A test for a difference in the associability of blocked and uninformative cues in human predictive learning

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Short title: Attention and the Redundancy Effect

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Abstract

In human predictive learning, blocking, A+AB+, and a simple discrimination, UX+ VX-, result in a stronger response to the blocked, B, than the uninformative cue, X (where letters represent cues, and + and – represent different outcomes). In order to assess if these different treatments result in more attention being paid to blocked than uninformative cues, Stage 1 in each of three experiments generated two blocked cues, B and E, and two uninformative cues, X and Y. In Stage 2, participants received two simple discriminations: either BX+ EX- and BY+ EY-, or BX+ BY- and EX+ EY-. If more attention is paid to blocked than uninformative cues, then the first pair of discriminations will be solved more readily than the second pair. In contrast to this prediction, both discriminations were acquired at the same rate. These results are explained by the theory of Mackintosh (1975), by virtue of the assumption that learning is governed by an individual rather than a common error term.

Learning about the relationship between a single stimulus and an outcome can be influenced by the presence of other stimuli. An example of this effect is provided by the phenomenon of blocking, where learning about the relationship between an initially neutral stimulus and an outcome is restricted if the stimulus is accompanied by another stimulus that has previously signalled the same outcome (e.g. Kamin, 1969; Shanks, 1985). Findings such as this lend support to the claim that learning about individual stimuli is governed by a common error term. That is, the extent to which all the cues on a trial collectively predict an outcome determines how much is learned about each of them. In the above example, the presentation of a compound comprising the neutral cue and a cue that already signals the outcome will result in the outcome being expected after the compound, and thus permit little or no learning about the neutral cue.

The idea that learning in humans and animals is governed by a common error term has proved extremely successful and a variety of theories incorporate this proposal (e.g. Le Pelley, 2004; Pearce & Mackintosh, 2010; Rescorla & Wagner, 1972). The results of a human predictive learning experiment conducted by Uengoer, Lotz, and Pearce (2013), however, appear to pose a challenge to these theories. A group of participants was presented with a sequence of trials involving pictures of different items of food that were presented either individually or in pairs. Participants were told on each trial whether the food they had just seen would be followed by stomach ache in a hypothetical patient. Some of the training trials involved a blocking treatment, for example A+ AB+, in which one cue, A, could be used to predict the outcome, +, on both trials and the other cue, B, was uninformative. Other training trials involved what we shall refer to as a simple discrimination, UX+ VX-, in which the presence or absence, -, of the outcome on each trial could be predicted by whether U or V was present, whereas X was uninformative. Subsequent test trials in which participants were asked to state the likelihood that different foods caused stomach ache revealed that B was

regarded as a more likely cause of stomach ache than X. For an equivalent result using appetitive conditioning with rats and pigeons see Pearce, Dopson, Haselgrove and Esber (2012). The stronger response to B after A+ AB+ training, than to X after UX+ VX- training, has been referred to as the redundancy effect (Jones & Pearce, 2015) because both cues were redundant as far as predicting the correct outcome of the trials was concerned.

Superficially, the redundancy effect is not surprising. In the case of the above example, B was always followed by the outcome, whereas X was intermittently followed by the outcome and on this basis it would be natural to regard B as a more likely cause of stomach ache than X. However, both B and X were accompanied by other foods during training, and it is their presence that makes the results problematic for theories that incorporate a common error term. Take, for example, the Rescorla-Wagner (1972) theory. According to this theory, the repeated pairing of a food with an outcome provides the opportunity for an increase in the strength of an association between these events. The rule that governs this change is given by Equation 1, where the associative strength of food A is represented by V_A, λ is the asymptotic value for the strength of the association, and V_T is the sum of the associative strengths of all the stimuli that are present on the trial in question. The learning rate parameters, α and β (with values between 0 and 1), represent the salience of the stimulus and the outcome, respectively. Thus, according to Equation 1, changes in associative strength are governed by a common error term, with a value of $\lambda - V_T$, which applies to all the stimuli present on a particular trial.

$$\Delta V_A = \alpha\beta(\lambda - V_T) \qquad 1$$

The error term in Equation 1 leads to the prediction that training of the kind A+ AB+ will result in A gaining asymptotic associative strength of magnitude λ, whereas B will ultimately have no associative strength. It further follows from Equation 1 that training with UX+ VX- will result in X having a measure of positive associative strength. This outcome is

expected because some of the gains in the associative strength of X on reinforced trials will be protected from extinction on the nonreinforced trials by the presence of V, which will gain negative associative strength. In other words, the theory predicts the opposite outcome to that reported by Uengoer et al. (2013). Moreover, it is not just the Rescorla-Wagner (1972) theory that is unable to explain the redundancy effect. Other theories of associative learning that incorporate a common error term also predict a pattern of results that is opposite to the redundancy effect (e.g. Esber & Haselgrove, 2011; Gluck & Bower, 1988; Le Pelley, 2004; Pearce & Mackintosh, 2010). In all of hese theories, changes in associative strength take place to individual stimuli, but even if it is assumed that such changes take place to configurations of stimuli (e.g. Pearce, 1994), as Uengoer et al. (2013, p. 331-2) point out, it is still not possible to find a suitable explanation for the redundancy effect.

Faced with this problem of explaining their findings, Uengoer et al. (2013) suggested they may be a consequence of changes in the amount of attention paid to B and X. They proposed that because on AB trials it is possible to refer to either A or B in order to predict that the outcome will occur, then attention to B may be sustained at a relatively high level. On trials with UX and VX, however, by referring to U or V it is possible to predict more accurately the trial outcome than by referring to X. Thus attention to X might be reduced. If it is assumed that the attention paid to a stimulus is reflected by its associability (e.g. Mackintosh, 1975) – that is, by how rapidly it enters into associations - these differences in attention may then result in more being learned about the relationship between B and the outcome, than X and the outcome. Of course, this analysis leaves open the question of whether learning is governed by a common error term. We shall return to this question in the General Discussion, once the results from all the experiments have been described.

The above appeal to changes in attention as an account for the redundancy effect is challenged by the results of a study by Le Pelley, Beesley, and Suret (2007; see also Kruschke

& Blair, 2000; Le Pelley, Beesley, & Griffiths, 2014). In this study, human participants received training in a causal learning task in which they were first shown a certain stimulus (e.g. A), which was followed by a given outcome. They then received blocking trials in which the compound AB was followed by the same outcome. Finally, trials were presented in which a new compound BZ was followed by a new outcome, where Z had not served as a blocked cue during previous training. Test trials at the end of the experiment then revealed that during the BZ trials, more was learned about the relationship between Z and the new outcome, than B and the new outcome. According to Le Pelley et al. this difference was due to the associability of B being reduced by the blocking treatment, which would then put this cue at a disadvantage during the BZ trials. The implication of this experiment is that blocking results in a loss of attention to a stimulus, which contradicts the suggestion by Uengoer et al. (2013) that blocking results in the blocked cue receiving considerable attention.

The many differences between the methodology employed by Le Pelley et al. (2007) and by Uengoer et al. (2013), mean it would be premature to reject the explanation offered by Uengoer et al. for the redundancy effect. For example, the blocking treatment adopted by Le Pelley et al. involved trials with A before trials with AB, whereas Uengoer et al. presented trials with A intermixed among trials with AB. It is also conceivable that there is a loss of attention to both blocked and uninformative cues, but the extent of this loss is greater for the latter than the former. Despite these considerations, the results reported by Le Pelley et al. pose a challenge to the proposal that more attention is paid to blocked than uninformative cues, and the present experiments were conducted in order to address this challenge. In each of the following predictive learning experiments, participants received a blocking treatment and a simple discrimination in which trials with A+, AB+, UX+, VX- were presented in an intermixed sequence. Testing was then conducted in order to determine if these different treatments resulted in the associability of B being greater than of X.

Experiment 1

The first experiment involved an allergy prediction task (e.g. Wasserman, 1990) and its design, which was based on a procedure used by Le Pelley and McLaren (2003) and Lochman and Wills (2003), is summarised in Table 1. During Stage 1, all participants were shown a variety of meals composed of foods presented individually, or in pairs. For each meal they were asked to predict the kind of allergic reaction that would be shown by a hypothetical patient. Each letter in Table 1 represents a different item of food, and the four possible allergic reactions are indicated by O_1, O_2, O_3, and O_4. The top two rows of the left-hand column depict a set of trials in which training with A and C was intended to block learning about B, and training with D and F was intended to block learning about E. The third and fourth rows in the column depict two simple discriminations, UX-O_1 VX-O_2, and UY-O_1 VY-O_2, in which X and Y were uninformative.

Insert Table 1 about here

Upon the completion of training in Stage 1, the blocked cues, B and E, and the uninformative cues, X and Y, were presented for a second stage that involved two groups, each of which received two simple discriminations, but with new allergic reactions. The blocked-cue group received discriminations in which the previously blocked cues were relevant, and the previously uninformative cues were irrelevant, BX-O_3 BY-O_3 EX-O_4 EY-O_4. The uninformative-cue group received discriminations in which the blocked cues were now irrelevant and the previously uninformative cues were now relevant – e.g. BX-O_3 BY-O_4 EX-O_3 EY-O_4. It is important to stress that the components of the two compounds that comprised each of the simple discriminations were the same: a blocked cue and an uninformative cue. Thus, the overall associative properties of the compounds would be equivalent and, according

to theories such as Rescorla & Wagner (1972), there is no reason to suppose that the discriminations would be solved more readily by one group than the other.

