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The Redundancy Effect on Human Predictive Learning: Evidence against a Propositional Interpretation

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Original article

Abstract

The redundancy effect is the finding of greater learning when an X stimulus is trained in an A+ AX+ blocking procedure, than when a Y stimulus is trained in a BY+ CY- discrimination procedure. These findings are new and theoretically challenging for all conditioning theories that calculate learning based on a common error. For this reason, we alternatively examined the possibility that the phenomenon is the result of a propositional reasoning. In an experiment, we replicated the basic effect and we found out that the addition of instructions on the occurrence of the consequences at a submaximal level does not have a significant impact on the redundancy effect. These findings are discussed with regard to a propositional and associative approach based on the assumption that the experimental stimuli share a common feature.

Keywords:
redundancy effect, blocking, discrimination, propositional reasoning.

Resumen

El efecto de redundancia en el aprendizaje predictivo humano: Evidencia en contra de una interpretación proposicional. El efecto de redundancia es el hallazgo de un mayor aprendizaje a un estímulo X entrenado en un procedimiento de bloqueo A+ AX+, que a un estímulo Y entrenado en un procedimiento de discriminación BY+ CY-. Estos hallazgos son nuevos y teóricamente desafiantes para todas las teorías del condicionamiento que calculan el aprendizaje en base a un error común. Es por ello que examinamos alternativamente la posibilidad que el fenómeno sea el resultado de un razonamiento proposicional. En un experimento, replicamos el efecto básico y encontramos que la adición de instrucciones sobre la ocurrencia de las consecuencias a un nivel sub-máximo no tiene un efecto significativo sobre el efecto de redundancia. Estos hallazgos son discutidos en relación con una aproximación proposicional y asociativa basada en el supuesto que los estímulos experimentales comparten un elemento común.

Palabras clave:
efecto de redundancia, bloqueo, discriminación, razonamiento proposicional.

Tabla de Contenido

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Introduction

In classical conditioning, a behaviorally neutral stimulus or conditioned stimulus (CS) acquires the ability to produce a conditioned response (CR) after it is paired with an unconditioned stimulus (US) that produces a biologically significant unconditioned response (UR). The first conditioning theories emphasized the idea of an automatic association (e.g., Bush & Mosteller, 1951) according to which the mere CS-US spatial-temporal contiguity was a sufficient condition for learning to occur. This idea was challenged by the observation of stimulus competition phenomena, whose prototype is blocking (Kamin, 1969), in which a CS that has developed an association with the US "blocks" the learning of any other CS in a subsequent phase where both stimuli are presented together and followed by the US. These findings led to new theories according to which the CS-US pairing is a function of the degree in which the US is predicted by all the CSs present in the trial, that is to say, the CS-US pairing is based on a common error mechanism (e.g., Rescorla & Wagner, 1972).

One of the first models proposed was the

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Rescorla-Wagner model (1972), according to which the amount of change in the associative strength between a CS and a US in a given trial is a function of the prediction error of the US for all CSs present in the trial (λ- ΣV). When the total amount of learning of the CSs (ΣV) equals to the asymptote of learning (λ), the error is zero and learning stops. The changes in the associative strength of a CS, ΔV, are given by the following equation: $\Delta V= \alpha\beta (\lambda - \Sigma V)$. Where λ is the asymptote of learning, ΣV is the sum of the associative strength of all the stimuli present in a trial, and α and β are learning parameters related to the intensity of CS and US, respectively. The association is still automatic in common error theories, but now they would not only depend on the CS-US contiguity, but also on the information value of the CSs. The blocking, according to these theories, would occur because the second stimulus is redundant, that is to say, it does not provide new information to the US predictability.

Recently, Pearce et al. (Jones & Pearce, 2015; Pearce, Dopson, Haselgrove, & Esber, 2012; Uengoer, Lotz, & Pearce, 2013) demonstrated greater learning for an X stimulus trained as part of an A+ AX+ blocking procedure than for a Y stimulus trained as part of a BY+ CY- discrimination procedure. Jones and Pearce (2015) called these findings as "redundancy effect". This is a recent finding that theoretically challenges all conditioning theories based on a common error mechanism such as the Rescorla-Wagner theory since they predict that the final associative value of Y in the discrimination procedure should be greater than the final associative value of X in the blocking procedure, which is contrary to the redundancy findings.

Since the common error theories are not able to explain the redundancy effect, other theoretical alternatives have been studied, which in principle can be grouped into 2 categories. The first category refers to the possibility that the phenomenon is produced by within-compound associations (Rescorla & Durlach, 1981). Specifically, the simultaneous presentation of two stimuli can result in an association between them and subsequently, the mere presentation of one of them alone could activate the representation of the other. According to this proposal, in test trials with the X stimulus, the participants could remember A, and since this was consistently paired with the US, it could encourage the participants to consider X as a reasonably strong predictor of the US. On the contrary, the test trials with Y could encourage the participants to remember B and C, and since one of these has been consistently paired without the US, the participants could consider Y as a weak predictor of the US. The experimental manipulation used to examine this hypothesis consisted in modifying the associative strength acquired by X and Y (first phase: A+ AX+, BY+ CY-) through the presentation of A- and Y+ in a second phase, which should produce a decrease of the response for the X stimulus and an increase of the response for the Y stimulus, that is to say, this should eliminate the redundancy effect. However, the results of a series of studies demonstrated that it is a robust phenomenon with this type of experimental manipulations (Pearce et al., 2012, Experiment 2 and 3; Uengoer et al., 2013, Experiment 2; Jones & Pearce, 2015, Experiment 1; Zaksaite & Jones, 2017). Consequently, we can discard the idea that this is a result of within-compound associations.

