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Human latent inhibition and the density of predictive relationships in the context in which the target stimulus occurs

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ABSTRACT
In two experiments, participants were exposed to a listing of actions performed by a fictitious Mr. X, over three days of his life. For most of his actions an outcome was described, but some were not followed by any outcome. On Day 3, Mr. X performed an action (the target action) that was followed by a novel outcome. For participants in the control condition, the target action that preceded the appearance of this outcome was also novel; for participants in the latent inhibition (LI) condition, Mr. X had performed the target action on repeated occasions during Days 2 and 3, without it producing any outcome. All the participants were tested on their ability to retrieve the action performed by Mr. X prior to the target outcome. In Experiment 1, retrieval of the target action (indicating a less effective target action–outcome association) was poorer in the LI than in the control condition. In Experiment 2, reducing the proportion (the *density*) of nontarget actions that brought outcomes during initial training was found to reduce the size of the LI effect. These results are predicted by the account of LI put forward previously [Hall, G., & Rodríguez, G. (2010). Associative and nonassociative processes in latent inhibition: An elaboration of the Pearce-Hall model. In R. E. Lubow & I. Weiner (Eds.), *Latent inhibition: Data, theories, and applications to schizophrenia* (pp. 114–136). Cambridge, England: Cambridge University Press]. A high density of predictive relationships ensures strong activation of the expectancy that some outcome will occur when the target action is first presented; this facilitates the formation of a target action–no-event association during training in the LI condition, thus enhancing the LI effect.

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When a target stimulus is repeatedly presented in the absence of relevant consequences, it subsequently enters into new associations less readily than a novel stimulus. This latent inhibition (LI) phenomenon has been studied both in animals and in humans (e.g., Lubow & Weiner, 2010), and it has been considered to be a selective attention phenomenon that helps to attenuate both learning about, and responding to, irrelevant stimuli. Various efforts have been made in order to specify what mechanism or mechanisms are responsible for this sort of modulation of processing. A widely accepted view is that stimulus preexposure in the absence of relevant consequences allows the organism to learn a stimulus–no-event association (e.g., Hall, 1991). This learning will have two main effects. First, to the degree that the stimulus–no-event association is strengthened, initial uncertainty about the consequences of the stimulus will decrease, and with it the degree to which the stimulus evokes exploratory attention will decrease. Second, the previously established stimulus–no-event association is likely to interfere with the expression of any new learning about a potential change in the consequences of the stimulus.

It must be acknowledged that the notion of a "stimulus–no-event" association and the mechanisms

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responsible for its formation have not been well specified. Hall and Rodríguez (2010) put forward an account that attempted to address this problem. They suggested that presentation of a novel stimulus will arouse some degree of expectation that an event will follow; this is characterized as involving the activation of a stimulus–event association. The ability to activate this association will depend, at least in part, on generalization from similar stimuli that the organism has experienced in the past as being followed by some outcome. Each of the stimuli supporting generalization will tend to activate the particular outcome with which it has been associated, but the representation most effectively activated will be that coding for any feature that all these outcomes have in common. We refer to this simply as the representation of an event.

If the general expectation is confirmed by the occurrence of a particular event, then the acquisition and expression of the association between the novel stimulus and that event will be readily established, given that an association between the stimulus and some general features of the outcome will already be in place. However, when no event occurs after the presentation of the stimulus, and the expectation of occurrence of an event is disconfirmed, an inhibitory learning process (based on that proposed for simple extinction in the model of conditioning proposed by Pearce & Hall, 1980) is engaged. As applied to extinction, the model assumes that after pairings of a conditioned stimulus (CS) and an unconditioned stimulus (US) the presentations of the CS alone result in a development of a stimulus–no US association that acts to oppose the effects of a CS–US association established during the initial pairings. In the present procedure, stimulus presentations result in the development of a stimulus–no-event association that acts to oppose the activation of (or the effects of) the existing stimulus–event association. In line with the original Pearce–Hall model, this leads to a decline in the associability of the stimulus. Associability is high when there is a discrepancy between what is expected (that some event is going to occur) and what actually happens during nonreinforced exposure (no event happens). As a stimulus–no-event association develops, stimulus associability declines because the discrepancy between what is expected and what happens tends toward zero. These changes in the properties of the stimulus will retard its ability to function as a CS when subsequently it is paired with an US.

