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# The effect of cognitive load and outcome congruency on the learned predictiveness effect in human predictive learning

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The learned predictiveness effect or LPE is the finding that when people learn that certain cues are reliable predictors of an outcome in an initial stage of training (phase 1), they exhibit a learning bias in favor of these cues in a subsequent training involving new outcomes (phase 2) despite all cues being equally reliable in phase 2. In Experiment 1, we replicate the basic effect and found that the addition of a secondary memory task during phase 2 had no reliable influence on the LPE. In Experiment 2, we demonstrated that the same secondary task can either facilitate or disrupt the LPE, depending on whether the outcomes of phase 1 were affectively congruent or incongruent with the outcomes of phase 2. These findings are discussed in relationship to associative and inferential accounts of LPE.

Research has shown that when people learn new predictive relations between several cues and an outcome, they often exhibit a positive bias towards those cues that have been shown to be more reliable predictors of other outcomes in the past. The typical experiment demonstrating this so-called "learned predictiveness effect" or LPE comprises three phases. The first phase involves pairing of 4 compounds (AV, AW, DX and DY) with outcome 1 and other 4 compounds (BV, BW, CX, and CY) with outcome 2, such that each compound is formed by one element that is consistently paired with the same outcome (the so- called predictive cues: A, B, C and D) and one element that is equally paired with the two outcomes (the so-called nonpredictive cues: V, W, X and Y). In the second phase, participants learn to predict the occurrence of two new outcomes, O3 and O4, which are

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arranged to be reliably predicted by 4 novel compounds, each comprising one predictive and one nonpredictive cue from phase 1 (e.g., AX→O3 and BY→O4). In a final testing phase, evidence of the LPE comes from demonstrations of better learning of the O3 versus O4 discrimination for the cues that were predictive in phase 1 relative to those cues that were not (Le Pelley & McLaren, 2003; Lochmann & Wills, 2003). The empirical reality of the effect has been well established with a range of procedures (see Le Pelley, Mitchell, Beesley, George, & Wills, 2016 for a review) and there is relative agreement in that it is related to a diminished attention allocated to the nonpredictive cues during the second stage of training (Beesley & Le Pelley, 2011; Le Pelley, Suret, & Beesley, 2010; Le Pelley, Vadillo, & Luque, 2013; Mitchell, Griffiths, Seetoo, & Lovibond, 2012). But how or why this differential attention might occur is now being subjected to considerable debate. Roughly, it can be said that the interpretations fall into two classes: associative and propositional.

Associative interpretations are based on the assumption that predictive learning involves the formation of a link between the representation of a cue and the representation of an outcome. This link or association is formed in a relatively automatic way through direct experience with these representations; that is with little cognitive control and effort. Within this framework, one possible interpretation of LPE is that the differential acquisition of the O3/O4 discrimination in the second phase of the experiment is due to the fact that the participants learned "associatively" to attend more to the predictive than to the non-predictive cues of phase 1. Although this effect might be described through various associative mechanisms, the predominant explanation is based on Mackintosh's (1975) proposal that the amount of associability or attention allocated to a cue in a given trial depends on whether this cue was or was not the best predictor of its outcomes in the past. One appeal of this explanation is that it is based on the same mechanism that might underlie some related observations on Pavlovian conditioning with non-humans, such as "learned irrelevance" (e.g., unpaired presentations of the experimental stimuli retard the subsequent acquisition of a conditioned response; Mackintosh, 1973) or "extra-dimensional shift effects" (e.g., learning that one stimulus dimension is irrelevant for solving a task, retards the acquisition of a subsequent discriminative response in which that dimension is relevant; Shepp & Schrier, 1969).

In contrast, propositional interpretations of predictive learning (Mitchell, De Houwer & Lovibond, 2009) would posit that the LPE is mainly the result of an effortful higher-order cognitive process where participants would infer that whatever was useful to solve the task in phase

1, might also be useful to solve the task in phase 2. The usage of this inferential process would lead the participants to pay more or exclusive attention in phase 2 to the previously predictive cues of phase 1, which would be reinforced by the fact that the discrimination between O3 and O4 is successfully solved by means of this strategy. Thus, the propositional view is equally successful than the associative view in embracing the well documented fact that the nonpredictive cues are less attended in the second phase. The appeal of this account is that it provides a natural explanation for the fact the LPE can be abolished by declarative instructions, such as simply telling the participants that the predictive value of the cues in phase 1 will be reversed in phase 2 (e.g., Mitchell et al., 2012).

Although these two types of accounts appear to be quite opposite, they are not mutually exclusive. That is, the LPE might result from the use of both, automatic bias and inferential processes acting in parallel or interacting. Consistent with this two-process view, some authors have provided evidence that although the LPE effect can be abolished by explicit instructions (e.g., by a controlled process), it cannot be totally reversed, even when the participants are told that the nonpredictive cues will be relevant in phase 2 and that the predictive cues will not (Shone, Harris, & Livesey, 2015; Don & Livesey, 2015). From this data, it might be argued that in the majority of the procedures demonstrating the LPE, both associative and propositional influences might be at work, associative influences being particularly effective with extended training (e.g., Don & Livesey, 2015; Logan, 1988; Mackintosh, 1969; Schneider & Shiffrin, 1977) and propositional inferences being particularly effective when the participants have reasons to assume that cue reliability is transferable between the two phases and when they have sufficient cognitive resources available to make a relatively effortful inference (e.g., Mitchell et al., 2012).

The aim of the following experiments was to further develop our understanding of the way in which these factors might influence the degree to which the LPE can be observed. In particular, the two experiments examined the effect of cognitive load and interphase similarity on the LPE using a conventional procedure that has been proved to be useful to study this phenomenon in previous research.

## EXPERIMENT 1

The first goal of this experiment was to replicate the learned predictiveness effect with our participants and procedures. For this, we employed the standard conceptual design of learned predictiveness and an experimental situation similar to that of Le Pelley, Beesley, and Griffiths (2011). The task consisted of asking participants to learn to predict which sound will be played in the computer (outcome) after the presentation of a compound of two symbols (cues). As outlined in Table 1, in phase 1 participants were exposed to a sequence of slides or trials in which compounds AV, AW, DX and DY were followed by outcome 1 and compounds BV, BW, CX, and CY were followed by outcome 2. According to these contingences, cues A-D were designated as the "predictive cues" and cues V-Y were designated as the "nonpredictive cues". In phase 2, four new compounds comprising one predictive and one nonpredictive cue were formed (AX, BY, CV, DW) and participants learned which of two new sounds (O3 and O4) were predicted by them. After viewing the two phases, participants were asked to rate the extent to which novel compounds formed by predictive cues (AC and BD) and novel compounds formed by nonpredictive cues (VX and WY) predict O3 and O4. Ratings reflecting better O3-O4 discrimination for the "predictive compounds", AC and BD, than for the "nonpredictive compounds", VX and WY, would be taken as evidence of LPE.