The second category refers to the possible attentional nature of the phenomenon. According to this, the blocked cue X could draw more attention than the Y stimulus subjected to a discrimination procedure (Uengoer et al., 2013). In order to examine this alternative, Jones and Zaksaite (2017) monitored the look of the participants during the A+ AX+ BY+ CY- training through eye-tracking as an overt attention measure (e.g., Beesley & Le Pelley, 2011). Contrary to expectations, the results showed that there are no differences in the time people spent looking at the X and Y stimuli. In another investigation, Uengoer, Dwyer, Koening and Pearce (2017) presented in a first phase B and E stimuli in an A+ AB+ and D+ DE+ blocking procedure respectively, and the X and Y stimuli in a discrimination procedure UX+ VX- and UY+ VY-, respectively. In a second phase, the participants received two discriminations, either BX+ EX- and BY+ EY- or BX+ BY- and EX+ EY-. They expected that, if more attention is paid to the blocked cue, the first discrimination pair (BX+ EX- and BY+ EY-) should be more easily solved than the second pair (BX+ BY- and EX+ EY-). Contrary to expectations, both discriminations were acquired in a similar way, excluding the idea that the redundancy effect is due to differences in the focused attention to X and Y stimuli.

In summary, the findings on redundancy are challenging for all conditioning theories and they could even be considered as an additional test for those who question that the human classic conditioning is exclusively regulated by automatic processes (Lovibond & Shanks, 2002; Mitchell, De Houwer, & Lovibond, 2009). Specifically, if a person learns that the AX compound causes a consequence, and then the person learns that A alone also causes this consequence, the logical conclusion with regard to X is uncertain and the conclusion is not necessarily that X causes the consequence or blocking (e.g., Cheng, 1997; Jones, Zaksaite, & Mitchell, 2019). This is consistent with the difficulty to observe blocking in human conditioning (e.g., Davey & Singh, 1988), whose failure in causal learning tasks and autonomic conditioning preparation has been considered as an indirect evidence that in humans only those competence phenomena that can be logically deducible or that can be inferred from instructions that reduce the uncertainty on the causal value of X occur (e.g., Beckers, De Houwer, Pineño, & Miller, 2005). On the contrary, if a person learns that the BY compound causes a consequence, and then the person learns that C and Y do not cause it, then the person could conclude that Y is irrelevant to solve the discrimination since B causes the consequence and C does not cause it. Therefore, it would be reasonable to observe the redundancy effect, that is, a greater learning with X than with Y.

If the ambiguous causal status of blocked cue X favors the redundancy effect, then reducing the uncertainty associated with X should also reduce the probability of observing the redundancy effect. One method to do it consists on giving verbal instruction or pre-training people in order they can learn that the stimuli produce twice as many consequences when they are accompanied by other stimuli (additive consequences) than when they are alone or when the consequences of a simple stimulus or a compound of stimuli occur with a submaximal intensity, as, for example, 50% of the maximum magnitude of consequence (e.g., Beckers et al., 2005; De Houwer, Beckers, & Glautier, 2002). The results of these manipulations show a greater blocking effect in the additive condition than in a non-additive one (Lovibond, Been, Mitchell, Bouton, & Frohardt, 2003) and also in the submaximal condition than in control or maximum condition (De Houwer et al., 2002).

Since the conditioning theories are not able to explain the redundancy effect, the purpose of the present investigation is to examine if this could be the result of a propositional reasoning (e.g., Mitchell et al., 2009). To do so, the participants were subjected to a causal learning procedure where they had to predict if the consumption of certain foods causes allergic reactions in a fictitious patient. Specifically, the participants were trained with different types of trials consisting of A+, AX+, BY+, CY-, DW+ (foods that alone or in a combination with other foods produced an allergic reaction (e.g., A+) or not (e.g., CY-). In this phase, in order to reduce the possible uncertainty associated with the causal value of the blocked cue X, half of the participants were distributed to the “submaximal” group and were given feedback on their performance, by indicating to them that the consequences occur at a submaximal intensity (50% of the maximum magnitude of consequence; Beckers et al., 2005; De Houwer et al., 2002), while the other half did not receive such feedback (“control” group). Subsequently, at a test phase, the participants chose their causal judgments to each of the stimuli presented alone (A, B, C, W, X, Y). We expect to obtain blocking evidence in the form of greater learning with W than X and a redundancy effect in the form of greater learning with X than Y. In addition, if the submaximal manipulation of the consequences reduces the uncertainty associated to the causal value of X, we expect to observe a greater blocking effect and a lower magnitude or absence of the redundancy effect in the submaximal group than in the control group.

Method

Participants

A total of 24 undergraduate students of Universidad de Talca voluntarily participated in this experiment (*mean* age = 22.0, *SD* = 2.6 years, 17 men). There were evaluated individually, and they did not have previous experience in any similar investigation. The participants were randomly assigned to the “Submaximal” group (n = 12) and to the “Control” group (n = 12). The content of the informed consent and the procedure of the experiment were approved by the Ethics Committee of Universidad de Talca.