An implication of this account is that the strength of the initial expectancy that some event will follow the stimulus will influence the degree of LI that occurs. The learning responsible for LI depends on prediction error (Westbrook & Bouton, 2010), and this will be large when the initial expectancy is strong. Rapid acquisition of the stimulus–no-event association will ensure fast extinction of the expectancy that some event is going to occur and thus produce a fast decline in associability. (A simulation demonstrating this effect, using the equations of Hall & Rodríguez, 2010, is presented in Supplemental Material 1.) One implication of this analysis has been tested and confirmed by Rodríguez and Hall (2008) who manipulated the strength of the expectancy of an event by presenting the critical stimulus in compound with another, salient, cue during preexposure. The experiments to be reported here address the same issue, but use a different procedure for manipulating initial event expectancy.

As we have noted, Hall and Rodríguez (2010) assumed that the initial strength of the stimulus–event association would be determined by generalization from similar stimuli that the organism had experienced in the past, followed by some outcome (i.e., followed by the occurrence of "an event"). What follows is that it should be possible, by manipulating conditions likely to enhance the degree of generalization from stimuli similar to the target event, to increase the initial expectation and thus enhance the magnitude of the LI effect. In the experiments to be reported here, we arranged that initial exposure to nonreinforced presentations of the target event should occur in a context provided by the presentation of other similar events that were followed by an outcome. In Experiment 1 we determined that it was possible to obtain a LI effect with human participants using this novel procedure. In Experiment 2 we reduced the proportion of trials on which these other, contextual (i.e., nontarget), stimuli were followed by an outcome. In this case, generalization to the target stimulus of the expectancy that some event will follow will be weakened. We predict that LI should develop less readily than when the target is preexposed in a context in which there is a high density of stimulus–event pairings.

Experiment 1

Participants in this experiment were presented, during training, with a series of statements describing the activities of a fictional Mr. X over three days of his everyday life. For most of his actions a description of its outcome was then presented (e.g., "Mr. X hears his alarm clock. . . and he wakes up"). For some, however (e.g., "Mr. X takes a phone call"), no outcome was specified. At the end of this training all participants received a single trial in which the description of an activity was followed by a novel outcome. For participants in the LI condition, the action described on this trial had been presented previously without any outcome; for those in the control condition the action was presented for the first time. On a final test trial the subjects were asked to recall what action Mr. X. had performed prior to the outcome that occurred on the final trial. A LI effect would be demonstrated if the subjects given preexposure to the target action were less successful on this test than the control subjects.

The target stimulus (the action described on the final training and test trials) was presented 11 times during the training phase for the LI group (control subjects were presented with a different event on the equivalent trials). These 11 trials were embedded in a sequence of 126 other trials in which other actions by Mr. X were described. On a minority of these trials the action described was not followed by an outcome, ensuring that the target stimulus would not stand out as the only one not followed by an outcome. The rest were all followed by the description of an outcome. For half of these the outcome was the same on every occasion the stimulus action appeared; for the remainder a different outcome was described on each of the (three) trials on which a particular stimulus action occurred. Although this latter arrangement cannot be expected to establish a strong association between the stimulus action and a given outcome, it allowed us to enhance the number of possible outcomes with which events similar to the target stimulus might become associated.

All participants in this experiment experienced the same set of contextual trials (i.e., the same set of nontarget trials), the aim being simply to demonstrate a difference between the LI and control groups in these conditions. According to our analysis, having a large proportion of trials in which stimuli have an outcome will increase the likelihood of seeing a powerful LI effect. In Experiment 2 we investigated the effects of reducing this proportion.

Method

The participants were 32 students, 10 males (mean age = 23.6 years, *SD* = 3.4) and 22 females (mean age = 22.1 years, *SD* = 5.6), from the University of the Basque Country, who volunteered for the experiment. They were assigned at random to either the LI group (*n* = 16) or the control group (*n* = 16). They were tested individually, the material being presented on a standard PC. They were informed simply that they would be taking part in an experiment involving cognitive tasks.