Given the current controversy about the nature of the LPE, and considering the supposition that controlled processes are demanding of working memory capacity in a way that automatic processes are not (e.g., Wills, Graham, Koh, McLaren, & Rolland, 2011; Schneider, & Shiffrin, 1977), the second aim of the experiment was to examine the influence of cognitive load during phase 2 training on the LPE. If the LPE depends, at least in part, on controlled processes operating in phase 2, it should be affected by a cognitive load manipulation during this stage of learning. In this experiment we follow this reasoning by comparing the potential LPE in two groups, with and without a secondary memory task performed during phase 2. The secondary task was a very simple digit-remembering procedure that we have demonstrated to be effective in disrupting some potential influences of controlled processes in predictive learning (Vogel, Glynn, & Wagner, 2015).

## METHOD

**Participants.** Sixty-four students of University of Talca participated in the experiment in exchange for course credit. They were tested individually and had no previous experience in similar research. Participants were randomly assigned to Group No Load (n=32) or to Group Load (n=32).

**Materials.** Stimuli were presented and data collected with a personal computer connected to a 15-inch color screen and programmed with the E-prime software (Version 1.1; Psychology Software Tools, Inc., Pittsburgh, PA). The cues designated as A-D and V-Y in Table 1 were represented by eight symbols (#, $, {, %, @, X, >, =) and the outcomes designated as O1-O4 by words representing sounds (splash, laser, boom and ring) and their corresponding sound clip of 500 ms. of duration.

**Table 1. Designs of Experiments 1 and 2. Letters A-Y represent different symbols that could be followed by outcomes 1 to 4 (i.e., O1-O4).**

| Phase 1 | Phase 2 | Test |
|---|---|---|
| AV→O1 | AX→O3 | AC |
| BV→O2 | BY→O4 | BD |
| AW→O1 | CV→O3 | VX |
| BW→O2 | DW→O4 | WY |
| CX→O2 | | |
| DX→O1 | | |
| CY→O2 | | |
| DY→O1 | | |

**Procedure.** The major features of the task and the programming environment were patterned after Le Pelley et al. (2011). The instructions asked the participants to learn, through information presented on the computer screen, which sound will occur after the presentation of a pair of symbols.

The proper task began with phase 1 training as indicated in Table 1. Each trial type of this phase was presented once, in random order, in 24 blocks of 8 trials each. At the beginning of each trial, the sentence “What sound will occur after these symbols” (Verdana font 8-point-black) appeared on the center of the screen simultaneously with the two symbols (Verdana font 40-point-black) and the two possible outcomes (Verdana font 10-point-black). The symbols were presented in white rectangles measuring 25% x 20% of the display screen; one located in the top-center (75% of the vertical axis and 50% of the horizontal axis of the screen) and the other in the bottom-center (25% of the vertical axis and 50% of the horizontal axis of the screen) of the display. The possible outcomes were presented in white rectangles measuring 20% x 10% of the display screen; one to the left (50% of the vertical axis and 25% of the horizontal axis of the screen) and the other to the right (50% of the horizontal axis and 75% of the vertical axis of the display screen) of the sentence. This display remained unchanged until the participant clicked on one of the rectangles containing the outcomes. Once the participant entered his or her response, the color of the chosen rectangle changed into blue and after a delay of 600 ms., the programmed sound was played through the earphones for 500 ms. Next, the words “CORRECT” (in green) or “INCORRECT” (in red), were presented in the center of the screen for 1300 ms. The top panel of Figure 1 exemplifies the presentation of a pair of symbols and the modification that would occur if the participant responded that the pair was followed by “Boom”, and that this was, in fact, the programmed sound. The trial terminated with a new empty screen of 1 sec. duration. The screen background was grey throughout.

Once participants completed phase 1, they were presented with the following sentence: *“The first part of the task has finished. Next you are going to see the same symbols but combined in different pairs that provoke two new sounds. Now, your task is to decide which sound will occur after each pair of symbols”*. Then, the participants of both groups received 6 blocks comprising each of the 4 trial types of phase 2. The procedure was identical to phase 1, except that the location of symbols and outcomes in the display was switched. That is, in phase 2 the symbols were located at the left and right center of the display and the outcomes in the top- and bottom-center of the display. The middle panel of Figure 1 exemplifies the presentation of a pair of symbols and the modification that would occur if the participant responded that the pair was followed by “Splash”, and that this was not the programmed sound.

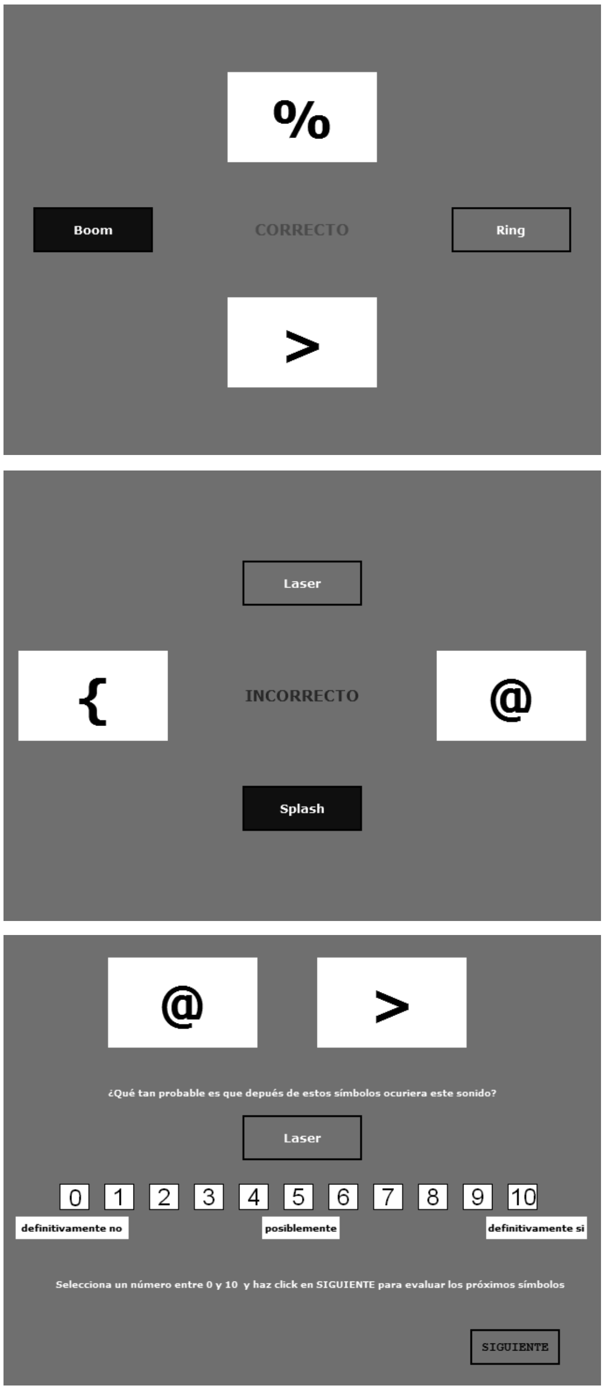



**Figure 1. Examples of the screens presented to the participants during phase 1 (top panel), phase 2 (middle panels) and testing (bottom panel) in Experiment 1.**