Materials

The stimuli were presented, and the data were collected with a computer connected to a 14-inch screen programmed with the E-prime 1.1 software (Psychology Software Tools, 2004). Stimuli designated as A-D and W-Y were represented by the images of 7 different foods (apple, pear, banana, grapes, watermelon, orange, and strawberry). Symbols "+" and "-" represented the presence of the consequence or stomach discomfort (Nausea) or its absence (No Reaction).

Procedure

The main characteristics of the task and the programming of the experimental environment were similar to that proposed by Uengoer et al. (2013). The purpose of the task was that the participants learned to predict if the consumption of a food or a pair of them would produce an allergic reaction (nausea) in the fictitious patient, "Mr. X".

The experimental task consisted of 2 phases: training and testing. During the training, the participants received a total of 50 trials (10 trials per each type of stimulus, A+, AX+, BY+, CY- and DW+). At the beginning of each trial, the sentence "Mr. X ate" is shown (Verdana font, size 8, white) in the upper left side of the screen in parallel with the image of one food or two foods. The size of the food images was 20% x 20% in relation to the size of the screen. When images of two foods were displayed, one of these was displayed at the upper center of the screen (108 pixels of the vertical axis and 300 pixels of the horizontal axis) and the other food was displayed on the upper right side of the screen (108 pixels of the vertical axis and 508 pixels of the horizontal axis). The presentation of the stimuli was followed 2 seconds after by the phrase "Do you think Mr. X will have nausea?" (Verdana font, size 8, white) and the participants had to answer by selecting "Yes" or "No" (Courier Font, size 9, black) by clicking the respective button. "Yes" answers (240 pixels of the vertical axis and 72 pixels of the horizontal axis) and "No" answers (240 pixels of the vertical axis and 192 pixels of the horizontal axis) were represented by white rectangles whose size was 5% x 15% of the screen. This screen remained unchanged until the participant clicked one of the rectangles containing the answers. Once the participant selected an answer, the rectangle of the chosen answer changed from white to yellow, and the rectangle containing the unselected answer changed from white to blue-green and along with it, feedback was displayed at the bottom of the screen accompanied by a sound that the participants heard through headphones during 500 milliseconds. The feedback consisted in the black words "CORRECT" or "INCORRECT" over the word "Nausea" for the (+) reinforced trials or "No reaction" utterance for (-) not reinforced trials, both in red with a size of 8% x 80% of the screen. To reduce the uncertainty associated to the blocked cue X, and to examine its effect on the redundancy, half of the participants were randomly distributed to the "submaximal" group and they additionally received instructions under the feedback, which consisted in the phrase "NAUSEA: 50 out of 100 points" for the reinforced trials (i.e., A+, AX+, BY+, DW+) and "NO ALLERGIC REACTION: 0 out 100 points" for not reinforced trials (i.e., CY-), while the other half of the participants were assigned to the "control" group and received the feedback alone. These instructions were similar to those used by Soto, Vogel, Castillo and Wagner (2009).

After completing the training phase, the participants received the following message: "Now we would like that you estimate which is the probability with which each food causes NAUSEA to Mr. X." During this phase, the image of one food or a pair of foods was displayed in the upper center of the screen, and the participants had to answer, "How likely is that this food causes NAUSEA to Mr. X?" The participants answered by selecting a number from 0 (definitely not likely) to 10 (definitely likely) at an 11-point scale. The bottom panel of Figure 1 shows an example of a test trial. The participants rated each of the foods alone in two opportunities (12 trials in total, 2 of every type A, B, C, W, X, Y).

The designation of specific foods to the A-D conditions was partially counterbalanced across participants by means of their different allocation in one of four subgroups. Specifically, in subgroup 1, the assignment for A, B, C, D was apple, pear, banana, grapes, respectively. Subgroup 2 was identical to subgroup 1, except that foods A and B were switched by C and D (A with C, B with D). In subgroup 3, the assignment for A, B, C, D was grapes, apple, pear and banana, and subgroup 4 was identical to subgroup 3, except that foods A and B were switched by C and D (A with C, B with D). Apart from that, 3 different assignments of watermelon, orange and strawberry foods were made to W-Y. Specifically, in one case, W, X, Y were represented by watermelon, orange, and strawberry, respectively, and by strawberry, watermelon and orange, respectively in the second case, and orange, strawberry, and watermelon, respectively in the third case.

The position (left vs. right) of the food images forming a compound was balanced throughout the experiment. That is, in half of the training trials the stimuli were presented in one position (e.g., AX), and in the other, the position was reversed (e.g., XA).

Since there are 4 different assignments of A-D foods and 3 assignments for W-Y, there is a total number of 12 different participant conditions. The experiment was carried out with 2 repetitions, consisting of 24 participants distinguished by its assignment to one of both experimental groups, "submaximal" (n = 12) and "control" (n = 12), and within each experimental group to one of the 3 food assignments to W-Y and to one of the 4 different A-D assignments.