A different outcome is predicted if more attention is paid to blocked than uninformative cues. According to this analysis, the training in Stage 1 will result in more attention being paid to B and E, than to X and Y. These differences in attention should then facilitate the acquisition of the simple discriminations during Stage 2 in the blocked-cue group, and hinder their acquisition in the uninformative-cue group.

Method

Participants. A group of 60 students of Philipps-Universität Marburg (of which 45 were females) participated in Experiment 1. Their age varied between 19 and 40 years, with a median of 22. They either participated in order to meet course requirements or were paid for their attendance (8 €/h). Participants gave informed written consent to participate in the experiment. They were randomly allocated to the two groups as they arrived at the experimental room. They were tested individually and required approximately 14 min to complete the experiment. Participants gave informed written consent to participate in the experiment.

Apparatus. Instructions and further necessary information were presented in German on the screen of a PC computer that was programmed in Visual Basic 2010 and used a Windows 7 operating system. The participants moved a computer mouse to make their responses. Pictures of the following foods served as cues for the experiment: apples, bananas, carrots, grapes, lemon, lettuce, oranges, pears, pineapples and strawberries. For each participant, these foods were assigned randomly to the different letters A, B, C, D, E, F, U, V, X and Y. The names of the four allergic reactions were diarrhoea, dizziness, fever, and rash, which were assigned to outcomes O_1, O_2, O_3, and O_4 at random for individual participants.

Procedure. Each participant was initially asked to read the following instructions on the screen:

This study is concerned with the question of how people learn about relationships between different events. In the present case, you should learn whether specific allergic reactions are related to the consumption of certain foods.

Imagine that you are a medical doctor. One of your patients suffers from specific allergic reactions after meals. To discover the foods the patient reacts to, your patient eats specific foods and observes the allergic reaction that occurs. The results of these tests are shown to you on the screen one after the other. You will always be told what your patient has eaten. Sometimes, he has only consumed a single kind of food and on other times he has consumed two different foods. Please look at the foods carefully.

Thereafter you will be asked to predict the kind of allergic reaction your patient will show. For this prediction, please click on the appropriate response button. After you have made your prediction, you will be informed about the actual allergic reaction that occurred. Use this feedback to find out how your patient reacts to certain foods. Obviously, at first you will have to guess because you do not know anything about your patient. But eventually you will learn with which allergic reactions your patient responds to certain foods and you will be able to make correct predictions.

For all of your answers, accuracy rather than speed is essential. Please do not take any notes during the experiment. If you have any more questions, please ask them now. If you do not have any questions, please start the experiment by clicking on the Next button.

Trials started with the presentation of one or two pictures of food shown on a black background in the centre of the screen. On trials with two pictures, the different types of food were presented side by side, with the left-right allocation determined randomly. The sentences *The patient ate the following food(s)* and *Which reaction do you expect?* were presented

above and below the cues, respectively. Participants made their predictions by clicking one of two response buttons shown side by side on the bottom half of the screen. The button on the left was labelled with one reaction, and the one on the right with a different reaction. Immediately after a response, a feedback window appeared in the centre of the screen informing the participant about the actual allergic reaction of the patient. After clicking on the feedback window, the stimuli disappeared and the next trial started without further delay.

Stage 1 consisted of 168 trials divided into seven blocks. All participants were trained with the trial types A-O_1, C-O_1, D-O_2, F-O_2, AB-O_1, CB-O_1, DE-O_2, FE-O_2, UX-O_1, UY-O_1, VX-O_2, and VY-O_2, each presented twice per block. Stage 2 was introduced by the following instruction that was presented in the middle of the screen: *In the next part you should predict the following allergic reactions*. Below this statement, the two names of the reactions assigned to outcomes O_3 and O_4 were presented side by side. After clicking an *OK*-button, Stage 2, which comprised 24 trials divided into three blocks, commenced. The blocked-cue group (n = 30) received the following trials, BX-O_3, BY-O_3, EX-O_4, and EY-O_4, and the uninformative-cue group received BX-O_3, BY-O_4, EX-O_3, and EY-O_4. Each of the four trial types was presented twice per block for both groups. The remaining details were the same as for Stage 1.

Results and Discussion

The .05 level of significance was used for all statistical tests in this and the following experiments. Stated probability levels were based on the Greenhouse-Geisser (1959) adjustment of degrees of freedom where appropriate (for clarity of exposition we have reported reported uncorrected degrees of freedom). We used partial eta squared (η_P^2) as the measure of effect size.

The left-hand panel of Figure 1 presents the mean proportion of trials on which the correct prediction was made about the reaction to the food on display, across the seven, 24-trial blocks of Stage 1 separated by groups. There is a suggestion that the improvement in performance of the blocked-cue group as training progressed was superior to that of the uninformative cue group, but this difference was not significant. A Trial Block (1 - 7) × Group ANOVA revealed a main effect of trial block, $F(6, 348) = 61.42$, $MSE = .011$, $p < .001$, $\eta_P^2 = .51$, thereby showing an increase of correct predictions over the course of training. The main effect of group, $F(1, 58) = 1.43$, $MSE = .09$, $p = .24$, and the interaction, $F < 1$, were not significant.

Insert Figure 1 about here

The right-hand panel of Figure 1 depicts the mean proportion of correct predictions across the three, 8-trial blocks of Stage 2 for each group. The performance of the two groups was similar throughout this stage. A Trial Block (1 - 3) × Group ANOVA yielded a main effect of block, $F(2, 116) = 21.78$, $MSE = .024$, $p < .001$, $\eta_P^2 = .27$, but neither the effect of group, nor the interaction was significant, Fs < 1. The experiment failed to reveal any evidence of the Stage-2 discrimination being easier to master by the blocked-cue group than the uninformative-cue group. It thus appears that the training in Stage 1 did not result in more attention being paid to the blocked than the uninformative cues when they were reintroduced for the second stage of the experiment. Of course, this interpretation must be viewed with caution, because it rests on accepting the lack of a significant difference between the two groups as an evidence of a genuine absence of an effect. One obvious way to address this problem is to consider the use of Bayesian statistical approaches, which quantify the strength of the evidence relative to the null and some stated alternative (or range of alternatives – e.g. Dienes, 2014; Rouder, Speckman, Sun, Morey, & Iverson, 2009). However, because there is no previous literature on which to base a principled specification of an expected effect of

attentional change in our current design, we will postpone implementing a Bayesian analysis until the final experiment has been described. To anticipate the remainder of the results, by that stage we will have three independent estimates of the lack of a difference between test-phase responding to previously blocked or uninformative stimuli (Experiments 1, 2A, and 3), as well as one estimate of the size of effect produced when attention is modulated by comparing responding to previously informative and blocked stimuli (Experiment 2B).

Experiment 2A

At face value, the results from Experiment 1 imply that the attention paid to the blocked cues, B and E, was similar to that paid to the uninformative cues, X and Y, by the end of Stage 1. This conclusion, however, rests on the assumption that the use of different outcomes in Stages 1 and 2 did not prevent any changes of attention that may have occurred in Stage 1from influencing learning in Stage 2. Whether such an assumption is acceptable is a matter of debate. On the one hand, Le Pelley and McLaren (2003) have shown that changes in associability, engendered by a causal judgement paradigm with one set of outcomes, remained effective when the same cues were paired with a different set of outcomes. The implication of this result is that any changes in attention during Stage 1 of Experiment 1 would have survived the transition to Stage 2. On the other hand, Mackintosh (1975) proposed that changes in attention, or associability, are specific to individual outcomes. In support of this claim he was able to show that the low associability that is predicted for a stimulus, because its occurrence is uncorrelated with the delivery of water, will not remain low if it is subsequently paired with shock (Mackintosh, 1973). Given these conflicting findings, it was deemed prudent to perform an experiment similar to the one just described, but with the same outcomes used in both stages. If the results should again reveal no difference between the groups during Stage 2, then it would strengthen considerably the

conclusion that the failure to detect a difference between the groups in the equivalent stage of Experiment 1 was not due to the use of a new pair of outcomes for the second stage of training.

A potential problem with using the same outcomes in both stages of Experiment 2A, is that associations acquired in Stage 1, might influence directly the acquisition of new associations in Stage 2. In order to prevent this influence from taking place, the stimuli used in Stage 2 were different to those used in Stage 1. The obvious problem now is that any changes in attention brought about by the Stage-1 training might not transfer to Stage 2. To take account of this possibility stimuli from the same dimension were used to represent the different classes of cue in Stage 1, as well as their counterparts in Stage 2. It was expected that any changes in attention to either the blocked or uninformative cues in Stage 1 would transfer to the cues belonging to the sane dimensions in Stage 2 (e.g. Kruschke, 1996). At the same time, it was further expected that the use of new stimuli in Stage 2 would ensure the associative properties of stimuli from the same dimension would be similar, and thus prevent the associations acquired in Stage 1 from influencing directly the acquisition of the Stage-2 discrimination.

In keeping with Experiment 1, two groups received training in Stage 1 that was intended to create two blocked cues and two uninformative cues, followed by two simple discriminations in Stage 2 to assess the associability of both sets of cue. Trials were followed by either O_1 or O_2 in both stages of the experiment. All the cues were squares containing stimuli from four different dimensions: colours, letters, shapes, and columns of circles aligned in different orientations (see Figure 2). Each dimension was assigned to a different cue function for Stage 1; blocking cues might have been different letters, blocked cues different colours, uninformative cues from the simple discriminations different shapes, and the informative cues from simple discriminations different orientations of columns of circles.