Participants in Group Load were asked to perform a digit-remembering task concurrently with the causal leaning task during phase 2. For this, in addition to the instructions for phase 2 provided to both groups at the end of phase 1, they were introduced to the digit remembering task. For the secondary task, at the beginning of each trial of phase 2, the computer presented the sentence: *"Remember the following number"*, followed by the appearance a three-digit number for 1 sec. After 3 sec., of blank screen, the symbols for that trial were presented, and participants made a prediction and received feedback. Immediately thereafter, a new screen appeared with the text *"Type the number you were remembering and press RETURN to move to the next trial"*, and participants had an opportunity to report the three-digit number. Apart from this, the phase 2 training for Groups Load and No load was identical.

Upon completion of phase 2, the participants of both groups were presented with the testing trials. During this phase, a pair of symbols appeared in the top center of the screen together with the following instruction*: "How likely is that after these symbols the following sound will occur? Click the button below to hear the sound"*. A rectangle with the word representing O3 was presented underneath the instructions. Participants clicked on this box to play sound O3, which also brought up a rating scale from 0 (definitely not) to 10 (definitely yes), which they used to rate the compound. On the immediately succeeding test trial, participants rated the same cues with respect to outcome 4. The four tested compounds, AC, BD, VX and WY, appeared at random order. The bottom panel of Figure 1 depicts an example of one test trial.

The assignment of specific symbols to the conditions A-D and V-Y was partially counterbalanced across participants of each group by means of their different allocation in one of four subgroups, each with a different assignment of symbols as A-Y. Specifically, in subgroup 1 the assignment for A, B, C, D, V, W, X and Y was #, $, {, %, @, X, >, and =, respectively. Subgroup 2 was identical to subgroup 1 except that the symbols used for the predictive cues A, B, C and D were switched with the symbols of the corresponding nonpredictive cues V, W, X, and Y. Subgroups 3 and 4 were identical to subgroups 1 and 2 respectively, except that the symbol assigned to one cue was switched with the symbol assigned to the following cues (e.g., A with B, C with D, V with W, and X with Y). This counterbalancing ensured that the critical compounds were composed equally often by the same pairs of symbols. The position (top vs. bottom in phase 1 and left vs. right in phase 2) of the symbols forming a compound was equated across the experiment. That is, in half of the trials the stimuli were presented in one position and in the other the relative position was reversed. There were two different assignments of sounds to the outcomes. Specifically, in one case O1, O2, O3 and O4, were represented by boom, ring, laser and splash respectively; and by laser, splash, boom and ring, respectively in the other case.

Since there were 4 different symbol assignments and 2 outcome assignments, there were a total of 8 different participant conditions. The experiment was run in two replications, each consisting of 16 participants distinguished by assignment to one of the two training groups, No Load or Load, and within each such group to one of the two outcome assignment and the four different symbols assignments.

**Statistical analysis**. Learning over training in the No Load and Load groups was examined through the mean percent of correct responses over successive blocks of 8 trials (phase 1) or successive blocks of 4 trials (phase 2), which were each statistically analyzed using a Group X Block mixed design ANOVA.

For the test data, a discrimination ratio for each compound was calculated by diving the rating of the paired outcome by the sum of the ratings of the paired and of the alternate outcome (i.e., O3/ (O3 +O4) for AC and VX and O4/ (O4+O3) for BD and WY). This produced ratios ranging from 0 to 1, where scores greater than 0.5 indicate that the correct cue-outcome contingency of phase 2 was learned. These ratios were analyzed by a 2 (Group: No Load vs. Load) X 2 (Cue: Predictive vs. Non predictive) mixed design ANOVA.

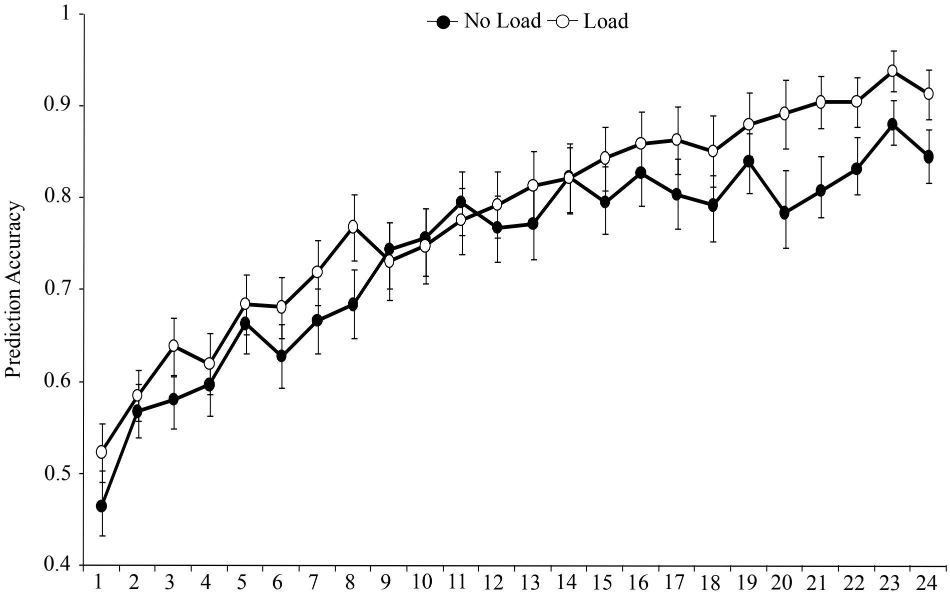
It has been commonly recognized that the LPE is expected to occur only if participants have learnt the contingencies of phase 1 (Le Pelley & McLaren, 2003; Mitchell et al., 2012). On the other hand, it is also expected that any difference between predictive and nonpredictive cues that resulted from phase 1 should be apparent right from the beginning of phase 2; and because of this, LPE is assumed to be relatively independent of the amount of learning reached in the second phase. Thus, the majority of studies on the LPE have adopted selection criteria based exclusively on phase 1 performance (e.g., Don & Livesey, 2015; Le Pelley, Calvini & Spears, 2013; Le Pelley & McLaren, 2003; Le Pelley et al., 2011; Mitchell et al., 2012; Shone et al., 2015). Consequently, we set a criterion of 50% or more accuracy in phase 1 of the experiment. One participant in Group No Load and 2 participants in Group Load failed to meet this selection criterion, so their data were excluded from all analyses. Also, in order to reduce error variance with the critical testing data, we planned to remove outliers using the interquartile range rule (Leys, Ley, Klein, Bernard, & Licata, 2013;

Myers & Well, 1995). Specifically, outliers were defined as participants whose difference between the discrimination ratios of predictive and nonpredictive cues was smaller than Q1-1.5*IQR or greater than Q3+1.5*IQR, where Q1, Q2, and IQR stand for quartile 1, quartile 2, and interquartile range, respectively of each group. With this method, no outliers were found in the present experiment. This left 31 participants in Group No Load and 30 participants in Group Load.