Statistical analysis

The 10 training trials with each type of stimulus (50 trials in total) were grouped in 5 blocks of 2 trials each, in which the proportion of correct responses was calculated for the "submaximal" and "control" groups. The statistical significance of the interest effects was examined through a mixed 2 (group: submaximal, control) X 5 (stimulus: A, AX, BY, CY, DW) X 5 (blocks: block 1…block 5) ANOVA with the proportion of correct responses as a dependent variable. Apart from that, the 2 test trials with each type of stimulus (12 trials in total) were grouped per stimulus (A, B, C, W, X, Y) and the statistical significance of the interest effects was examined through a mixed 2 (group: submaximal, control) X 6 (stimulus: A, B, C, W, X, Y) ANOVA with the mean prediction as dependent variable. In order to examine whether there were differences in the magnitude of the effects between the groups, 2 t tests of independent samples were conducted with a blocking rate (the difference between W and X) in one case, and one of redundancy (the difference between X and Y) in another as dependent variables. A high value of those rates (maximum value of 10), would indicate the presence of a higher magnitude of the examined effect. Following a similar approach by Jones et al. (2019), we used a Bayesian t-test to evaluate the strength of support for the null hypothesis (Cauchy prior with a width of .707). The resulting Bayes factors (B_{01}) indicate the level of support for the null and alternative hypotheses. According to Jeffreys (1961), values higher than 3 support the null hypothesis, whereas values lower than 0.33 support for the alternative hypothesis.

Results and discussion

Figure 1 presents the proportion of correct responses during the course of the training for the submaximal (upper panel) and the control group (bottom panel). We could observe that there were progressive changes in the proportion of correct responses to each of the stimuli during the course of the trials. In addition, there were no differences in the performance when both groups were compared. Consistent with our observations, the mixed 2 (group: sub maximal, control) X 5 (stimulus: A, AX, BY, CY, DW) X 5 (blocks: block 1…block 5) ANOVA revealed a main effect of stimuli, $F(4, 88) = 4.896$, $p = .001$, η^2 *partial* = .182, and block, $F(4, 88) = 60.107$, $p < .001$, η^2 *partial* = .732, and a marginally significant stimulus x block interaction effect, $F(16,352) = 1.523$, $p = .089$, η^2 *partial* = .065 (all remaining *ps* > .157).

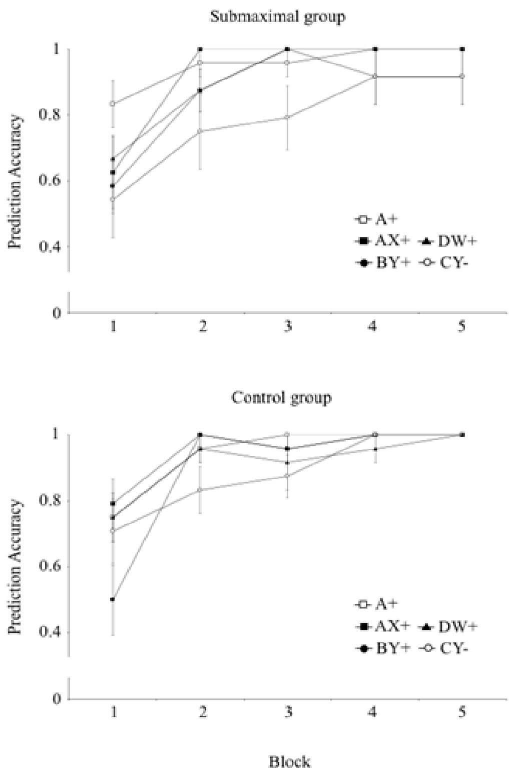

Figure 1. Mean proportion of correct responses over the training blocks of training of Groups Submaximal (top plot) and Control (bottom plot) of Experiment. The error bars represent to standard error of the mean.

Figure 2 presents the predictive mean values assigned to the stimuli for the submaximal and control groups in the test phase. We could observe that, in general, there was greater learning with stimulus A, then with B, W, X and Y. C was the stimulus with the lowest predictive value. With regard to the comparison between the groups, we observed there were no great differences in the predictive values assigned to each of the stimuli. Most importantly, we observed there was a blocking effect in the way of greater learning with stimulus W than X, and a redundancy effect since there is greater learning with stimulus X than Y in both groups.

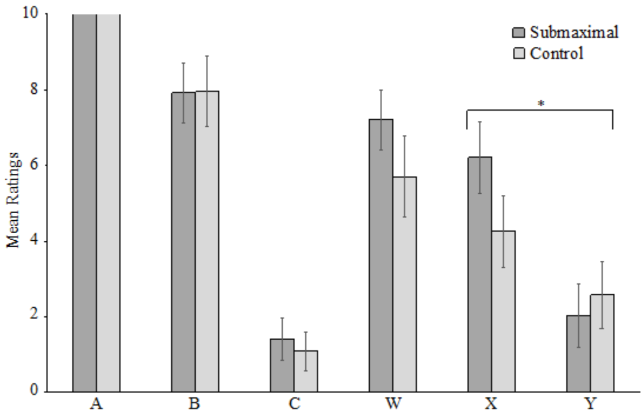

Figure 2. Mean ratings during testing for the stimulus A-Y of Groups Submaximal and Control of Experiment. The error bars represent to standard error of the mean. **p* < .05.