Upon the completion of Stage 1, the blocked-cue group received training with two new cues taken from the original blocked dimension, and two new cues from the original uninformative dimension. Cues from the blocked dimension were relevant to the solution of the new simple discriminations, while cues from the uninformative dimension were irrelevant to their solution. The same stimuli were used for the uninformative-cue group, but now those belonging to the uninformative dimension were relevant in the new task, and those belonging to the blocked dimension were irrelevant. If the Stage-1 training results in more attention being paid to the blocked than the uninformative dimension, then the discrimination in Stage 2 will be acquired more readily by the blocked-cue than the uninformative-cue group.

A summary of the treatment for the two groups can be seen in Table 2 where cues A_1-A_4 were selected from the blocking dimension, cues B_1-B_4 were selected from the blocked dimension, cues U_1-U_2 were selected from the informative dimension for the Stage-1 simple discriminations, and cues X_1-X_4 were selected from the uninformative dimension for the Stage-1 simple discriminations. The left-hand column summarises the Stage-1 training that was given to all groups. The training in Stage 2 for the blocked-cue group can be seen in the centre column of the table, and for the uninformative-cue group in the right-hand column. Given the nature of the experimental stimuli, it was necessary to use a different cover story to the one used for the allergy prediction task in Experiment 1. Accordingly, for the present and subsequent experiment we adopted a cover story used by Uengoer and Lachnit (2012), which has proved to be suitable for detecting changes in the associability of relevant and irrelevant stimuli (Kattner, 2015; Uengoer & Lachnit, 2012).

Insert Table 2 about here

Method

Participants. The participants were 48 students of Philipps-Universität Marburg (34 females). Their age varied between 18 and 55 years, with a median of 23. They received the same recompense as the participants for the previous experiment. Participants were randomly allocated to the two groups as they arrived at the experimental room. They were tested individually and required approximately 12 min to complete the experiment. Participants gave informed written consent to participate in the experiment.

Apparatus. Sixteen squares (with 4-cm sides) presented on a computer screen were used as cues (see Figure 2). They were divided into four groups of four (Colour, Orientation, Shape, and Letter). Squares of the stimulus type Colour were each filled with a solid colour (green, red, blue, or yellow). Squares of the stimulus type Orientation each displayed three dark grey circles on a light grey background that were arranged in line in one of four orientations (45°, 135°, horizontal, or vertical). Squares of the stimulus type Shape displayed a white line drawing of one of four geometric forms (circle, parallelogram, star, or triangle) on a black background. Squares of the stimulus type Letter showed one of four capital letters (G, K, M, or S) in black font on a white background. In each group, the assignment of the stimulus types Colour, Orientation, Shape, and Letter to the four dimensions was counterbalanced across participants. The assignment of the role played by different instances from a dimension was implemented randomly for each participant, with one restriction: either the 45° stimulus and the 135° stimulus, or the horizontal stimulus and the vertical stimulus, were allocated together in the same stage. The two different outcomes were the names of two boroughs of New York City: Brooklyn and Queens.

Insert Figure 2 about here

Procedure. Participants were initially asked to read the following instructions on the screen:

This study is concerned with the question of how people learn about relationships between different events. Imagine that you are a special agent in a department for the investigation of serial crimes and that the New York Police Department seeks your support. The current case is about a series of mysterious housebreakings in two boroughs of New York City, Brooklyn and Queens. The special thing about this case is that at each crime scene the criminal leaves one or two cards. Your colleagues suppose that by these cards left at a crime scene the criminal announces in which borough he will strike next. Your job now is to pursue this lead.

Therefore, you receive access to the files of the inquiry. In the following, you will search the files of the housebreakings in a chronological order. For each housebreaking, you will be shown which cards the criminal left at the crime scene. Thereafter, you will be asked to predict whether the next housebreaking took place in Brooklyn or in Queens. For this prediction, there will be two appropriate response buttons available. After you have made your prediction, you will be informed in which borough the next housebreaking actually took place. Use this feedback to find out which cards signal a housebreak in Brooklyn and which cards signal a housebreak in Queens.

Obviously, at first you will have to guess, as you do not know anything about the criminal. But eventually you will learn about the method by which the criminal acts. On the basis of this knowledge, you should make correct predictions-as many as possible.

For all of your answers, accuracy rather than speed is essential. Please do not take any notes during the experiment. If you have any more questions please ask them now. If you don't have any questions, please start the experiment by clicking on the Next button.

Each trial started with the presentation of one or two squares shown on the top half of the screen. On trials with two squares, the stimuli were presented side by side. Each square appeared at a distance of 4 cm from the centre of the display and the left-right allocation was determined randomly on each trial. Participants were told that the squares were cards left by the criminal at the crime scene. They were also asked to predict whether the next

housebreaking would take place in Brooklyn or in Queens. Participants made their predictions by clicking on one of two answer buttons labelled *Brooklyn* and *Queens*. Immediately after they responded, another window appeared, telling the participants in which of the two boroughs the next housebreaking had actually taken place. Participants had to confirm that they had read the feedback by clicking on a button showing *OK*. Thereafter, the next trial started. Stage 1 consisted of 120 trials divided into five blocks. All participants were trained with the trial types displayed in the left-hand column of Table 3. Within each block, each of the twelve trial types was presented twice in a random order.

After the participants completed Stage 1, they immediately received a second discrimination between stimulus compounds composed of novel cues from two of the dimensions. Cues from the blocked dimension were relevant and cues from the uninformative dimension were irrelevant for the blocked-cue group, whereas cues from the uninformative dimension were relevant and cues from the blocked dimension were irrelevant for the uninformative-cue group. Stage 2 consisted of 24 trials divided into three blocks. Within each block, each of the four trial types was presented twice in a random order. Procedural details that have been omitted were the same as for Experiment 1.

Results and Discussion

The left-hand panel of Figure 3 shows that the mean proportion of correct predictions made by the two groups increased at the same rate as training progressed. A Trial Block (1 - 5) × Group ANOVA revealed a main effect of trial block, $F(4, 184) = 22.93$, $MSE = .014$, $p < .001$, $\eta_P^2 = .33$, indicating that the proportion of correct predictions increased over the course of training. The effect of group, $F < 1$, and the Trial Block × Group interaction, $F(4, 184) = 1.31$, $MSE = .014$, $p = .28$, were not significant.

Insert Figure 3 about here

The right-hand panel of Figure 3 shows that during Stage 2, the mean proportion of correct predictions across the three, 8-trial blocks was very similar for the two groups. A Trial Block (1 – 3) × Group ANOVA yielded a main effect of trial block, $F(2, 92) = 17.96$, $MSE = .02$, $p < .001$, $\eta_P^2 = .28$, but neither the main effect of group nor the Trial Block × Group interaction reached significance, Fs < 1.

The failure to observe any difference between the blocked-cue and the uninformative-cue groups during Stage 2 lends no support to the proposal of Uengoer et al. (2013) that training of the kind A+ AB+ UX+ VX- results in more attention being paid to the blocked cue, B, than the uninformative cue, X. The present results are thus consistent with those from Experiment 1. We suggested that the failure to find any differences in the associability of the blocked and uninformative cues in Experiment 1 was due to the use of different outcomes in the two stages of the experiment. That is, the training in Stage 1 may have resulted in more attention being paid to the blocked than the uninformative cues, but this difference was erased by the introduction of new outcomes at the start of Stage 2. Clearly, such an explanation is not appropriate for the present results, because the same two outcomes, O_1 and O_2, were used throughout the experiment.

Inspection of Table 2 will reveal that during Stage 1, the blocked cues, B_1 and B_2, were followed by different outcomes, whereas the uninformative cues, X_1 and X_2, were followed by the same outcomes. Such training might have resulted in X_1 and X_2 being regarded as functionally equivalent and make it more difficult to discriminate between them than between B_1 and B_2 (e.g. Hall, 1991). If it is assumed that these differences transferred to the new cues used in Stage 2 then, had we found that the blocked-cue group solved its discrimination more readily than the uninformative-cue group, this outcome would have been difficult to interpret. It might have occurred for the reason just put forward, or it might have occurred because the training in Stage 1 resulted in more attention being paid to blocked than

uninformative cues. As it turned out, there was no difference between the groups in Stage 2, and there is little to be gained by pursuing this alternative explanation for our results.

A more viable explanation for the results from Experiments 1 and 2A is that after the training in Stage 1, the attention paid to, and hence the associability of, the blocked and uninformative cues was at a similar low level. Support for this explanation can be found in a number of related theories, all of which assume that the training in Stage 1 will result in the blocked and the uninformative cues having low associability (e.g. Le Pelley, 2004; Mackintosh, 1975). Support for the foregoing explanation can also be found in evidence showing that the associability of blocked cues (e.g. Le Pelley et al., 2007), and uninformative cues (e.g. Le Pelley & McLaren, 2003; Dopson, Esber, & Pearce, 2011; Pearce, Esber, George, & Haslegrove, 2008; Uengoer & Lachnit, 2012) is lower than of the more relevant stimuli with which they are paired for training.