## RESULTS AND DISCUSSION

Figure 2 presents the mean percent of correct responses over successive blocks of 8 trials (phase 1) or successive blocks of 4 trials (phase 2) for Groups No load and Load. As expected, participants in the two groups exhibited a very similar pattern of acquisition in phase 1. This was confirmed by the mixed design ANOVA, which showed a reliable main effect of Block, $F(23, 1357) = 35.322$, $p < 0.001$, partial $\eta^2 = 0.374$, but no reliable effect of Group, $F(1, 59) = 1.779$, $p = 0.187$, partial $\eta^2 = 0.029$, or Group X Block interaction, $F(23, 1357) < 1$. The bottom plot shows that, despite the concurrent memory task performed by Group Load, the acquisition of phase 2 contingencies was similar in the two groups, which is supported by a reliable main effect of Block, $F(5, 295) = 17.526$, $p < 0.001$, partial $\eta^2 = 0.229$, but no reliable effects of Group, $F(1, 59) < 1$, or Group X Block interaction, $F(5, 295) < 1$. These data show clearly that participants learned the task in both phases. The percentage of correct responses of groups No Load and Load, respectively, was 84.48% and 91.33% in the last block of phase 1 and 82.26% and 78.33% in the last block of phase 2.

Figure 3 depicts the mean discrimination ratios for the predictive (AC and BD) and nonpredictive (VX and WY) compounds in Groups No Load and Load in testing. The figure shows that although all four discriminations indexes are above 0.5 -reflecting an appropriate learning of phase 2 contingencies- the data revealed a trend to an LPE in the form of lower discrimination ratios for the nonpredictive compounds than for the predictive compounds in both groups. Accordingly, the 2 (Cue: predictive vs. non predictive) X 2 (Load: No Load vs. Load) ANOVA revealed only a reliable main effect of Cue, $F(1, 59) = 5.925$, $p = 0.018$, partial $\eta^2 = 0.091$ (all remaining $ps > 0.335$).



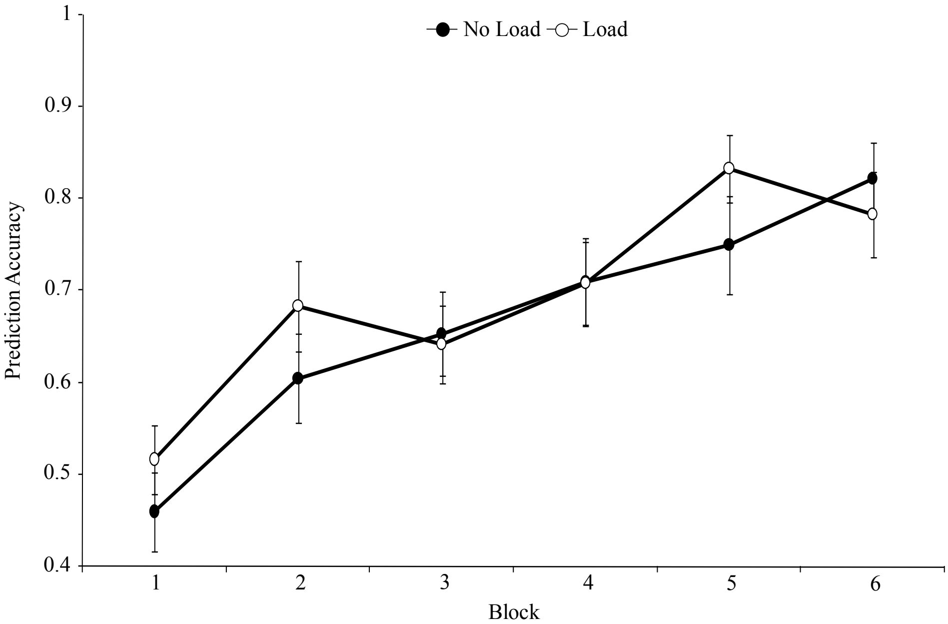




**Figure 2. Mean proportion of correct responses over the training blocks of phase 1(top plot) and phase 2 (bottom plot) of Groups No Load and Load of Experiment 1. The error bars represent to standard error of the mean.**

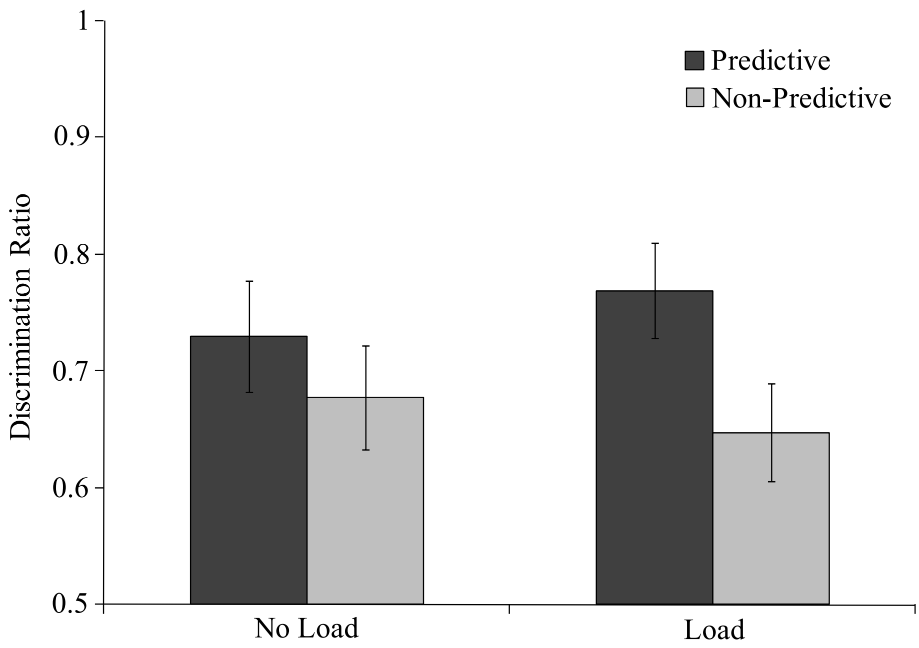



**Figure 3. Mean discrimination ratios during testing for the predictive and nonpredictive compounds of Groups No Load and Load of Experiment 1. The error bars represent to standard error of the mean.**

One conclusion that might be drawn from this pattern is that Experiment 1 replicated the LPE observed in several others studies and that the current load manipulation was inconsequential. As reasonable as this conclusion might be, there are some aspects of our data that suggest an alternative interpretation. First, notice in Figure 3 that the difference between predictive and nonpredictive cues was greater in the Load than in the No Load condition. Although this difference did not reach statistical significance in the form of a reliable Cue X Group interaction (i.e., $F(1, 59) < 1$), we computed the simple effects of cue in each group to assess the reliability of the LPE in each group. The difference between predictive and nonpredictive cues was reliable in Group Load, $F(1, 59) = 5.707$, $p = 0.020$, partial $\eta^2 = 0.088$ but not in Group No Load, $F(1, 59) = 1.087$, $p = 0.301$, partial $\eta^2 = 0.018$.