Consistent with our observations, the 2 (group: submaximal, control) x 6 (stimuli: A, B, C, W, X, Y) ANOVA only revealed a main effect of stimuli, $F(5, 110) = 40.99$, $p < .001$, η^2 *partial* = .651 (all remaining *ps* > .324). Most interesting, there was a marginally significant blocking effect, which consisted of greater learning with stimulus W than X, $t(23) = 1.921$, $p = .067$, Cohen`s $d = .392$ (although the Bayesian *t* test suggested that the evidence supporting the null hypothesis was insufficient, $B_{01} = .969$) and a redundancy effect statistically significant, which consisted of greater learning with stimulus X than Y, $t(23) = 3.610$, $p = .001$, Cohen`s $d = .737$. In addition, there were no differences between the groups in the blocking rates, $t(22) = -.351$, $p = .729$, Cohen's $d = -.143$, $B_{01} = 2.561$, and redundancy rates, $t(22) = 1.599$, $p = .124$, Cohen's $d = .653$, $B_{01} = 1.083$ (although a Bayesian *t* test suggested that the evidence in favor of the null result was insufficient in cases both). In conclusion, our results show that the manipulation of submaximal intensities of the consequences did not have an effect on redundancy, which suggests that the mechanism behind the phenomenon would not be rational-propositional in nature (Mitchell et al., 2009).

General discussion

Our findings show a redundancy effect since there is greater learning when an X stimulus is trained in an A+ AX+ blocking procedure, than when a Y stimulus is trained in a BY+ CY- discrimination procedure, and a marginally significant blocking effect since there is greater learning with W than X. These findings are consistent with previous reports supporting the robustness of the redundancy effect (e.g., Pearce et al., 2012) and also with prior failures to replicate the blocking phenomenon (Maes et al., 2016).

Recent findings of the redundancy effect are consistent with a propositional perspective of human conditioning (e.g., Mitchell et al., 2009) given the uncertain causal value of stimulus X in a blocking procedure (A+ AX+). Accordingly, it is reasonable to expect that people will rate an intermediate score to X and a lower score to Y, which is irrelevant to solve the discrimination (BY+ CY-). From this perspective, a possible interpretation is that the elimination of the uncertainty associated with the causal value of X could produce a greater blocking effect and, consequently, a reduction or even the elimination of the redundancy effect. However, this hypothesis is not supported by the present research since our submaximal manipulation of consequences did not have an effect on redundancy. This could suggest that the mechanism behind the phenomena would not be rational-propositional in nature.

In addition, our submaximal manipulation also had no effect on the magnitude of the observed blocking, which is consistent with a series of failures in blocking replication that call its robustness into question (Maes et al., 2016). Despite the great number of publications reporting blocking (e.g., Dopson, Pearce, & Haselgrove, 2009; Dwyer, Haselgrove, & Jones, 2011; Pearce, Graham, Good, Jones, & McGregor, 2006), a series of replication failures has been reported recently. In principle, these failures can be divided into 2 categories. The first category refers to the inconsistency of blocking demonstrations in non-human animals (Maes et al., 2016). Although apparently there is no decisive study, and taking into account the countless experimental conditions, it is very likely that the blocking is a phenomenon dependent on certain characteristics associated with stimuli (for a more detailed discussion of this subject, please refer to Maes et al., 2018 and Soto, 2018). The second category refers to the almost non-existent observation of blocking in humans (e.g., Hinchy, Lovibond, & Ter-Horst, 1995; Kimmel & Bevil, 1991, 1996; Mitchell & Lovibond, 2002). Although it is consistent with the hypothesis that the humans solve these tasks through inferences (blocking is not logically deducible), due to the low number of studies, it is not possible to come to a final conclusion in this respect.

The redundancy effect is a new phenomenon and it is theoretically challenging for all conditioning theories. However, Vogel and Wagner (2017) recently used the Rescorla-Wagner model (1972) as a prototypical example to show that the redundancy effect can be explained by this type of theories if it is assumed that the experimental stimuli share a common element. In order to present additional details on the way the Rescorla-Wagner model calculates the different values for X and Y in a redundancy procedure, computer simulations were carried out. The simulated training included 3 phases. An initial phase of consistent basic training in the presentation of A+, a second phase consisting in a compound training in which AX+, BY+, CY-, DW+ are presented, and a final test phase to evaluate the answers to the critical stimuli W, X and Y.

Figure 3 depicts the results of the simulations with the standard Rescorla-Wagner model. The upper left panel shows the associative strength for the first phase of basic training. As it can be observed, there is a progressive increase in the associative strength for A+ during the course of the training until an asymptote is reached. The upper right panel shows the results of the simulations for the training of a compound of stimuli. It can be observed that, as a result of the maximum associative strength acquired by A+ in the basic training, the AX+ compound does not develop a learning associative strength in this phase, while DW+ and BY+ show progressive changes of the associative strength throughout the training. The associative strength of CY- tends to decrease during the course of the training. Finally, the bottom panel shows the results of the test. We observed that W reached a higher associative strength than X, which means that the model predicts blocking for X. Moreover, we observed that Y reached a higher associative strength than X, which means that the model is not able to predict the redundancy effect.