As an altertnative to the foregoing explanation for our results, it is possible that Stage 1 resulted in more attention being paid to the blocked than the uninformative cues in Stage 1, but these changes were too fragile to survive the introduction of the new cues at the outset of Stage 2. In order to choose between these opposing accounts, Experiment 2B used the same Stage-1 training as Experiment 2A, but the training for Stage 2 was different (see Table 3). During Stage 2 of the experiment, two groups received two simple discriminations, which involved two new cues from the previously blocked dimension and two new cues from the previously informative dimension. For the blocked-cue group, stimuli from the blocked dimension were relevant and stimuli from the informative dimension were irrelevant to the solution of these discriminations (see centre column in Table 3). In contrast, for the informative-cue group stimuli from the informative dimension were relevant to the solution of the new discriminations, and stimuli from the blocked dimension were irrelevant (see right-hand column of Table 3). If changes in attention take place during Stage 1, which result in

the associability of informative cues being high, and of blocked cues being low, and if these changes are able to survive the transition to Stage 2 then, during Stage 2, the simple discriminations will be solved more readily by the informative-cue than the blocked-cue group. On the other hand, if any changes in attention that take place during Stage 1 are unable to transfer to the new cues in Stage 2, then during the final stage the performance of the two groups will be similar.

Insert Table 3 about here

Experiment 2B

Method

The 48 participants (36 females), whose age varied between 18 and 43 years (median of 22 years), were students from Philipps-Universität Marburg. They were allocated to the two groups, tested in the same way, and received the same recompense as the participants for the previous experiments. Participants required approximately 11 min to complete the experiment. The apparatus and procedure were the same as for Experiment 2A, except that during Stage 2, the cues belonged to the blocked and the informative dimensions, rather than the blocked and the uninformative dimensions.

Results and Discussion

The left-hand panel of Figure 4 shows the mean proportion of correct predictions across the five, 24-trial blocks of Stage 1 separated by groups. As can be seen, the Stage 1-discriminations were acquired in the same manner across the two groups. A Trial Block (1 - 5) × Group ANOVA yielded a main effect of trial block, $F(4, 184) = 47.86$, $MSE = .013$, $p < .001$, $\eta_P^2 = .51$, but neither the main effect of group, $F < 1$, nor the Trial Block × Group interaction, $F(4, 184) = 2.07$, $MSE = .013$, $p = .11$, reached significance.

Insert Figure 4 about here

The right-hand panel of Figure 4 presents the mean proportion of correct predictions across the three, 8-trial blocks of Stage 2 for each group. It is evident that the mean proportion of correct responses was consistently greater for the informative-cue than the blocked-cue group. A Trial Block (1 – 3) × Group ANOVA revealed a main effect of trial block, $F(2, 92) = 16.19$, $MSE = .016$, $p < .001$, $\eta_P^2 = .26$, and a main effect of group, $F(1, 46) = 4.72$, $MSE = .07$, $p = .035$, $\eta_P^2 = .09$, showing that the proportion of correct predictions was higher in the informative-cue group than in the blocked-cue group. The Trial Block × Group interaction was not significant, $F(2, 92) = 1.77$, $MSE = .016$, $p = .18$.

The results from Stage 2 show quite clearly that the simple discriminations were acquired more readily by the informative-cue than the blocked-cue group. This pattern of results can be readily understood if it is accepted that during Stage 1, the training resulted in more attention being paid to the informative than the blocked cues. It thus appears that the Stage-1 treatment adopted in the previous experiments was sufficient to generate changes in attention to at least some of the stimuli. It also appears that the methodology adopted in Stage 2 was sufficiently sensitive to detect these changes. In view of these observations, it is likely that the failure to detect any differences between the groups during Stage 2 of Experiment 2A was because the training in Stage 1 failed to result in more attention being paid to the blocked than the uninformative cues.

Experiment 3

The failures above to find evidence of more attention being paid to blocked than uninformative cues is inconsistent with an explanation for the redundancy effect proposed by Uengoer et al. (2013). It should be noted, however, that none of the present experiments has provided a demonstration of the redundancy effect. It is thus possible that had we tested for

this effect in the previous experiments we would have been unsuccessful, in which case the failure to detect any difference in the attention paid to blocked and uninformative cues would not pose a challenge to the explanation offered by Uengoer et al. for the effect. Experiment 3 was conducted with this criticism in mind.

The training in Stage 1 was similar to that for Stage 1 of Experiments 2A and 2B, except that the scenario involved predicting if a fever, O_1, or no fever, O_2, would follow one or two of the cues used in the two previous experiments. Towards the end of Stage 1, a series of test trials was conducted in which participants were asked to predict the likelihood that the outcome of fever would follow each of the cues, presented alone, that were shown in Stage 1. A demonstration of the redundancy effect would be revealed by a stronger response to the blocked cue (B_1 in Table 2) than the uninformative cues (X_1 and X_2 in Table 2). After a spell of further training, the blocked-cue group received the Stage-2 training given to the blocked-cue group in Experiment 2A, and the uninformative-cue group received the training given to the uninformative-cue group of that experiment. As for the previous experiments, the failure to detect any difference between the groups would indicate that similar levels of attention were paid to the blocked and the uninformative dimension at the outset of Stage 2.

Method

Participants. The 48 participants (30 females), whose age varied between 18 and 32 years (median of 23 years), were students from Philipps-Universität Marburg. They were allocated to the two groups, tested in the same way, and received the same recompense as the participants for the previous experiments. Participants required approximately 14 min to complete the experiment.

Apparatus and Procedure. The apparatus and stimuli were the same as those used in Experiment 2A, except for the stimuli used as outcomes. The outcomes were the occurrence

of a fictitious fever symptom (O_1) and the absence of this symptom (O_2). Each participant was initially asked to read the following instructions on the screen:

This study is concerned with the question of how people learn about relationships between different events. Imagine that you are a staff member in a medical laboratory. Currently, you are investigating the causes of a mysterious fever disease – Ontario Fever. It is assumed that Ontario Fever is caused by specific bacteria in drinking water. Your job now is to pursue this lead.

Your assistants analysed different water samples and documented those containing bacteria. Some of these samples contained a single bacterium. In other samples, two bacteria were documented. The names of the bacteria are long and complicated. In order to ease your job, each bacterium will be represented by a specific symbol.

In the following, you will search the water samples one after another. For each sample, you will be shown the identified bacterium or bacteria. Thereafter, you will be asked to predict whether the people who drank the water suffered from Ontario-Fever or not. For this prediction, there will be two appropriate response buttons available. After you have made your prediction, you will be informed whether Ontario-Fever actually occurred. Use this feedback to find out which of the bacteria cause Ontario-Fever and which of the bacteria are harmless.

Obviously, at first you will have to guess, as you do not know anything about the causes of Ontario-Fever. But eventually you will learn about the causes of this disease. On the basis of this knowledge, you should make correct predictions-as many as possible.

For all of your answers, accuracy rather than speed is essential. Please do not take any notes during the experiment. If you have any more questions please ask them now. If you don't have any questions, please start the experiment by clicking on the Next button.

The presentation of the stimuli on each trial was the same as for Experiment 2A. Participants were told that the squares represented bacteria and were asked to indicate whether

they expect the occurrence of fever or its absence. Participants made their predictions by clicking on one of two answer buttons labelled *Ontario-Fever* and *no symptoms*. Immediately after they responded, a feedback-window appeared, telling the participants whether Ontario-Fever actually occurred or not. After participants had clicked on a button showing *OK*, the feedback-window disappeared and the next learning trial started.

Stage 1 consisted of 120 trials divided into five blocks. The training schedule was identical to the Stage-1 training in Experiment 2A (see Table 2). Within each block, each of the twelve trial types was presented twice in a random order. After the participants completed Stage 1, they received a number of test trials with individual stimuli. The test stage was introduced by the following instruction: "Now, your task is to judge the likelihood with which specific bacteria cause Ontario-Fever. For this purpose, single bacteria will be shown to you on the screen. Use all the information that you have collected up to that time."

On each test trial, one square was shown in the centre of the screen, together with the question (presented above the cue): *What is the likelihood that the bacterium causes Ontario-Fever?* Participants gave their ratings using a scale ranging from 0 (labelled *certainly not*) to 10 (labelled *very certain*). The rating scale was presented in the bottom half of the screen. The 11 values of the rating scale appeared side by side and participants chose one value by clicking on it. After participants confirmed their choice by clicking on an OK button, which was presented below the rating scale, the next test trial started immediately. Participants did not receive any feedback during this stage. The ten cues (A_1, A_2, A_3, A_4, B_1, B_2, U_1, U_2, X_1, X_2) were each presented individually, twice, in a random sequence.

The test trials were followed by additional trials from the initial stage of training, which were introduced by the instruction: "Now, you will be presented again with the analyses of the water samples and you should predict, once more, whether Ontario-Fever occurred or not." The details of the Stage-2 phase of training were identical to those of Stage

1. Stage 2 consisted of 48 trials divided into two blocks. As for Stage 1, each of the twelve trial types was presented twice in a random order within each block.

Training for Stage 3, which was identical to Stage 2 of Experiment 2A (see Table 2) commenced immediately after the completion of Stage 2. Thus, participants received a discrimination between compounds composed of novel cues from the blocked and uninformative dimensions. For the blocked-cue group, the cues from the blocked dimension were relevant and cues from the uninformative dimension were irrelevant. For the uninformative-cue group, cues from the uninformative dimension were relevant and cues from the blocked dimension were irrelevant. Stage 3 consisted of 24 trials divided into three blocks. Within each block, each of the four trial types was presented twice in a random order.

Results and Discussion

The mean proportions of correct responses across the five, 24-trial blocks of Stage 1 are depicted in the left-hand side of Figure 5. The results for the two, 24-trial blocks of Stage 2, which took place after the tests with individual cues, and which involved the same training as for Stage 1, can be seen in the centre section of Figure 5. There was no difference between the performance of the two groups during these two training stages. A Trial Block (1 - 5) × Group ANOVA for Stage 1 revealed a main effect of trial block, $F(4, 184) = 55.36$, $MSE = .014$, $p < .001$, $\eta_P^2 = .55$, but the effect of group and the interaction were not significant, Fs < 1. A similar ANOVA for Stage 2 revealed a significant main effect of trial block, $F(1, 46) = 4.68$, $MSE = .003$, $p < .04$, $\eta_P^2 = .09$. The effect of group and the interaction were not significant, Fs < 1.