Thus, contrary to our expectation the LPE seems to be greater in Group Load than in Group No Load. Although this pattern might be due to just random variation, it is somehow puzzling that it is not anticipated neither by associative nor by propositional accounts of the LPE. Indeed, if this effect were reliable, it would suggest that cognitive load and LPE interact in a more complex manner than we originally thought. One possibility is that perhaps some aspects of the instructions or the task itself encouraged some participants to think that the two phases were sufficiently independent from each other. Thus, they may have supposed that those cues that were the best predictors of certain outcomes in phase 1 will not be, necessarily, the best predictors of new outcomes in a subsequent stage. Thus, it might be the case that the automatic process that biased the participants towards ignoring the "nonpredictive cues" of phase 1 competed with an effortful cognitive process by which they attempted to avoid what they think is an incorrect resolution of the task. According to this hypothesis, the competition will most likely be resolved in favor of the learned predictiveness bias if the cognitive process is weakened (e.g., by cognitive load). Experiment 2 was designed to comment further on this possibility.

## EXPERIMENT 2

In search for a possible explanation of why our experimental procedure might have encouraged participants to consider the two phases as independent, we noticed that the outcomes we used in the two phases of Experiment 1 can reasonably be classified as "strong and aversive" sounds (ring and boom) or as "soft and pleasant" sounds (laser and splash). Although the presentation of each sound in phases 1 and 2 was counterbalanced, all participants received the "aversive" sounds (e.g., ring and boom) in one phase and the "pleasant" sounds in the other (laser and splash). Although this is a post-hoc and very subtle observation, it is consistent with a study by Le Pelley, Oakeshott, Wills, and McLaren (2005) who demonstrated that outcome's nature might affect the emergence of LPE. They found that when the affective valence of the outcomes was similar in both phases (e.g., aversive: allergic reactions), there was a robust LPE, but when outcomes were different (e.g., aversive: allergic reactions vs. appetitive: enjoyment reactions), there was a null effect. As Le Pelley et al. (2005) suggested, this might mean that the automatic mechanism that controls changes on cue-associability is reinforcer specific. But, an inferential account it is equally plausible. That is, it could be argued that the more similar are the two phases, the more likely it is that the participants infer generalizability of the predictive value of the cues across the phases.

Experiment 2 was designed to further examine this issue by assessing the effects of two variables on the LPE. One variable was the congruence in the valence of the outcomes of phase 1 and phase 2 and the other variable was cognitive load. In a "congruent" condition, participants were presented with outcomes of similar affective valence in both phases, while in the "incongruent" condition they received outcomes with different affective valence in each phase. If, as suggested by Le Pelley et al. (2005) and by the results of our Experiment 1, outcome congruency was an important determinant of LPE, then the effect should be more likely to be found in the congruent than in the incongruent condition. Furthermore, if the influence of outcome congruency on the LPE is driven by a controlled process, it is expected that cognitive load will have opposite effects in the congruent and incongruent conditions. Thus, half of the participants in each condition were presented with the same secondary memory task as that used in Experiment 1. Since we hypothesize that the associative and inferential processes would "cooperate" to produce an LPE in the congruent condition but that they would "compete" with each other in the incongruent condition, we expect that cognitive load would reduce the likelihood of the LPE in the congruent condition but would increase it in the incongruent condition.

In summary, in Experiment 2 the LPE was compared in four groups resulting from a 2 x 2 design manipulating the similarity in the affective valence of the outcomes across phases (Congruent vs. Incongruent conditions) and cognitive load during phase 2 (No Load vs. Load conditions).

## METHOD

**Participants.** A total of 128 students of University of Talca participated in the experiment in exchange for course credit. They were tested individually and had no previous experience in similar research. Participants were randomly assigned to the following conditions: Congruent No Load (n =32), Congruent Load (n=32), Incongruent No Load (n =32) and Incongruent Load (n=32).

**Materials and procedure.** All of the materials, procedure and statistical analysis were identical to those of Experiment 1 except for the following. First, we used new outcomes consisting of sounds that were unequivocally judged as pleasant or unpleasant by 10 independent participants on a scale from 0 (unpleasant) to 10 (pleasant) points. Based on these ratings, we selected water (M = 9.05), birds (M = 8.80), bells (M = 7.35), and click (M = 6.00), as pleasant sounds; and alarm (M = 1.70) and boom (M = 2.95), as unpleasant sounds[1]. Second, participants in the congruent condition experienced pleasant sounds in both phases (water and bells or click and birds, respectively, counterbalanced) and participants in the incongruent condition experienced pleasant sounds in phase 1 (water and bells) and aversive sounds (boom and alarm) in phase 2, or vice versa. Half of the participants in each condition performed a digit-remembering task concurrently with the causal learning task identical to that of Experiment 1. Third, the statistical analyses were similar to those of Experiment 1 except for the addition of Outcome-congruency as a 2-levels between -subjects factor in the ANOVAs.

All participants met the selection criterion of 50% or more correct responses in phase 1. Two participants of Group Incongruent-Load and 3 in Group Incongruent-No Load qualified as outliers according to the Interquartile Range Rule described above, so they were discarded from further analysis. This left 29 participants in Group Incongruent No Load, 32 participants in Group Congruent No Load, 30 participants in Group Incongruent Load, and 32 participants in Group Congruent Load.