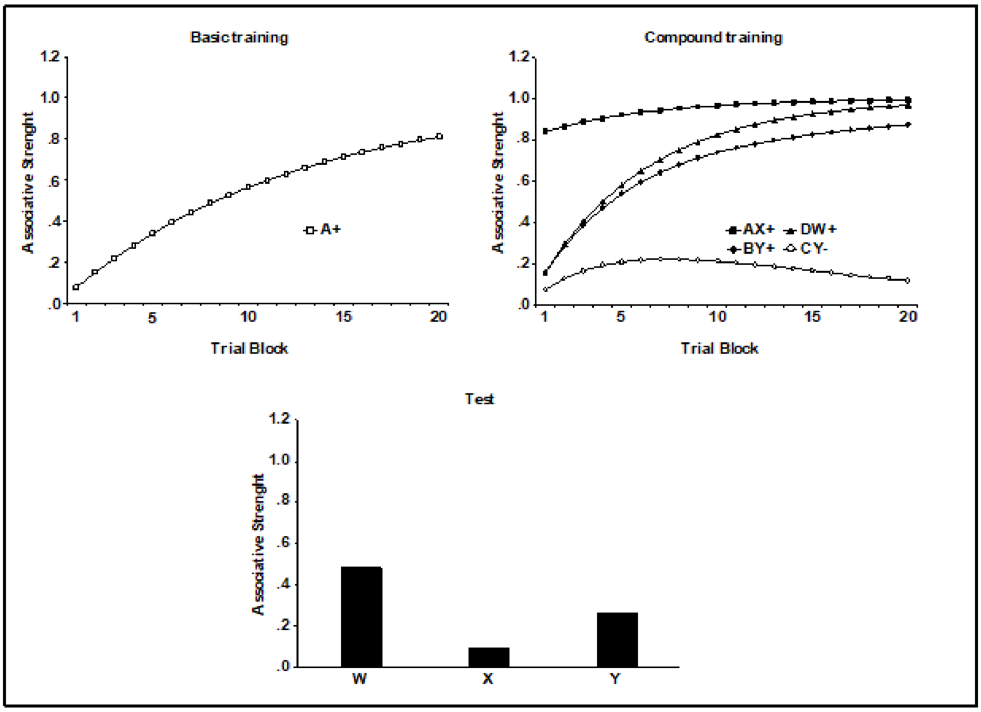

Figure 3. Simulations of the redundancy effect according to the Rescorla-Wagner model. The upper left panel shows the associative strength for the first phase of basic training, involving the following trial type: A+, where "+" stands for reinforced and "–" for nonreinforced. The upper right panel shows the results of the simulations for the training of a compound of stimuli, involving the following trial types: AX+, BY+, CY- and DW+. The bottom panel shows the results of the test (W, X and Y). The parameters were $\lambda = 1$, $\alpha = 0.4$ (all stimulus), $\beta^+ = 0.2$, $\beta^- = 0.1$.

According to Vogel and Wagner (2017), the redundancy effect could be the result of an additional associative influence of some aspects of the stimuli that are shared by all the CSs (Haselgrove, 2010; Vogel, Ponce, & Wagner, 2016). Specifically, apart from the experimental stimuli, there is a common additional element, "K", that would be simultaneously activated with any CS, which would represent the similarity between CSs. Following the proposal of Haselgrove (2010) and Vogel and Wagner (2017), exactly the same simulation was conducted with the Rescorla-Wagner model described in Figure 3, but in this opportunity the training included the presence of a common element, K, on each type of trial, AK+ AXK+ BYK+ CYK- DWK+. Figure 4 shows the results of the simulations. The upper left panel presents the associative strength for the first phase of the basic training. Exactly like the simulations with the standard model, there is a progressive increase in the associative strength for AK+ during the course of the training until an asymptote is reached. In addition, the upper right panel shows the results of the simulations for the compound training. It can be observed that the AXK+ compound does not develop a higher associative strength while DWK+ and BYK+ show an increase in the associative strength, and CYK- presents a decrease during the course of the training. Finally, the bottom panel shows the test results, where it can be observed that WK reached a higher associative strength than XK, suggesting that the model predicts the blocking effect. It can also be observed that XK reached a higher associative strength than YK, i.e., the model is able to predict the redundancy effect.

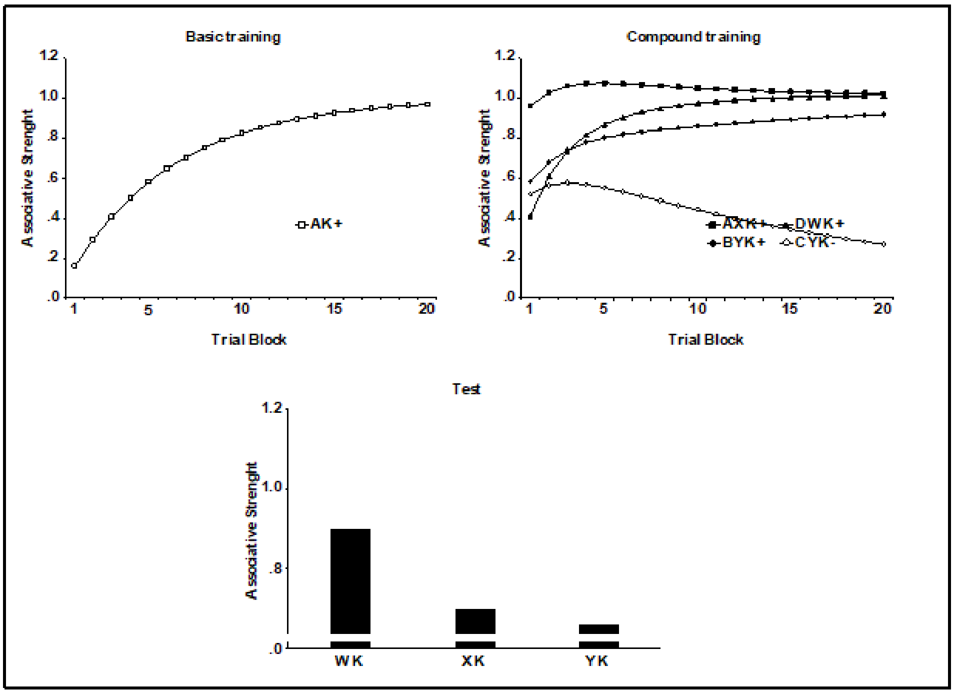

Figure 4. Simulations of the redundancy effect according to Rescorla-Wagner model with the common element assumption. The upper left panel shows the associative strength for the first phase of basic training, involving the following trial type: AK+, where "+" stands for reinforced and "–" for no reinforced. The upper right panel shows the results of the simulations for the training of a compound of stimuli, involving the following trial types: AXK+, BYK+, CYK- and DWK+. The bottom panel shows the results of the test (WK, XK and YK). The parameters were the same as those of Figure 3.