Insert Figure 5 about here

Ratings for the blocked and uninformative cues from the test trials with individual stimuli that followed Stage-1 training can be seen in Figure 6, with the results from the

blocked-cue group depicted on the left-hand side, and the results from the uninformative-cue group shown on the right-hand side. For each group, the grey bar corresponds to the mean rating for the blocked cue, B_1, which had previously been paired with fever; the white bar represents the response to the uninformative cues from the simple discriminations, in terms of the mean rating for the trials with cues X_1 and X_2. For each group, the mean rating for the blocked cue was greater than the mean rating for the uninformative cues. A Cue (blocked [B_1] vs. uninformative [X_1/X_2]) × Group ANOVA revealed a main effect of cue, $F(1, 46) = 16.67$, $MSE = 4.90$, $p < .001$, $\eta_P^2 = .27$, showing that the ratings for the blocked cue were higher than for the uninformative cues, thus demonstrating the redundancy effect. No Cue × Group interaction was detected, $F < 1$, indicating that the redundancy effect was equally strong across the two groups. The main effect of group was also not significant, $F(1, 46) = 1.47$, $MSE = 11.61$, $p = .23$.

Insert Figure 6 about here

The mean ratings for the remaining test trials with the blocked-cue and uninformative-cue groups, respectively, were: 9.01 ($SD = 1.79$) and 9.00 ($SD = 2.11$) for A_1 and A_2 combined; 0.80 ($SD = 1.79$) and 0.90 ($SD = 2.24$) for A_3 and A_4 combined; 2.13 ($SD = 2.36$) and 1.98 ($SD = 2.33$) for B_2; 9.08 ($SD = 1.83$) and 8.85 ($SD = 1.66$) for U_1; 1.08 ($SD = 1.99$) and 1.79 ($SD = 2.49$) for U_2.

During the final stage of the experiment, the results of which are shown in the right-hand side of Figure 5, there was no difference between the performance of the blocked-cue and the uninformative-cue groups. A two-way ANOVA with the factors of trial block (1 - 3) and group revealed a main effect of trial block, $F(2, 92) = 43.63$, $MSE = .011$, $p < .001$, $\eta_P^2 = .49$. The main effect of group, $F < 1$, and the Trial Block × Group interaction, $F(2, 92) = 1.32$, $MSE = .011$, $p = .27$, were not significant.

The results from the test trials with individual cues replicate the redundancy effect that was demonstrated by Uengoer et al. (2013), who also used human participants. Thus the rating as a predictor for the outcome of fever was significantly greater for the blocked cue that had previously been paired with this outcome, but always in the presence of cues that by themselves had been paired with the outcome, than for the two uninformative cues, which had been intermittently paired with this outcome during the simple discriminations. The blocked and uninformative cues were from different dimensions, and in the final stage of the experiment it was found that there was no difference between the associability of additional, novel cues from these dimensions. To the extent that the associability of a cue reflects the attention it is paid, these results lend no support to the suggestion that the redundancy effect is a consequence of more attention being paid to a blocked than an uninformative cue. It is possible that these changes in attention did indeed take place, but they did not transfer to the novel stimuli used for the final stage of the experiment. We are unable to reject this possibility completely, but it gains no support from the results of Experiment 2B. In that experiment, differences in associability were found with novel cues from the two dimensions, after different cues from each of these dimensions had previously served either as blocked cues or as the informative cues from a simple discrimination. The clear implication of these findings is that changes in associability spread to other cues from the same, but not different dimensions, and that the method of testing is adequate for detecting these changes.

We noted in Experiment 1 that the lack of a significant difference between the performance of the two groups, during the test stage, implied that by the end of Stage 1 the same amount of attention was paid to the uninformative cues from the simple discriminations as to the blocked cues. In order to test this claim formally, we performed a meta-analysis of Experiments 1, 2A, and 3 to derive a combined estimate of the difference in test stage performance between groups using previously uninformative and blocked stimuli. The meta-

analysis used Exploratory Software for Confidence Intervals (ESCI, Cumming, 2013; see also Cumming 2012) with a fixed-effects model. Because performance across testing improved towards asymptote, thus potentially compressing the differences between groups, we based this meta-analysis on the first block of trials only. In order to derive a principled estimate of an expected effect of attentional change in our current design, we examined performance on the first block of testing for Experiment 2B. These methods produced a combined estimate of the mean blocked vs uninformative difference of 0.008 (SEM 0.029) and the mean blocked vs informative difference was 0.141 (SEM 0.056). The Bayes factor relates to the ratio of probability for the observed data under a model based on the null hypothesis compared to a model based on some specified alternative. Here, the alternative was specified by using the blocked vs informative difference to set an upper bound on the possible effect size of the blocked vs uninformative difference[1]. Using the Dienes (2008) Bayes factor calculator revealed that the Bayes factor was 3.03 in favour of the null – supporting the idea that, across Experiments 1, 2A, and 3, there was in fact no difference in performance at test due to increased attention to previously blocked over uninformative stimuli.

General Discussion

Taken together, the results from the above experiments lend little support to the suggestion by Uengoer et al. (2013) that the redundancy effect is a consequence of a blocked cue receiving more attention than the uninformative cue from a simple discrimination. In three experiments, the attention paid to the two types of cue was assessed by examining how readily a final discrimination was acquired when one type of cue was relevant and the other was irrelevant to its solution. There was no evidence of the test discrimination being acquired

[1] See Dienes, 2014, for an analysis of the use of an upper bound alternative model. Note also that other possible specifications of the alternative model – such as using the blocked vs uninformative difference to estimate a rough expectation of the effect size for the blocked vs uninformative difference – would, in the present circumstances, provide a less conservative estimate of the strength of evidence in favour of the null.

more readily when the blocked cues, or cues belonging to the blocked dimension, were relevant to its solution, than when the uninformative cues, or cues belonging to the uninformative dimension, were relevant to its solution. This pattern of results should not have been observed if the training in Stage 1 resulted in more attention being paid to blocked than uninformative cues.

The failure to find support for the proposals of Uengoer et al. (2013) raises the possibility that the method for detecting differences in attention, by comparing the associability of the cues, was inadequate. A different, more sensitive test might have revealed support for their proposals. The obvious counter to this argument is that the methodology in Experiment 2B was capable of revealing acquired differences in the associability of cues when the final discrimination involved blocked cues and informative cues.

The cover stories for the predictive learning task varied from experiment to experiment. It is thus difficult to argue that our failure to detect a difference in the associability of blocked and uninformative cues is of restricted generality. On the other hand, the cover story used for Experiment 3 was very different to the one used for Experiments 2A and 2B, and the cues used for Experiment 3 were very different to those used for Experiment 1. It might be argued therefore that the redundancy effect observed in Experiment 3 would not have been observed with the training conditions used for the earlier experiments. While this argument remains possible, it is worthy of note that Experiment 3 provides a clear demonstration of the redundancy effect, as well as a clear failure to reveal any evidence of more attention being paid to blocked than uninformative cues. Moreover, this failure was also found in Experiment 2A where the cues were the same as those used in Experiment 3. A similar failure was also found in Experiment 1, where the cover story was similar to that for Experiment 3. Such a pattern of results is entirely in keeping with the conclusion that the

redundancy effect we observed, does not depend on more attention being paid to blocked than uninformative cues, regardless of the cover story on which the task is based.

If the redundancy effect is not a consequence of more attention being paid to the blocked than the uninformative cue, then it might be worth entertaining the possibility that it is due to learning being governed by an individual rather than a common error term. In other words, the results suggest learning about a stimulus is governed, not by Equation 1, but by Equation 2.

$$\Delta V_A = \alpha_A \beta(\lambda - V_A) \qquad 2$$

In this equation, the change in associative strength of a stimulus is determined on every trial by the discrepancy between its current associative strength and the asymptote of conditioning set by the magnitude of the outcome. Since the blocked stimulus in all of the above experiments was repeatedly paired with the outcome, whereas the uninformative cue for a simple discrimination was paired intermittently with the outcome, it then follows that the former will gain associative strength more rapidly than the latter, and to a higher asymptote. Thus, Equation 2 provides a trivially simple explanation for the redundancy effect. Of course, this explanation is not without its shortcomings. It fails to explain the associability changes revealed by the differences between the two groups in Experiment 2B, and it fails to explain why a blocked cue does not ultimately gain the same level of associative strength as the blocking cue.

An obvious route to addressing these failings is to turn to the proposals of Mackintosh (1975). He argued that changes in associative strength are determined by Equation 2, and that effects such as blocking can be attributed to changes in associability, that is in the value of α, during the course of training. The value of α for a given cue was assumed to increase when it was a better predictor of the outcome than all the other stimuli combined on a given trial, and to reduce when the cue was a poorer predictor than all the other stimuli. Hence during

blocking, A+ AB+, once the associative strength of A is greater than of B, the value of α for A, α_A, will increase while α_B will decrease. These changes will eventually result in the value of α_B falling to zero, at which point no further learning about B will take place, and the response to B will remain weaker than to A. A similar loss of associability will also occur for the uninformative cue, X, from a simple discrimination, UX+ VX-. Given that B and X will both suffer a loss of associability, these decrements should not affect, at least qualitatively, the explanation just offered for the redundancy effect.