Participants received the following on-screen instructions in Spanish: *When you are ready, please press the space-bar of the keyboard to start. The automatic presentation of a sequence of screens will then begin*.

Once the participant had pressed the space-bar, the automatic presentation of 138 trials of training began. There were 126 trials that provided the context, 11 presentations of the target stimulus (or the control stimulus event for the control condition), and a single final trial in which the target stimulus was paired with an outcome. Each trial consisted of a 5-s presentation of a text line (font Arial, size 24) describing in one phrase an action performed by Mr. X (e.g., *Mr. X reads the newspaper . . .*). Below this text line, in the middle of the screen, a clip-art illustration of the action was presented simultaneously. On some trials, the action performed by Mr. X was followed by an outcome. On these, 2 s after the beginning of the trial, another text line (Arial font, size 24) describing the outcome appeared below the clip art and remained present for the duration of the trial. A plain white screen, 0.5 s in duration, was presented between trials. (See Figure 1, for screen captures of the different types of trial.)

The trials were organized as three large groups, each of which was presented as being a day in the life of Mr. X. The beginning of each "day" was signalled with a 5-s screen (*Day 1, Day 2,* or *Day 3)* indicating the number of the day. Each day included six blocks of seven contextual trials (i.e., nontarget trials). The beginning and the end of these blocks were not made explicit to the participants. On three of the trials in each block the action described was followed by the same outcome on all three days; on three trials the action was followed by a different outcome on each of the days. On the remaining trial of each block, no outcome followed the action described. All the specific actions and outcomes that were used as

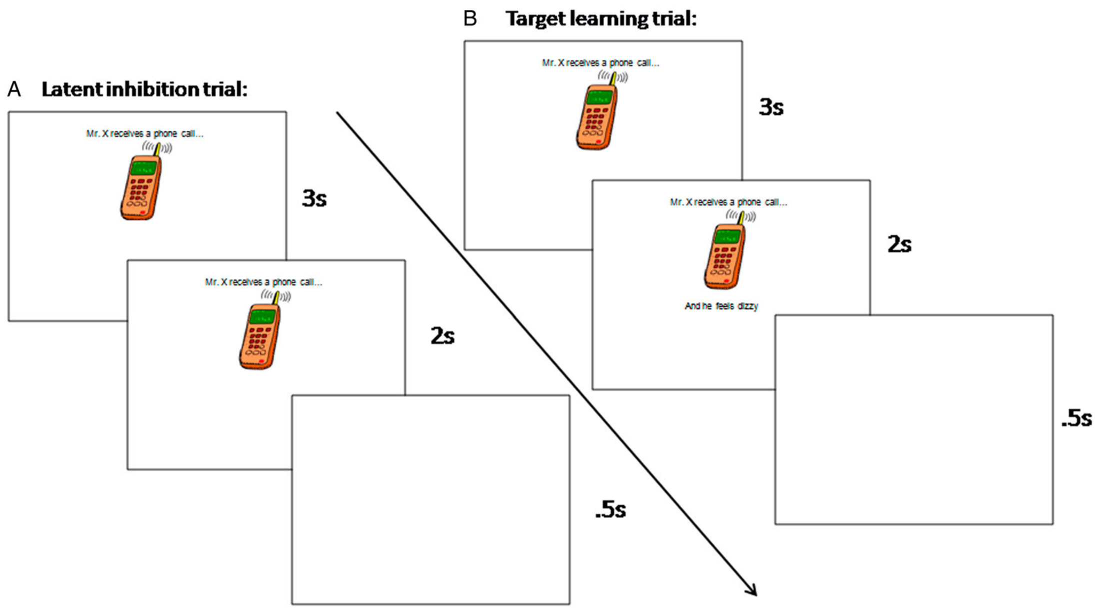

Figure 1. A: Screenshots and temporal duration of a latent inhibition trial. B: Screenshots and temporal duration of a target learning trial.

contextual trials, and the order of the trials in each block and on each day, are presented in Supplemental Material 2.