## RESULTS AND DISCUSSION

Figure 4 presents the mean percent of correct responses over training for all groups. The top plot shows that phase 1 was learned similarly by the four groups. This was confirmed by a 2 (Outcomes: Congruent vs. Incongruent) X 2(Load: No Load vs. Load) X 24 (Blocks: 1-24) mixed design ANOVA, which showed a reliable effect of Block, $F(23, 2737) = 83.330$, $p<0.001$, partial $\eta^2=0.412$ and no further reliable effects, ps>0.248. The bottom plot shows that although acquisition of phase 2 contingencies was a bit slower in the load conditions, all 4 groups learned well the discrimination. The ANOVA confirmed this pattern with significant main effects of block, $F(5, 595) = 23.868$, $p< 0.001$, partial $\eta^2=0.167$ and of load, $F(1, 119) = 12.297$, $p = 0.001$, partial $\eta^2=0.094$ (all remaining ps>0.184). This would suggest that, in addition to a potential interference with participant's inferences about the relative usefulness of the cues comprising each compound, the secondary task also impaired their rate

[1] A repeated measures ANOVA indicated a significant effect of sound, $F(5, 45) = 37.045$, $p<0.001$. Post-hoc pairwise comparisons indicated that the mean ratings of all "pleasant" sounds were significantly greater than those of all "unpleasant" sounds (ps <0.034).

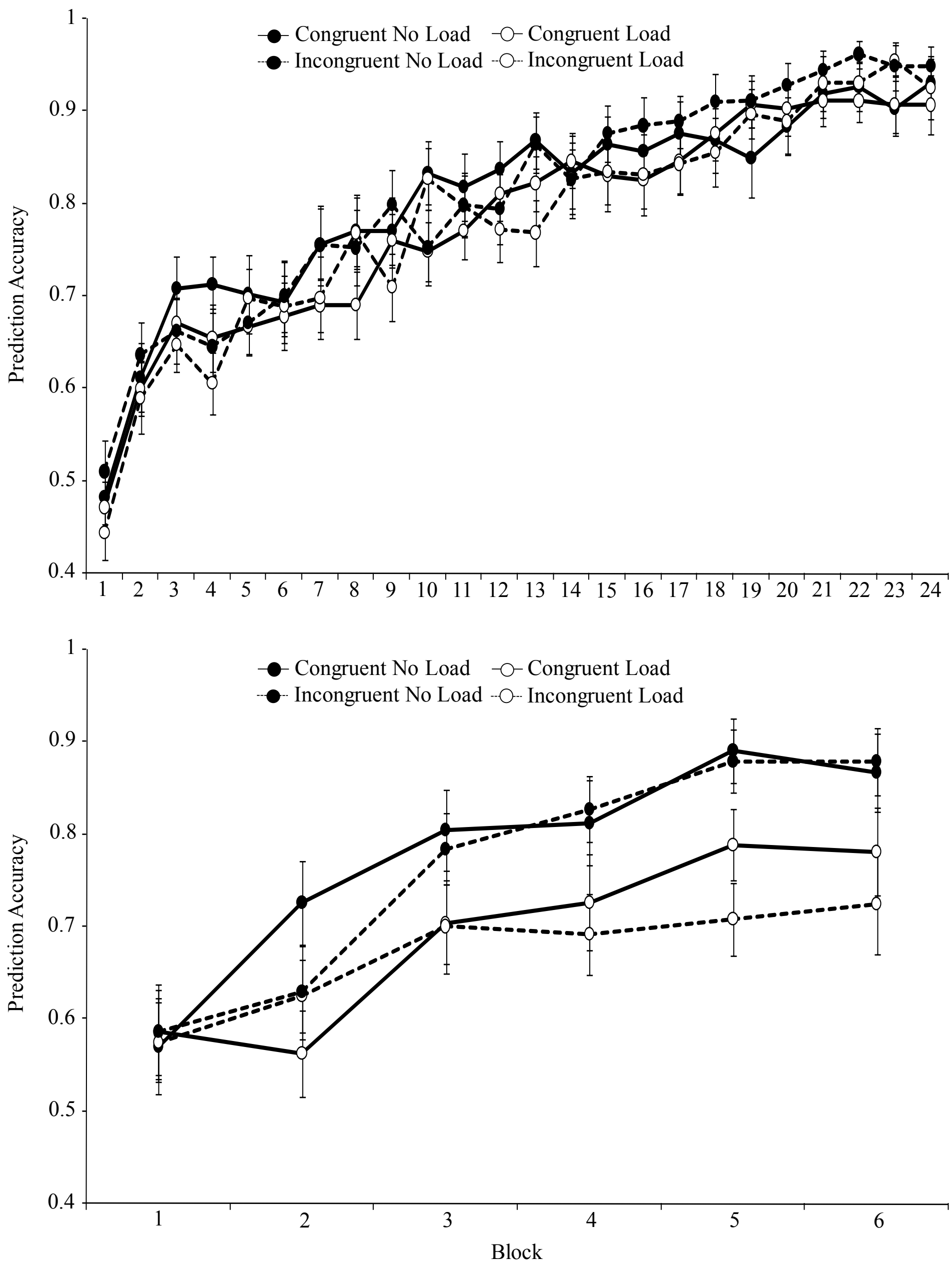



**Figure 4. Mean proportion of correct responses over the training blocks of phase 1 (top plot) and phase 2 (bottom plot) for the four groups of Experiment 2. The error bars represent to standard error of the mean.**