In order to confirm that this prediction follows from the formal theory of Mackintosh (1975), computer simulations were conducted, with changes in associative strength on any trial being determined by Equation 2. Mackintosh did not provide a precise rule for calculating changes in α on a given trial. We have therefore adopted Equation 3, which is based on proposals put forward by Le Pelley (2004) comparing the absolute error caused by cue A, $|\lambda - V_A|$, with the absolute error caused by the combined prediction of all other cues present on the trial, $|\lambda - V_{T\text{-}A}|$.

$$\Delta \alpha_A = \gamma(|\lambda - V_{T\text{-}A}| - |\lambda - V_A|) \qquad 3$$

The constant, γ, determines how rapidly changes in α take place and, for the purposes of the simulations, its value was set at .4. The value of λ was set at 1 on trials with an outcome, and at 0 on trials without an outcome. In order to impose an upper and lower limit on the amount of attention that may be paid to a cue, the value of α was allowed to vary between 0 and 1. The starting value of α was set at .5 for all experimental stimuli in all of the simulations. In order to permit attention to grow to a cue when it is paired by itself with an outcome, we assumed that it was presented against a context that was present on every trial and for which the starting value of α was .125. Finally, the value of β in Equation 2 was set at .4 for all trials.

The simulation was based on the training in Stage 1 of Experiment 3. There were, therefore, four trials of a blocking treatment, A+ C+ AB+ CB+, and four trials of a simple discrimination, UX+ VX- UY+ VY-. The sequence of the eight different trials was varied randomly from one block to the next, for eight blocks. The upper and lower panels of Figure 7 show, respectively, the predicted changes in associative strength and associability of the various stimuli. One important finding is that the associative strength of the blocked cue, B, is predicted to be higher than of the uninformative cues, X and Y, throughout the course of training, which confirms that the theory of Mackintosh (1975) is able to explain the redundancy effect.

Insert Figure 7 about here

A further important finding from the simulation is that α for the blocked and uninformative cues is predicted to fall to zero at a similar rate. As a consequence, there is no reason to expect a difference between the associability of these cues when they were used for Stage 2 of Experiment 1, and thus no reason to expect the discrimination in this stage to be acquired more rapidly by the blocked-cue than the uninformative-cue group.

Turning now to Experiments 2A and 3, which were similar in design to Experiment 1, except that the cues in Stage 2 were different to those in Stage 1, but from the same dimensions as their counterparts in Stage 1. In these circumstances, it follows from the proposals of Mackintosh (1975) that the changes in associability that take place during Stage 1 will generalise to the cues used in Stage 2. At the outset of Stage 2, therefore, the associability of the cues from the blocked dimension and the uninformative dimension will be equally low and there should be no difference in the rate at which the two groups acquire their discriminations. The results from both experiments confirmed this prediction.

The outcome from Experiment 2B can also be explained by the theory of Mackintosh (1975). The results from the computer simulation shown in the lower panel of Figure 7

indicate that by the end of Stage 1 the value of α for the cues from the informative dimension, U and V, will be higher than for cues from the blocked dimension, B. As a consequence of the generalisation of these differences in α to the cues introduced for Stage 2, the new discriminations are correctly predicted to be mastered more readily by the informative-cue than the blocked-cue group.

The foregoing analysis of the redundancy effect, in terms of the theory of Mackintosh (1975), can also explain some puzzling findings reported by Uengoer et al. (2013, Experiment 3) in their investigation of this effect. The experiment included trials of the kind P+/- PQ+/-, which can be described as a blocking treatment using a partial reinforcement schedule. Test trials revealed a stronger response to the blocked cue, Q, than to the uninformative cue, X, of the simple discrimination, UX+ VX-. If it is assumed that learning is governed by Equation 2, then this result is difficult to understand because these different treatments should have resulted in a similar response to X and Q, as they were both paired with the outcome according to the same schedule. However, if changes in associability take place during training, in the manner predicted by Mackintosh (1975), then the correct outcome of the test trials is predicted, even if changes in associative strength are governed by Equation 2.

This prediction is made because P was present on a greater number of training trials than Q, which will ensure that initially the associative strength of P will be greater than of Q. On those trials in which PQ is paired with an outcome, therefore, P will be a better predictor of the outcome than Q, and the value of α_P will increase while the value of α_Q will decrease. In contrast, on PQ trials without an outcome, Q will be a better predictor for this absence than P, with the result that α_Q will rise and α_P will fall. The partial reinforcement schedule will thus prevent the value of α_Q from falling to zero with the consequence that the associative strength of Q will eventually reach the asymptote imposed by the partial reinforcement schedule. Not only will this state of affairs result in a stronger response to Q than X, from UX+ VX-, but it

will also result in a complete absence of blocking with the response to Q matching that to P. The results confirmed these predictions.

Vogel and Wagner (2017) have shown how it is possible for the Rescorla-Wagner (1972) model to explain the redundancy effect, if it is assumed that all the stimuli used for training share a common feature. If this feature is represented by K, then the sequence of trials, A+ AB+ UX+ VX-, can be characterised as AK+ ABK+ UXK+ VXK-, which leads Equation 1 to predict that the response to B will be stronger than to X. This difference, however, is predicted to be most marked during the early trials of training, and to disappear as the effects of training reach asymptote. To our knowledge, there is no evidence confirming this transient nature of the redundancy effect. This does not mean the explanation is wrong, however, and we therefore examined, by means of a computer simulation based on Equation 1, whether the analysis offered by Vogel and Wagner can account for the redundancy effect demonstrated in Experiment 3.

The application of this analysis to the experiment is complicated because four different dimensions of stimuli were assigned to the four different cue functions. Thus, blocked cues might have been colours, blocking cues might have been shapes, and so on. In keeping with the spirit of the analysis offered by Vogel and Wagner (2017), we assumed that this arrangement would result in more generalisation between cues with the same function than between cues with a different function. To capture these differences, therefore, each cue was characterised by three elements. One element represented the unique features of the cue, one element represented the features of the cue that were shared with the other cues from the same dimension, and one element represented the features of the cue that were shared with all other cues, K. The values of the parameters were the same as those used by Vogel and Wagner: λ was 1 and 0 for trials with and without an outcome, respectively, α for all cues was .4, and β was .2 and .1 for trials with and without an outcome, respectively.

The results from the simulation, for the predicted acquisition of associative strength by a blocked cue, B, and an uninformative cue, X, can be seen in Figure 8. It is evident that the response to the blocked cue is predicted to be stronger than to the uninformative cue, but not to a large extent and only during the initial training trials. With further training this relationship is predicted to reverse. Given that any outcome from the test trials would have been consistent with this analysis, Experiment 3 does not provide a satisfactory test of the account put forward by Vogel and Wagner (2017).

Insert Figure 8 about here

Less ambiguous findings concerning this analysis of the redundancy effect can be found in the experiment described above by Uengoer et al. (2013, Experiment 3) in which a partial reinforcement schedule was used for a blocking treatment, P+/- PQ+/-. Given that changes in associative strength are assumed by Vogel and Wagner (2017) to be governed by Equation 1, it follows that the associative strength of Q will eventually be driven to zero, with the result that the response to Q will be considerably weaker than to P. In fact, the experiment revealed a similar response to both stimuli.

Finally, the proposals of Vogel and Wagner (2017) are unable to explain the findings from Stage 2 of Experiment 2B. In the absence of any mechanism that allows the associability of stimuli to change with experience, Equation 1 is unable to predict why the Stage-2 discrimination was acquired more readily by the informative-cue than the blocked-cue group. These differences in associability can, as we have seen, be readily explained by the theory of Mackintosh (1975). Moreover, this theory can also explain comfortably all of the other results that are reported above. Given this success, it would seem there are still good reasons to take seriously a theory that was proposed more than 40 years ago.

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Table 1. The design of Experiment 1

Stage 1	Stage 2	
Both groups	Blocked-cue group	Uninformative-cue group
A-O_1, AB-O_1	BX-O_3, BY-O_3	
C-O_1, CB-O_1	EX-O_4, EY- O_4	
D-O_2, DE-O_2		
F-O_2, FE-O_2		BX-O_3, BY-O_4
UX-O_1, VX-O_2		EX- O_3, EY-O_4
UY-O_1, VY-O_2		

Note. Letters represent different food types; O_1-O_4 represent different allergic reactions.

Table 2. The design of the training that was given to both groups in Stage 1, and the different training that was given to each of the two groups in Stage 2, of Experiment 2A.

Stage 1	Stage 2	
Both groups	Blocked-cue group	Uninformative-cue group
A_1-O_1, A_1B_1-O_1	B_3X_3-O_1, B_4X_3-O_2	
A_2-O_1, A_2B_1-O_1	B_3X_4-O_1, B_4X_4-O_2	
A_3-O_2, A_3B_2-O_2		
A_4-O_2, A_4B_2-O_2		B_3X_3-O_1, B_3X_4-O_2
U_1X_1-O_1, U_2X_1-O_2		B_4X_3-O_1, B_4X_4-O_2
U_1X_2-O_1, U_2X_2-O_2		

Note. A_1-A_4 = blocking dimension, B_1-B_4 = blocked dimension, U_1-U_2 = informative dimension, X_1-X_4 = uninformative dimension. O_1= Brooklyn, O_2 = Queens. A similar design was used for Experiment 3 except that O_1= Ontario Fever, O_2 = no symptoms.

Table 3. The design of the training that was given to both groups in Stage 1, and the different training that was given to each of the two groups in Stage 2, of Experiment 2B.