Day 1 consisted of just the trials listed in Supplemental Material 2. The distribution of trials (and blocks) used for Days 2 and 3 was identical to that used in Day 1 except that presentations of the target action were introduced. For all participants, the critical learning trial, about which they would be tested subsequently, was added before the first trial of the last block of trials of Day 3 listed in Supplemental Material 2. On this trial, the action performed by Mr. X (the target action) was followed by an outcome that had never occurred before (the target outcome . . . *and he feels dizzy*). For participants in the LI group Mr. X had performed the target action once in each of the six blocks of trials of Day 2 (the target action being inserted after the third, the fifth, the second, the sixth, the fourth, and the first contextual trial in Blocks 1–6, respectively) and in each of the first five blocks of Day 3 (the target action being inserted after the seventh, the second, the eighth, the fourth, and the third trial in Blocks 1–5, respectively). On these 11 trials prior to the critical learning trial the target action was not followed by any outcome (i.e., these were the preexposure trials to the target stimulus). In order to equate the number of actions performed by Mr. X in the two groups, rather than preexposure trials in which Mr. X performed the target action, participants in the control group had equivalent trials in which Mr. X performed another (nontarget) action that was also not followed by any outcome. For half of the participants, the target action was *Mr. X receives a phone call*, and the nontarget action was *Mr. X listens to music from his MP3 player*. For the other half of the participants, the arrangement was reversed.

After the last trial of Day 3, a screen informed the participants that they were going to be tested after pressing the space-bar. The test consisted of a screen in which participants were asked to write down what action was performed by Mr. X before he felt dizzy. The participants had 30 s to give their responses. The dependent variable was the accuracy of the answer. If this was that Mr. X received or responded to a phone call the answer was coded as correct; it was coded as incorrect if the participants reported that Mr. X performed any other action, or if they made no response

Results and discussion

As Figure 2 shows, almost all the participants in the control group answered the test question correctly whereas many in the LI group could not do so. A chi square analysis (in this and subsequent analyses the alpha level was set at .05) performed on the data shown in the figure confirmed reliability of the

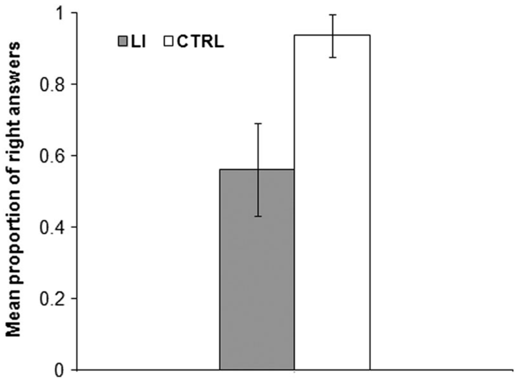

Figure 2. Mean proportion of right answers shown on the test in Experiment 1 by the latent inhibition (LI) and the control (CTRL) groups. Vertical error bars indicate standard error values.

difference between the groups; $\chi^2(1) = 6.00$, $p = .037$. We conclude that preexposure to the critical event (the target action) retarded the acquisition of a target–outcome association on the final trial, or the expression of that learning on the test (or both); that is, a LI effect was obtained.

It is of interest that this instance of LI was obtained in a situation in which the participants were given no task to perform, apart from that of observing the sequence of events presented on the screen. Although the LI effect is well established for nonhuman animals, it has been obtained less reliably with human subjects, and it has been suggested that the effect might be found with humans only when preexposure to the critical stimulus is given in the context of a masking task (see e.g., Lubow, 1989; Lubow & Gewirtz, 1995). Lubow and Gewirtz (1995) proposed that the importance of the masking task was that it diverts attention away from the preexposed event, preventing controlled processing and thus allowing operation of the automatic processing system that is responsible for LI. An alternative interpretation (see, e.g., Le Pelley & Schmidt-Hansen, 2010) is that the use of masking task often permits the subject to learn explicitly that the target stimulus is uncorrelated with the event that will subsequently be paired with it, producing the phenomenon known as learned irrelevance (Baker & Mackintosh, 1977) rather than LI. Learned irrelevance cannot play a role in the present procedure, as there is no indication of the critical outcome until the final trial in which it is paired with the target stimulus. It is possible, however, that embedding presentations of the target event in a long and complex sequence of other events and pairings of stimuli and outcomes is enough to prevent the controlled processing of concern to Lubow and Gewirtz (1995). Our own proposed mechanism (which may be additional to, rather than an alternative to, that of Lubow & Gewirtz, 1995) is that the contextual trials (i.e., the nontarget trials) promote LI because they ensure that the expectation that some event will follow the target cue is high, when that cue is first presented. Experiment 2 allows a test of this suggestion.