In conclusion, our findings show that the redundancy effect is robust, being present despite the submaximal manipulation of the consequences. This suggests that the nature of the phenomenon would not be rational-propositional. However, further empirical research is needed to continue exploring other theoretical alternatives such as the solution of the common element proposed by Vogel and Wagner (2017). Although this theoretical proposal is consistent with the findings of Pearce et al. (2012; Jones & Pearce, 2015; Uengoer et al., 2013) and those of the present investigation, there are still many uncertainties to be clarified from both a theoretical and an empirical point of view. From a theoretical perspective, the approach presented by Vogel and

Wagner (2017) still requires further quantitative refining since these authors have tentatively conceived the generalization as a simple theoretical element based on the similarity of the stimuli, which represents a simplification of their multifactorial nature (e.g., Soto, Gershman, & Niv, 2014). In addition, according to this approach, the redundancy effect is directly proportional to the associative strength developed by the common element, so that it predicts that the redundancy is eliminated through the addition of not reinforced trials (e.g., H-) and substantially increases through the addition of reinforced trials (e.g., I+). This is a prediction that requires an empirical evaluation.

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References

Beckers, T., De Houwer, J., Pineño, O., & Miller, R. R. (2005). Outcome additivity and outcome maximality influence cue competition in human causal learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(2), 238-249. doi: 10.1037/0278-7393.31.2.238.

Beesley, T., & Le Pelley, M. E. (2011). The influence of blocking on overt attention and associability in human learning. *Journal of Experimental Psychology: Animal Behavior Processes, 37*(1), 114-120. doi: 10.1037/a0019526.

Bush, R. R., & Mosteller, F. (1951). A mathematical model for simple learning. *Psychological Review, 58*(5), 313-323. doi: 10.1037/h0054388.

Cheng, P. W. (1997). From covariation to causation: A causal power theory. *Psychological Review, 104*(2), 367-405. doi: 10.1037/0033-295X.104.2.367.

Davey, G. C., & Singh, J. (1988). The Kamin "blocking" effect and electrodermal conditioning in humans. *Journal of Psychophysiology, 2*(1), 17-25.

De Houwer, J. D., Beckers, T., & Glautier, S. (2002). Outcome and cue properties modulate blocking. *The Quarterly Journal of Experimental Psychology: Section A, 55*(3), 965-985. doi: 10.1080/02724980143000578.

Dopson, J. C., Pearce, J. M., & Haselgrove, M. (2009). Failure of retrospective revaluation to influence blocking. *Journal of Experimental Psychology: Animal Behavior Processes, 35*(4), 473-484. doi: 10.1037/a0014907.

Dwyer, D. M., Haselgrove, M., & Jones, P. M. (2011). Cue interactions in flavor preference learning: A configural analysis. *Journal of Experimental Psychology: Animal Behavior Processes, 37*(1), 41-57. doi: 10.1037/a0021033.

Haselgrove, M. (2010). Reasoning rats or associative animals? A common element analysis of the effects of additive and subadditive pretraining on blocking. *Journal of Experimental Psychology: Animal Behavior Processes, 36*(2), 296-306. doi: 10.1037/a0016603.

Hinchy, J., Lovibond, P. F., & Ter-Horst, K. M. (1995). Blocking in human electrodermal conditioning. *The Quarterly Journal of Experimental Psychology, 48*(1b), 2-12. doi: 10.1080/14640749508401433.

Jeffreys, H. (1961). *The theory of probability*. Oxford, UK: Oxford University Press.

Jones, P. M., & Pearce, J. M. (2015). The fate of redundant cues: Further analysis of the redundancy effect. *Learning & Behavior, 43*(1), 72-82. doi: 10.3758/s13420-014-0162-x.

Jones, P. M., & Zaksaite, T. (2017). The redundancy effect in human causal learning: No evidence for changes in selective attention. *Quarterly Journal of Experimental Psychology, 71*(8), 1748-1760. doi: 10.1080/17470218.2017.1350868.

Jones, P. M., Zaksaite, T., & Mitchell, C. J. (2019). Uncertainty and blocking in human causal learning. *Journal of Experimental Psychology: Animal Learning and Cognition, 45*(1), 111-124. doi: 10.1037/xan0000185.

Kamin, L. J. (1969). Predictability, surprise, attention, and conditioning. En B. A. Cambell & R. M. Church (Eds.), *Punishment and Aversive Behavior* (pp. 279-296). New York, NY: Appleton-Century-Crofts.

Kimmel, H. D., & Bevill, M. J. (1991). Blocking and unconditioned response diminution in human classical autonomic conditioning. *Integrative*

Physiological and Behavioral Science, 26(2), 132-138. doi: 10.1007/BF02691036.