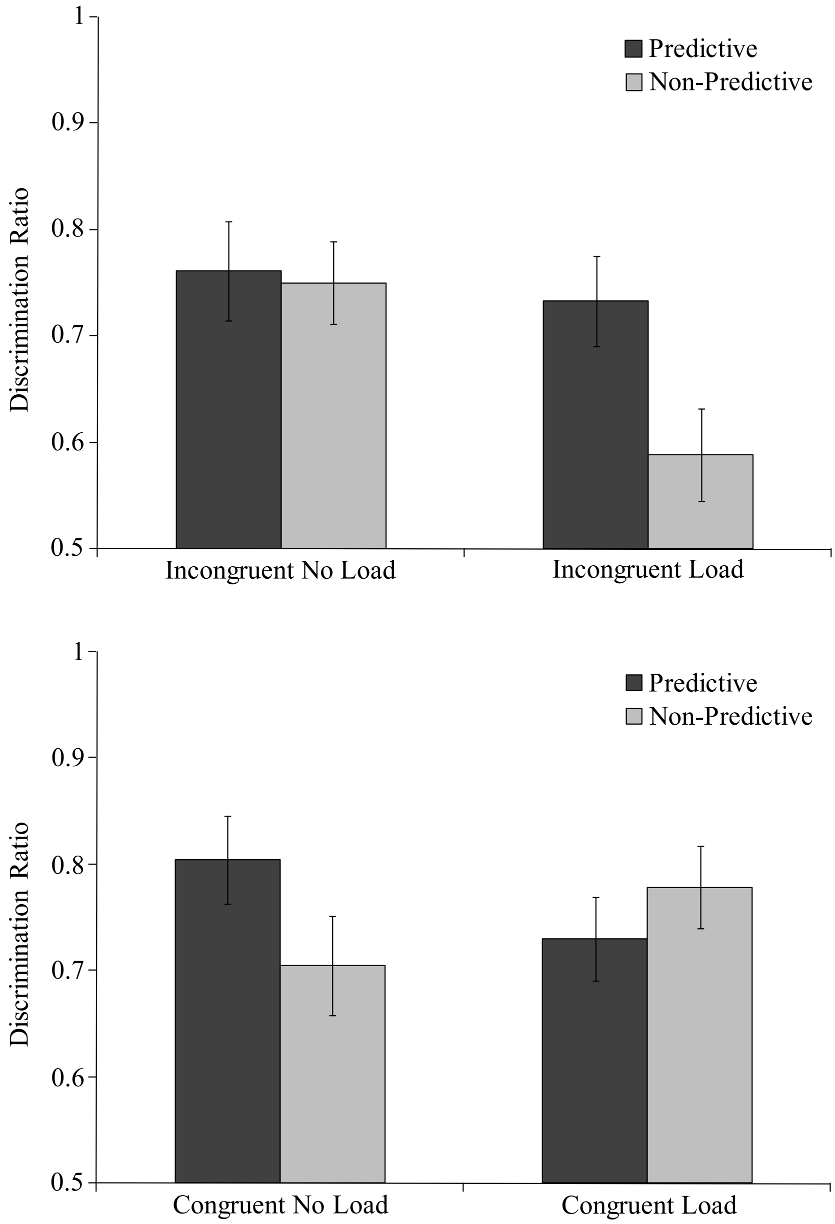



**Figure 5. Mean discrimination ratios during testing for the predictive and nonpredictive compounds of the four groups of Experiment 2. The top plots depict the data of the Incongruent No Load (left-hand plot) and Incongruent Load (right-hand plot) groups and the bottom plots the data of the Congruent No Load (left-hand plot) and Congruent Load (right-hand plot) groups. The error bars represent to standard error of the mean.**

of learning of the compounds as wholes. Since LPE is expected to occur independently of the degree of learning of phase 2, this result should have no impact in the critical comparisons at test. Furthermore, the absence of load x group interaction indicates that the effect of load is independent of the degree of congruency of the outcomes.

Figure 5 depicts the results of the testing phase for the 4 groups. As shown in the top plots, the pattern of results in the incongruent conditions is very similar to that observed in Experiment 1. That is, although both, the No Load and Load conditions exhibited some degree of LPE, in the form of higher discrimination ratios for the predictive than for the nonpredictive cues, the effect is more marked in the Load than in the No Load condition. Although the results with the incongruent condition replicate the descriptive pattern of Experiment 1, the bottom plot shows a different outcome for the congruent condition. That is, although participants in Group Congruent No Load produced higher discrimination ratios for the predictive than for the nonpredictive compounds, participants in Group Congruent Load exhibited just the opposite pattern. In agreement with these observations, the 2 (Cue: predictive vs non predictive) X 2 (Outcomes: Congruent vs. Incongruent) X 2 (Load: No Load vs. Load) ANOVA revealed a significant Cue X Outcomes X Load interaction, $F(1,119) = 9.571$, $p = .002$, partial $\eta^2 = .074$. Following this result, the cue x load interaction was reliable in the congruent, $F(1, 119) = 5.542$, $p = .020$, partial $\eta^2 = .083$, as well as in the incongruent condition, $F(1, 119) = 4.115$, $p = .045$, partial $\eta^2 = .067$. Finally, the simple effects of cue in each Load X Outcomes condition, revealed that the discrimination ratios for the predictive cues were significantly superior to those of the nonpredictive cues in the Congruent No Load, $F(1, 119) = 5.020$, $p = .027$, partial $\eta^2 = .040$ and Incongruent Load conditions, $F(1, 119) = 9.867$, $p = .002$, partial $\eta^2 = 0.077$. Conversely, no reliable difference between predictive and nonpredictive cues was observed in the Congruent Load, $F(1, 119) = 1.185$, $p = .278$, partial $\eta^2 = .010$, and Incongruent No Load, $F(1, 119) < 1$, conditions. In addition to this pattern of interaction and simple effects, the main effect of cues was reliable $F(1, 119) = 5.189$, $p = .025$, partial $\eta^2 = .042$. No further reliable effects were obtained.

These results indicate that the LPE was reliably affected by our cognitive load manipulation. However, the direction of the effect depended upon the convergence or similarity of the outcomes used in the two phases of the experiment. The fact that cognitive load appeared to either facilitate the LPE in the incongruent-outcome condition and to disrupt it in the congruent-outcome condition cannot be explained by purely outcome-specific associative mechanisms (Le Pelley et al., 2005) or by purely inferential accounts (Mitchell et al., 2012). Our data instead, are more in line with a dual-process account of LPE in which inferences are assumed to interact with an associative process of selective attention (e.g., Don & Livesey, 2015). The assumption is that depending on some cognitive clues provided to the participants, these two processes might interact in either a cooperative or a competitive fashion.

## GENERAL DISCUSSION

Overall, the present experiments demonstrate the effect of two variables on the LPE in human predictive learning: Outcome-congruency and cognitive load. The results of our “null hypothesis- significance testing-dichotomous decision"(Cohen, 1994) would lead us to conclude that our cognitive load procedure had a detrimental effect on the LPE when training was conducted with “affectively congruent” outcomes in the two phases (Experiment 2) and had either a facilitative (Experiment 2) or no demonstrable (Experiment 1) effect when training was conducted with incongruent outcomes. If we depart from this dichotomous decision procedure (Wilkinson & Task Force on Statistical Inference, 1999) and examine the means and confidence intervals of the critical effect in each group, a suggestive pattern appears. For this, Table 2 presents the means and confidence intervals for a “learned predictiveness index (LPI)" of the different groups involved in each experiment. The LPI was computed as the mean discrimination index for compounds involving predictive cues (AC and BD) minus the mean discrimination index for compounds involving nonpredictive cues (VX and WY). As can be seen, in the absence of cognitive load the degree of “affective similarity” or “congruency” between the outcomes used in the two phases of the experiment seems to be relevant to the LPE. Specifically, the mean LPI of Group Congruent No Load, in which efforts were made to create outcomes with similar affective valence across the two phases of training, was clearly superior to the mean LPIs of the Groups Incongruent No Load of Experiment 2 and No Load of Experiment 1, whose outcomes were incongruent. In general, the finding of greater LPI in participants trained with congruent outcomes, but not in participants without such an obvious congruency, is consistent with the data provided by Le Pelley et al. (2005).