Experiment 2

According to the Hall and Rodríguez (2010) account, the LI observed in Experiment 1 occurred because, when first presented, the target action had the ability to activate the expectancy that some outcome would occur. This expectancy would have been generated, at least in part, by generalization from the other actions signalling outcomes to which the participants had been exposed during training. In Experiment 1, this expectancy would be high when the target action was presented for the first time to the LI group. The first presentation of the target was in the first block of trials in the set referred to as Day 2. More than the 85% of the actions previously performed by Mr X on Day 1 (36 of 42) were followed by some type of outcome; accordingly, during the first presentation of the target action, the common elements that this action shared with previously experienced actions would have tended to activate the expectation that some outcome would occur. Generalization of the critical expectancy could be lowered, therefore, by reducing proportion of actions performed by Mr X on Day 1 that were followed by an outcomes. In these circumstances the LI effect should be attenuated (see the simulation in Supplemental Material 1).

This change in procedure could also have implications for the performance to be expected in the control group. For the participants in this condition in Experiment 1, the target action was novel when it was first presented at the end of Day 3. Thus not only would its associability be higher than in the LI group, it would also be able to evoke a stronger expectancy that some outcome would follow. If this expectancy serves to support formation of the association between the target action and its outcome, or to facilitate performance on the test that followed, it would contribute to the difference between the two groups, effectively enhancing the magnitude of the observed LI effect. It follows that reducing the proportion of actions performed by Mr. X that are followed by outcomes on Day 1 would reduce the generalization of the critical expectancy for the control group and thus the size of the latent inhibition effect.

In the present experiment we tested these predictions. There were four experimental groups. For two groups we replicated the conditions used in Experiment 1. We termed these conditions the LI (latent inhibition)–high and CTRL (control)–high groups as we assumed that there would be a high level of generalization between the actions performed by Mr. X during Day 1 and the target action. The other two groups, LI–low and CTRL–low, received identical training to that for the corresponding high groups, but for them none of the actions performed by Mr. X on Day 1 was followed by an outcome. We expected to replicate the results of Experiment 1 in the high groups. In the low groups we expected to observe reduced LI, this being mediated by two different effects. First, we expected to find worse test performance (i.e., worse retrieval of the target action on test) in group LI–high than in group LI–low (as a consequence of the enhanced acquisition of the stimulus–no-event association in group LI–high). In addition, we expected to find better test performance (i.e., better retrieval of the target action on test) in group CTRL–high than in group CTRL–low (a consequence of the facilitatory effect of the stronger target–event association in group CTRL–high).

It is worth noting that other prominent accounts of LI do not readily predict this pattern of results. For example, the theories proposed by Wagner (e.g., 1981) and by Mackintosh (1975) both propose that exposure to a target stimulus will produce a loss of effectiveness (because it is predicted by the context in the case of Wagner's theory; because it is a poor predictor of its consequences in Mackintosh's). They can thus accommodate the standard LI effect and an overall difference between the LI and CTRL groups; but there is no obvious reason why this change in effectiveness should be modified by the different density conditions (low vs. high) used in this experiment. Perhaps more critical, there is no mechanism by which stimulus effectiveness might be changed in a way that would allow these conditions of density to produce a reversal of the LI effect in the CTRL groups.

Method

Two hundred and sixteen students from the University of the Basque Country volunteered for the experiment. There were 82 males (mean age = 23.13 years, $SD = 6.14$) and 134 females (mean age = 24.27 years, $SD = 8.12$). They were assigned at random to one of four equal-sized ($n = 54$) groups: LI–High, LI–Low, CTRL–High, and CTRL–Low. The size of the groups was increased from Experiment 1 to Experiment 2, in an attempt to obtain the power necessary to detect the expected interaction between the exposure (LI vs. CTRL) and the density variables (low vs. high).