Stage 1	Stage 2	
Both groups	Blocked-cue group	Informative-cue group
A_1-O_1, A_1B_1-O_1	B_3U_3-O_1, B_4U_3-O_2	
A_2-O_1, A_2B_1-O_1	B_3U_4-O_1, B_4U_4-O_2	
A_3-O_2, A_3B_2-O_2		
A_4-O_2, A_4B_2-O_2		B_3U_3-O_1, B_3U_4-O_2
U_1X_1-O_1, U_2X_1-O_2		B_4U_3-O_1, B_4U_4-O_2
U_1X_2-O_1, U_2X_2-O_2		

Note. A_1-A_4 = blocking dimension, B_1-B_4 = blocked dimension, U_1-U_4 = informative dimension, X_1-X_4 = uninformative dimension. O_1= Brooklyn, O_2 = Queens.

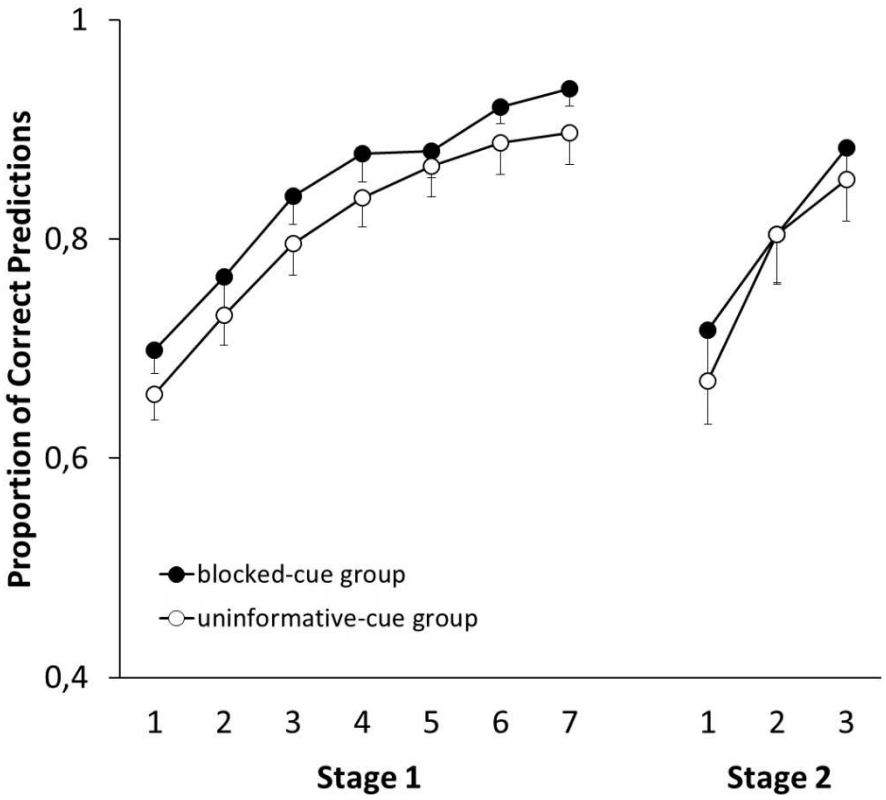

Figure 1. Mean proportion of correct predictions across the seven blocks of Stage 1 (left) and the three blocks of Stage 2 (right) for the two groups in Experiment 1. Error bars denote standard errors of the means.

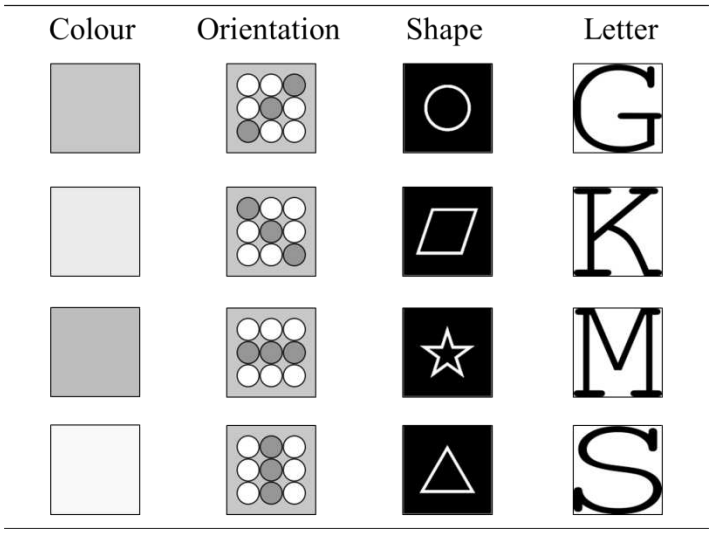

Figure 2. Stimuli from Experiments 2A, 2B, and 3. Colour-stimuli (first column) were squares in solid colours (green, red, blue, or yellow). Orientation-stimuli (second column) displayed dark grey circles arranged in certain orientations on a light grey background. Shape-stimuli (third column) displayed white line drawings of geometric forms on a black background. Letter-stimuli (fourth column) showed capital letters in black font on a white background.

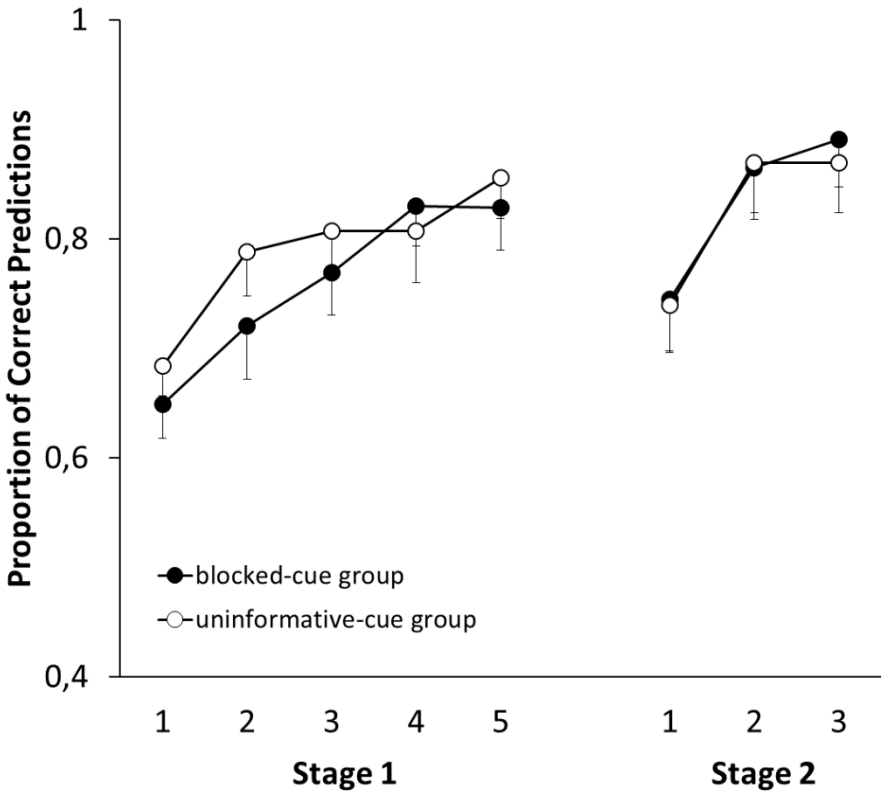

Figure 3. Mean proportion of correct predictions across the five blocks of Stage 1 (left) and the three blocks of Stage 2 (right) for the two groups in Experiment 2A. Error bars denote standard errors of the means.

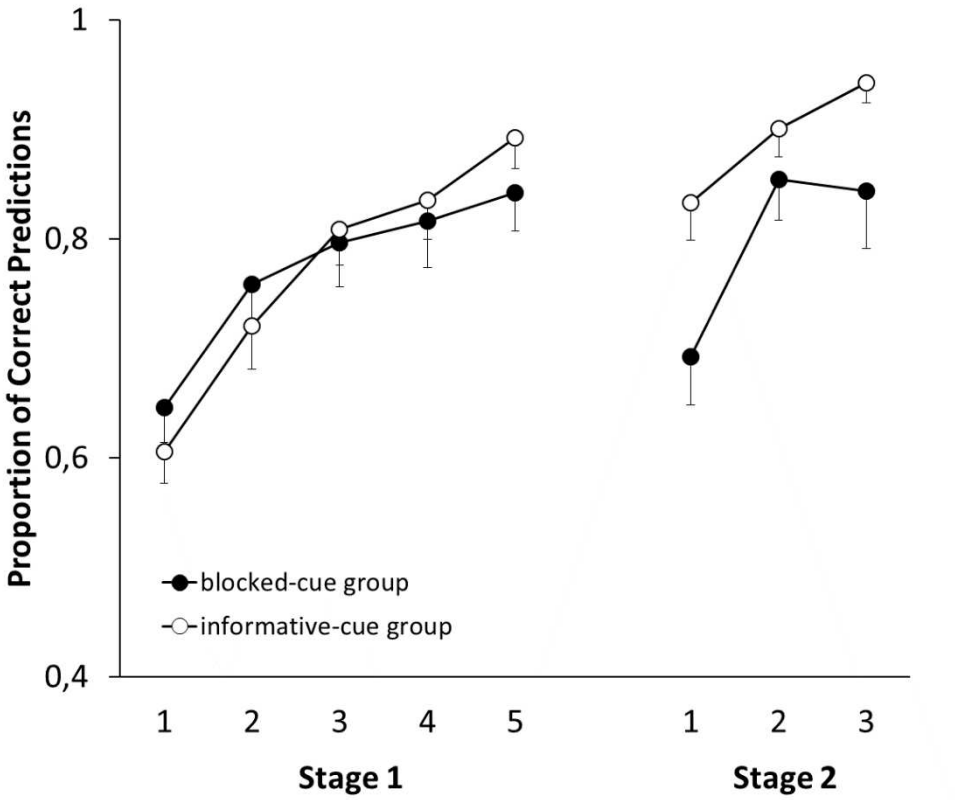

Figure 4. Mean proportion of correct predictions across the five blocks of Stage 1 (left) and the three blocks of Stage 2 (right) for the two groups in Experiment 2B. Error bars denote standard errors of the means.

