paradigm could be used to show stimulus exposure effects in human associative learning. In Experiment 1, exposure to the colour CSs and rabbit, uncorrelated with each

other, slowed subsequent learning more than did a comparison group only exposed to the rabbit. Experiment 2 showed that this group difference was maintained even if the rabbit was signalled by a different cue (a "magic word") during the exposure phase. This is consistent with animal studies showing that signalled exposure does not eliminate the effect of uncorrelated CS/US exposure (Baker & Mackintosh, 1979, Exp. 3). Experiment 3 showed CS/US exposure effects using visual as well as auditory cues and in a within-subject design. The general effect of CS/US exposure thus appears to be a robust phenomenon that can be obtained in humans under a variety of procedural manipulations.

Although animal studies also suggest that US exposure should slow subsequent CS–US association, we failed to find any evidence that mere exposure to the rabbit impaired learning. In Experiment 1, subjects given exposure to the rabbit actually showed a slight facilitation of subsequent learning, relative to subjects given no exposure phase. Possibly, the presence of a context shift between phases contributed to attenuating the effects of exposure to the rabbit alone, but not the combined effects of exposure to both colour CSs and the rabbit.

Another possibility is that the US exposure effect is strongest in paradigms where the US is a salient, behaviourally relevant cue. In the present experiments, the US (rabbit) was only a visual cue, with no particular motivational significance. Thus, our failure to find evidence of US exposure effects in Experiment 1 does not necessarily suggest that US exposure effects would not be robust in humans, given a more salient US. However, it does suggest that the combined effects of CS/US exposure are stronger and more easily demonstrated than are the effects of US exposure alone, in humans as in animals.

There remain several possible mechanisms that may have contributed to slow Phase-2 learning in the exposed groups. The first possibility is that explicit lack of correlation between CS and rabbit in Phase 1 slowed subsequent learning of an association between them in Phase 2. This would be analogous to the conclusion drawn in many animal studies of CS/US exposure (e.g., Mackintosh, 1973; Overmier & Wielkiewicz, 1983; Randich & LoLordo, 1979). A second possibility is that the current results reflect latent inhibition, in which prior exposure to the CS would slow subsequent learning, independent of exposure to the rabbit. A third and somewhat intermediate interpretation would be along the lines of the suggestion by Bonardi and Hall (1996) that presence of an uncorrelated US during CS exposure serves to strengthen the retardative effects of CS exposure: during CS exposure, the US becomes part of the exposure context. As a context shift between exposure and training phases reduces the effect of CS exposure, the presence of the US in both phases reduces the context shift, thereby strengthening the CS exposure effect. This account would also be consistent with the results shown here.

Gluck and Myers (1993; Myers & Gluck, 1994) presented a computational model that argues that the hippocampus and related medial temporal structures are critical for encoding environmental regularities, such as which cues co-occur, which cues never co-occur, and which cues precede and predict salient outcomes. According to this model, exposure to an uncorrelated cue and outcome should result in the formation of stimulus representations that reflect this lack of correlation; these representations will hinder subsequent formation of cue–outcome representations. Because these representations are assumed to depend on the hippocampal region, they should be attenuated or eliminated after hippocampal-region damage. Thus, the computational model predicts that the

effect of uncorrelated CS/US exposure should be disrupted by hippocampal-region damage (see Myers, Ermita, Hasselmo, & Gluck, 1998). This computational theory is consistent with recent data showing that hippocampal-region damage can eliminate CS/US exposure effects in animal conditioning (Allen, Chelius, & Gluck, 1998). We have recently shown that human subjects with hippocampal-region damage similarly show disrupted CS/US exposure effects using the paradigm of Experiment 2 (Myers, McGlinchey-Berroth, Warren, Monti, Brawn, & Gluck, 2000).

Clearly, there is much more study needed to determine the biological substrates and psychological mechanisms underlying CS/US exposure effects and relating it to CS exposure effects. Given the apparent robustness of the CS/US exposure effect in animals, together with the reliable effects of uncorrelated CS/US exposure to retard CS–US association in the current studies, CS/US exposure may be a valuable in the study of associative learning in humans with various memory and attentional disorders.

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APPENDIX

The "magic words" used in Experiments 1–3 were taken from the following set of 30 pronounceable nonwords:

tawe	bije	morv	ratch	zare	moel
slar	malp	melk	cort	hund	zoch
sarn	jant	slig	klid	noge	juff
frod	forl	hoor	fion	blae	dett
gwan	vair	rhyl	hewl	glep	zoyn