Kimmel, H. D., & Bevill, M. J. (1996). Blocking and unconditioned response diminution in human classical autonomic conditioning. *Integrative Physiological and Behavioral Science, 31*(1), 18-43. doi: 10.1007/BF02691479.

Lovibond, P. F., Been, S. L., Mitchell, C. J., Bouton, M. E., & Frohardt, R. (2003). Forward and backward blocking of causal judgment is enhanced by additivity of effect magnitude. *Memory and Cognition, 31*(1), 133-142. doi: 10.3758/BF03196088.

Lovibond, P. F., & Shanks, D. R. (2002). The role of awareness in Pavlovian conditioning: empirical evidence and theoretical implications. *Journal of Experimental Psychology: Animal Behavior Processes, 28*(1), 3-26. doi: 10.1037/0097-7403.28.1.3.

Maes, E., Boddez, Y., Alfei, J. M., Krypotos, A. M., D'Hooge, R., De Houwer, J., & Beckers, T. (2016). The elusive nature of the blocking effect: 15 failures to replicate. *Journal of Experimental Psychology: General, 145*(9), e49-e71. doi: 10.1037/xge0000200.

Maes, E., Krypotos, A. M., Boddez, Y., Alfei Palloni, J. M., D'Hooge, R., De Houwer, J., & Beckers, T. (2018). Failures to replicate blocking are surprising and informative-Reply to Soto. *Journal of Experimental Psychology: General, 147*(4), 603-610. doi: 10.1037/xge0000413.

Mitchell, C. J., De Houwer, J., & Lovibond, P. F. (2009). The propositional nature of human associative learning. *Behavioral and Brain Sciences, 32*(2), 183-198. doi: 10.1017/S0140525X09000855.

Mitchell, C. J., & Lovibond, P. F. (2002). Backward and forward blocking in human electrodermal conditioning: Blocking requires an assumption of outcome additivity. *The Quarterly Journal of Experimental Psychology Section B, 55*(4b), 311-329. doi: 10.1080/02724990244000025.

Pearce, J. M., Dopson, J. C., Haselgrove, M., & Esber, G. R. (2012). The fate of redundant cues during blocking and a simple discrimination. *Journal of Experimental Psychology: Animal Behavior Processes, 38*(2)*,* 167-179. doi: 10.1037/a0027662.

Pearce, J. M., Graham, M., Good, M. A., Jones, P. M., & McGregor, A. (2006). Potentiation, overshadowing, and blocking of spatial learning based on the shape of the environment. *Journal of Experimental Psychology: Animal Behavior Processes, 32*(3), 201-214. doi: 10.1037/0097-7403.32.3.201.

Psychology Software Tools Inc. (2004). E-Prime 1.1 [Software de computación]. Recuperado de: https://www.pstnet.com.

Rescorla, R. A., & Durlach, P. (1981). Within-event learning in Pavlovian conditioning. En N. E. Spear & R. R. Miller (Eds.), *Information Processing in Animals: Memory Mechanisms* (pp. 81-111). Hillsdale, NJ: Lawrence Erlbaum.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and non-reinforcement. En A. H. Black & W. F. Prokasy (Eds.), *Classical Conditioning II: Current Theory and Research* (pp. 64-99). New York: Appleton-Century-Crofts.

Soto, F. A. (2018). Contemporary associative learning theory predicts failures to obtain blocking. Comment on Maes et al. (2016). *Journal of Experimental Psychology: General, 147*(4), 597-602. doi: 10.1037/xge0000341.

Soto, F. A., Gershman, S. J., & Niv, Y. (2014). Explaining compound generalization in associative and causal learning through rational principles of dimensional generalization. *Psychological Review, 121*(3), 526-558. doi: 10.1037/a0037018.

Soto, F. A., Vogel, E. H., Castillo, R. D., & Wagner, A. R. (2009). Generality of the summation effect in human causal learning. *Quarterly Journal of Experimental Psychology, 62*(5), 877-889. doi: 10.1080/17470210802373688.

Uengoer, M., Dwyer, D. M., Koenig, S., & Pearce, J. M. (2017). A test for a difference in the associability of blocked and uninformative cues in human predictive learning. *Quarterly Journal of Experimental Psychology, 72*(2), 222-237. doi: 10.1080/17470218.2017.1345957.

Uengoer, M., Lotz, A., & Pearce, J. M. (2013). The fate of redundant cues in human predictive learning. *Journal of Experimental Psychology: Animal Behavior Processes, 39*(4), 323-333. doi: 10.1037/a0034073.

Vogel, E. H., Ponce, F. P., & Wagner, A. R. (2016). A theoretical analysis of transfer of occasion setting: SOP with replaced elements.

Behavioural Processes, 137, 19-32. doi: 10.1016/j.beproc.2016.06.013.

Vogel, E. H., & Wagner, A. R. (2017). A theoretical note in interpretation of the “redundancy effect” in associative learning. *Journal of Experimental Psychology: Animal Learning and Cognition, 43*(1), 119-125. doi: 10.1037/xan0000123.

Zaksaite, T., & Jones, P. M. (July, 2017). *The Redundancy Effect in Human Causal Learning: Evidence against a Comparator Theory Explanation*. Poster presented in Proceedings of the 39th Annual Meeting of The Cognitive Science Society, London, UK.