For participants in groups LI–high and CTRL–high, the task was identical to that described for the LI and control groups of Experiment 1. Groups LI–low and CTRL–low experienced just the same sequence of trials as the corresponding high groups, and differed only in that none of the actions performed by Mr. X on Day 1 was followed by an outcome. In all other respects, including the conditioning and test trials, the procedure was the same as that described for Experiment 1.

Results and discussion

Figure 3 shows the mean proportion of right answers shown on the test by each of the four groups. The groups in the high condition replicate the effect observed in Experiment 1, with almost all control subjects giving the right answer but less than 60% of the LI group doing so. This LI effect was reduced in the low condition. Consistent with the predictions derived from the Hall and Rodríguez (2010) account, this

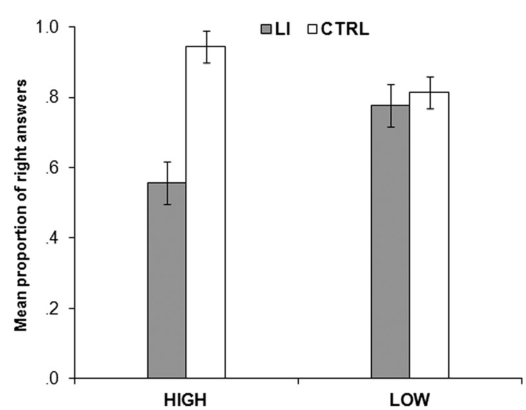

Figure 3. Mean proportion of right answers shown on the test in Experiment 2 by the latent inhibition (LI) and the control (CTRL) groups in the two conditions of density of predictive relationships (HIGH and LOW). Vertical error bars indicate standard error values.

attenuation was a consequence of effects in both the LI and the CTRL conditions: Group LI–high showed poorer test performance than group LI–low; and group CTRL–high showed better test performance than group CTRL–low.

A 2 (exposure: LI vs. CTRL) × 2 (generalization: high vs. low) × 2 (accuracy: correct vs. incorrect answers) three-way log-linear analysis performed with these data indicated that the highest order interaction (Exposure × Generalization × Accuracy) was significant, $\chi^2(1) = 9.87$, $p = .002$. To clarify the source of this interaction, separate chi-square tests were performed. These analyses revealed that there was a significant difference between the LI and CTRL groups in the high condition, $\chi^2(1) = 21.78$, $p < .001$, confirming the results of Experiment 1. There was no difference between the two low groups, $\chi^2(1) = 0.228$, $p = .623$, showing that the LI effect was abolished in this condition. In addition, the two LI groups differed significantly, $\chi^2(1) = 6.00$, $p = .014$, consistent with a larger LI effect in the high than in the low condition. Finally, although the effect was numerically small (see Figure 3), the difference between the two CTRL conditions was also significant, $\chi^2(1) = 4.28$, $p = .038$; that is, test performance was better in the subjects that had previously experienced the larger proportion of trials containing action–outcome pairings.

Our account of the effect of nonreinforced preexposure supposes that there will be changes in two properties of the target event: There will be a reduction in the expectation that some outcome will follow, and there will be a loss of associability. Both could contribute to the LI effect. That is, a low associability will retard the formation of a new association; and an expectation that no event will follow could interfere both with the acquisition and with the expression of a new association. Both types of change in the stimulus proceed more readily when the initial expectation of an outcome is high, and thus both could contribute to the difference in test performance between the high and low LI groups in this experiment. The CTRL groups, however, allow us to see the operation of just one of these mechanisms. For these groups the associability of the target event will be at the same (high) level for both high and low groups, when that event is presented for the first time on the conditioning trial. But according to our analysis, the expectation that some outcome will follow will be higher in the high than in the low CTRL group, allowing the prediction that performance on test will be superior in the high condition.

As we noted in the introduction of this experiment, this pattern of results is not to be expected on the basis of several other possible interpretations of the effect of manipulating the density of contextual predictive relationships. Our procedure for doing this was simply to eliminate all outcomes for the actions performed by Mr. X on the first set of trials (those referred to as Day 1) for subjects in the low condition. This necessarily introduces a range of differences between the groups in addition to the factor of theoretical interest. For example, at the empirical level, the high group will simply have had more experience of trials involving outcomes than will the low group. Again, participants in the low condition received less information on Day 1 than did participants in the high condition; and perhaps in some way, the overload experienced by high group might have influenced performance during conditioning, or on the test for latent inhibition. There are other possibilities, but all of them would seem to imply an overall difference between high and low conditions; they are ruled out, therefore, by the finding that high is superior to low in the test for the control subjects, but that the reverse is true for the LI groups.