Second, the addition of a secondary task (cognitive load) seems to have different effects on the LPE, depending on whether the outcomes of the two phases of training were congruent or incongruent. As seen in Table 2, the mean LPIs obtained by participants trained with incongruent outcomes and cognitive load (Group Load of Experiment 1 and Group Incongruent Load of Experiment 2), were clearly superior than those of their respective No load counterparts (Groups No Load and Incongruent No Load of Experiments 1 and 2, respectively). In contrast, in the case of congruent-outcome conditions used in Experiment 2, the LPIs were clearly superior in the absence than in the presence of cognitive load. Our results revealing an opposite pattern (i.e., disruption of LPE by cognitive load in congruent condition, and a slight facilitation of LPE in incongruent condition) mirrors previous research, suggesting that a secondary working memory task does not always impair the performance (Woodman, Vogel, & Luck, 2001), but even it might reduce distraction and facilitate selective attention (Park, Kim, & Chun, 2007), which would depend on the interactions and overlaps between the contents of working memory and the type of information being processed (Kim, Kim, & Chun, 2005; de Fockert, & Bremner, 2011; San Miguel, Corral, & Escera, 2008). Within this sort of account, it would be necessary to determine which kind of information processing variables are responsible for such a differential susceptibility to cognitive load in the congruent and incongruent conditions.

**Table 2. Mean and confidence intervals of learned predictiveness indexes (LPI) for Experiments 1 and 2.**

| Group /Experiment | LPI | CI 95% | Load | Outcomes |
|---|---|---|---|---|
| No load /Exp. 1 | 0.053 | (-0.047, 0.153) | No | Incongruent |
| Load /Exp. 1 | 0.122 | (0.020, 0.224) | Yes | Incongruent |
| Incong. No Load /Exp. 2 | 0.011 | (-0.082, 0.104) | No | Incongruent |
| Incong. Load /Exp. 2 | 0.144 | (0.053, 0.235) | Yes | Incongruent |
| Cong. No Load /Exp.2 | 0.100 | (0.012, 0.189) | No | Congruent |
| Cong. Load /Exp. 2 | -0.048 | (-0.137, 0.040) | Yes | Congruent |

From a purely empirical perspective, one conclusion that can be drawn from the present data is that the LPE is a complex phenomenon whose occurrence would depend on a number of interacting factors. Our data suggest that some variables such as the similarity between the outcomes and the availability of cognitive resources might be influential on the degree to which the LPE can be observed. This complex pattern is difficult to reconcile with explanations based solely on either associative mechanism (Le Pelley et al., 2005) or inferential processing (Mitchell et al., 2012). Instead, our data fit better with dual processes interpretations (Evans & Stanovich, 2013) in which associative and propositional factors interact in cooperative or competitive ways to produce an LPE with more or less ease.

There are a number of theoretical alternatives on how associative and propositional processes might interact (see Evans, 2003, 2008; Sloman, 1996). One possibility is that, in every learning situation, automatic processes are always present and dominate unless the learner is motivated and has the resources to engage in effortful controlled process (McLaren, Forrest, McLaren, Jones, Aitken, & Mackintosh, 2014). Thus, it can be assumed that during phase 1 of the experiments the participants progressively developed an automatic bias in favor of the processing of predictive versus nonpredictive cues in the future. If subsequently, by means of explicit instructions (Don & Livesey, 2015; Mitchell et al., 2012; Shone et al., 2015) or by some features of the experimental environment, such as the affective dissimilitude of the outcomes (Le Pelley et al., 2005; Experiments 1 and 2 in the present research) the participants are encouraged to consider the two phases as independent, the underlying automatic-LPE would be counteracted by a controlled process. In this competitive scenario, the LPE would still be apparent if the automatic process is made more compelling by a reduction in the cognitive resources that are required to exert the competing inference (the Incongruent Load conditions of Experiments 1 and 2). On the other hand, if the instructions or the features of the experimental environment encourage participants to believe in the transferability between the phases, then controlled processes would more likely cooperate with the automatic process leading to a robust LPE under the standard circumstances (Congruent No Load condition of Experiment 2). The null effect observed in the Incongruent No Load and Congruent Load conditions of Experiment 2 suggests that the involvement of controlled process is not trivial.

Of course this dual processes explanation is speculative and does not embrace our full pattern of data. For instance, it predicts the greatest LPE for the Congruent No Load condition, in which both automatic and controlled processes should align to produce the effect. But our data suggest that in this condition the LPE was not greater than that in the Incongruent-Load condition, in which the automatic but not the controlled processes should contribute to the LPE. Likewise, the combined behavioral effect of automatic and controlled processes would require some quantitative refinement to make testable predictions on the relative size of the LPE under different conditions. Obviously, further research is needed to examine several experimental parameters that appear, in principle, to be critical for the reported effects. For now, it just suffices to nominate a few, such as the amount of training and the quantitative and qualitative features of cognitive load and interphase similarity of the outcomes.

Finally, there are some methodological limitations of our study that might be usefully considered in future research. First, we did not record performance in the secondary task, which could have been an efficient way of measuring the efficacy of this manipulation or for selecting participants for statistical analysis. Second, there are other and perhaps more efficient strategies to impose cognitive load (Park et al., 2007; Pratt, Willoughby, & Swick, 2011; Wills et al., 2011). Also, since the no load participants of our experiments did not perform a secondary task they differed from their load counterparts in several respects; such as motor responses, visual input across trials, and trial duration. Third, we used only pleasant outcomes in the congruent groups of Experiment 2, which imposes a limitation in the generality of the findings. Finally, since it has been suggested that causal rating scales are measures of causal reasoning rather than associative processing (Don & Livesey, 2015; Shone et al., 2015), it seems potentially useful to consider this distinction in future research involving the type of variables manipulated in the present research. Furthermore, this type of assessments can be complemented with additional measurements, such as eye gaze (Beesley Nguyen, Pearson & Le Pelley, 2015; Le Pelley et al., 2011) and electrophysiological recording techniques (Feldmann-Wüstefeld, Uengoer, & Schubö, 2015; Luque, Morís, Rushby, & Le Pelley, 2015).

## RESUMEN

El efecto de la carga cognitiva y la congruencia de las consecuencias sobre el efecto de la predictibilidad aprendida en el aprendizaje predictivo humano**.** El efecto de la predictibilidad aprendida o LPE, es el hallazgo de que cuando las personas aprenden que algunos estímulos son predictores fiables de una consecuencia en una primera etapa del entrenamiento (fase 1), muestran un sesgo de aprendizaje a favor de éstos estímulos en un entrenamiento posterior que implica nuevas consecuencias (fase 2), a pesar de que todos los estímulos son igualmente fiables en la fase 2. En el

Experimento 1, replicamos el efecto básico y demostramos que la ejecución de una tarea de memoria secundaria durante la fase 2 no tuvo una influencia significativa sobre la LPE. En el Experimento 2, demostramos que la misma tarea secundaria puede facilitar o interrumpir la LPE, dependiendo de si las consecuencias de la fase 1 fueron congruentes o incongruentes afectivamente con las consecuencias de la fase 2. Estos hallazgos son discutidos en relación a las explicaciones asociativa e inferencial de la LPE.

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