General discussion

In these experiments, evidence for a robust LI effect was obtained when the target stimulus (the target action performed by Mr. X) was presented in a context in which similar stimuli experienced before (the other actions performed by Mr. X) were mostly followed by some sort of outcome. When, during initial training, these similar stimuli were not followed by an outcome the LI effect was abolished. This pattern of results was predicted by the Hall and Rodríguez (2010) account of LI. According to this, LI depends on a learning process (the formation of a stimulus–no-event association) that is triggered when the organism perceives a mismatch between an initial expectancy that some event will follow presentation of the stimulus and the absence of such an event during preexposure. The stronger this initial expectation, the more rapid will be the learning process responsible for LI. As the initial expectation will depend on generalization from other stimuli experienced previously, it is predicted that the learning and attentional mechanisms underlying LI will operate more efficiently in contexts in which a large proportion of stimuli similar to the target have been followed by some sort of outcome.

Although the outcome of these experiments is predicted by our theoretical account, we need to consider other possible explanations. In particular, it is well established that LI is sensitive to contextual factors, and that it can be attenuated or abolished when preexposure occurs in one context and conditioning and test in another (e.g., Channell & Hall, 1983; Lovibond, Preston, & Mackintosh, 1984). In our experiments the physical environment remained the same throughout, but there were changes in the background trials in which the critical trials were embedded. The target event was presented, during Days 2 and 3, in the context provided by the various other trial-types listed in Supplemental Material 2. Because we manipulated the density of predictive relationships by varying what happened on the trials that constituted Day 1, there was no difference between the high and low groups of Experiment 2 in the context present during training and test. The groups did differ, however, in that the high group had received prior exposure to this sort of context (on the trials that constituted Day 1) whereas the low group had not (having experienced only no-outcome trials on Day 1). It is possible that this factor plays a role in generating our results. The effect of prior exposure to the context has been studied, using rats as subjects and aversive conditioning techniques, by Hall and Channell (1986). They found that LI was more marked in subjects given context exposure prior to the experimental treatment, a result that parallels our finding of stronger LI in the high than in the low group.

Hall and Channell (1986) put forward the following explanation for their results. They suggested that initial exposure to the context would make the learning responsible for the LI effect less context dependent. They also argued that the introduction of unconditioned stimuli (shocks in these experiments) during the test phase would constitute a substantial change in context. For subjects not given context preexposure, this change of context would reduce the size of the LI effect to some extent (see also, Bonardi & Hall, 1996). Subjects given context preexposure, on the other hand, would be less affected by this change of context and would thus show LI in full measure.

It seems unlikely that this mechanism is responsible for the effect obtained in our experiment. As would be expected from their account, prior exposure to the context had no effect on the test performance of the control groups in the study by Hall and Channell (1986). To explain the results of the present Experiment 2, however, requires a mechanism that affects the control group as well as the LI group (see Figure 3). In addition, in our procedure the target outcome (equivalent to the shock US used in the procedure aversive conditioning procedure) was very similar to a large number of other outcomes presented during the session (see Supplemental Material 2). It is hard to see how the introduction of one more outcome (*Mr. X feels dizzy*) on the critical learning trial might be construed as introducing a change of context.

Returning to the explanation offered by Hall and Rodríguez (2010), its central feature is that LI proceeds rapidly when the initial expectation of an outcome is high. We have tested this by embedding the target event in a context of many other stimulus–outcome pairings; and we presented this procedure simply as a convenient technique for ensuring that the initial expectation evoked by the target event will be strong. One might speculate, however, that this arrangement—many events occurring, many of them of significance, but some of them not—is a fair parallel to the natural world of animals (including people). From this perspective, a mechanism of the sort suggested by Hall and Rodríguez (2010) would be especially useful in allowing fast learning about what stimuli are irrelevant and can be ignored.

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