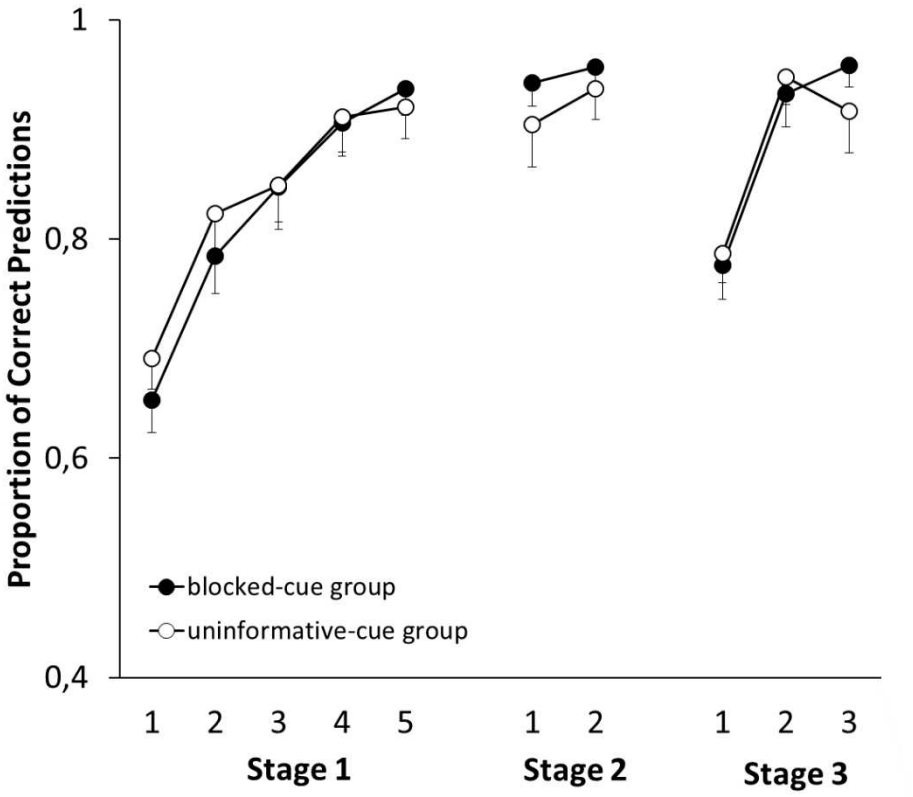

Figure 5. Mean proportion of correct predictions across the five blocks of Stage 1 (left), the two blocks of Stage 2 (centre), and the three blocks of Stage 3 (right) for the two groups in Experiment 3. Error bars denote standard errors of the means.

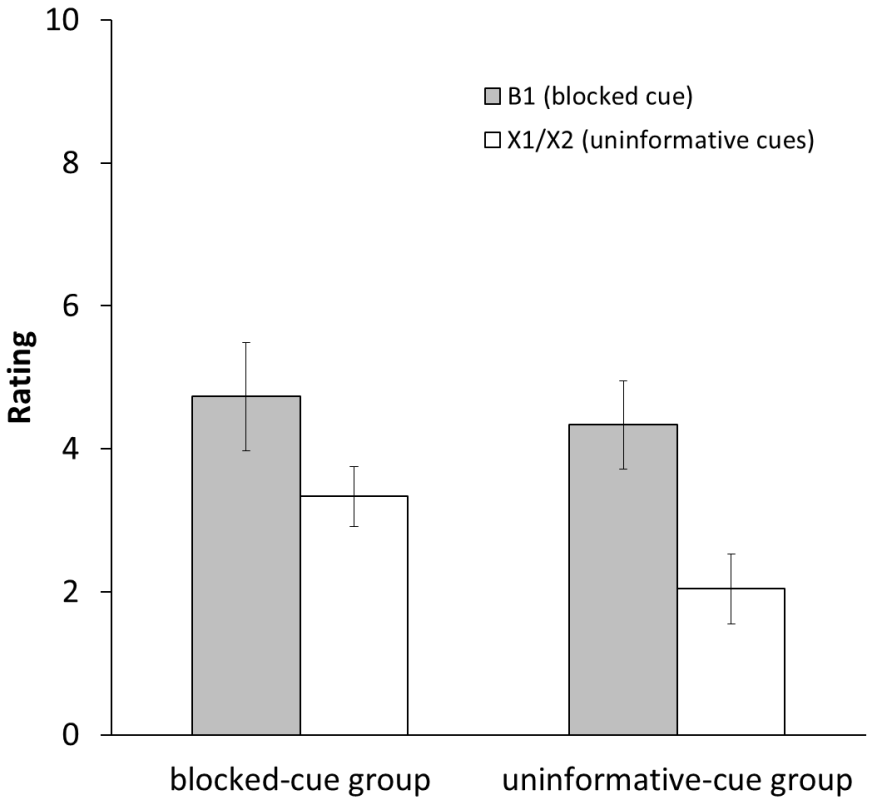

Figure 6. Mean ratings for the blocked and uninformative cues from the test following Stage 1 in Experiment 3. Grey bars correspond to the mean ratings for the blocked cue B_1, and the white bars represent responding to the uninformative cues in terms of the mean ratings collapsed across the trials with cues X_1 and X_2. Error bars denote standard errors of the means.

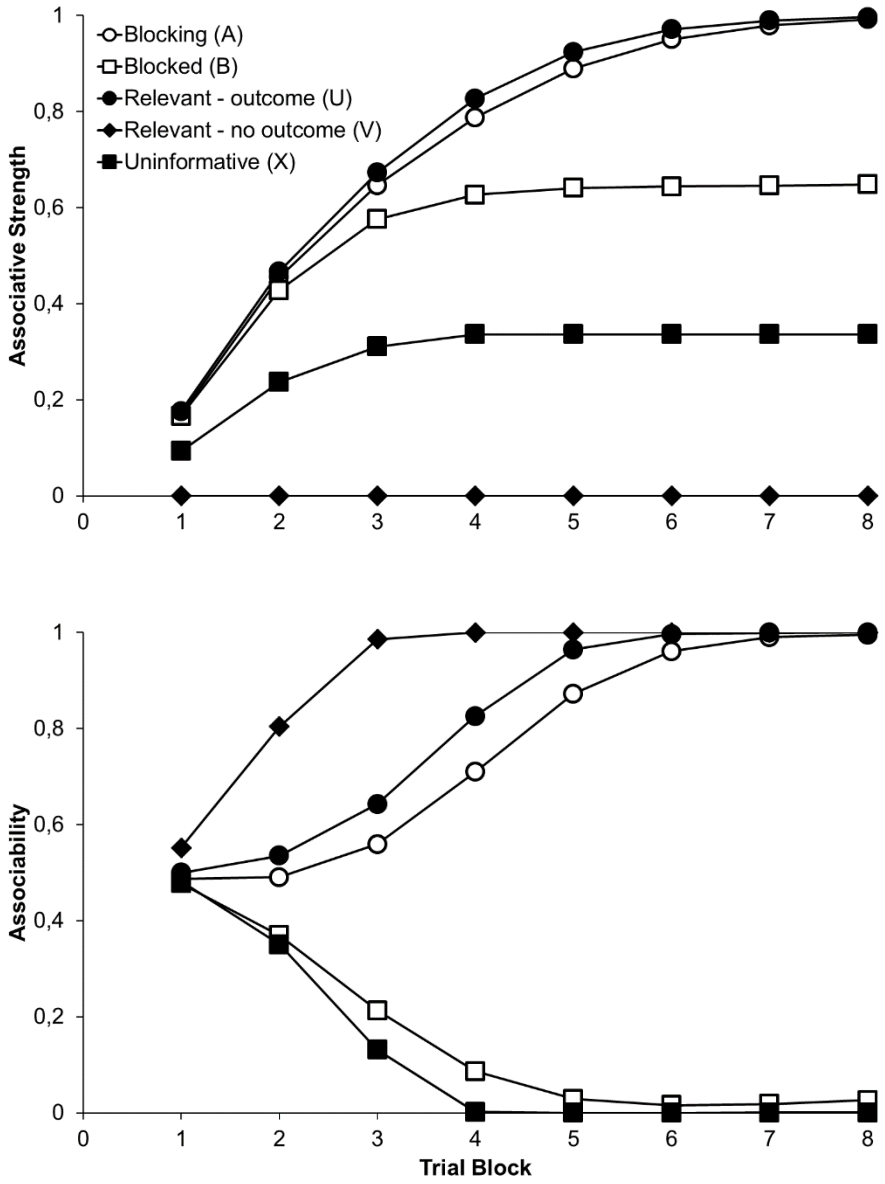

Figure 7. Changes in in associative strength (upper panel) and associabilty (lower panel predicted by the theory of Mackintosh (1975) for the blocking treatment, A+ C+ AB+ CB+ and the simple discrimination, UX+ VX- UY+ VY-, for Stage 1 of Experiment 3.

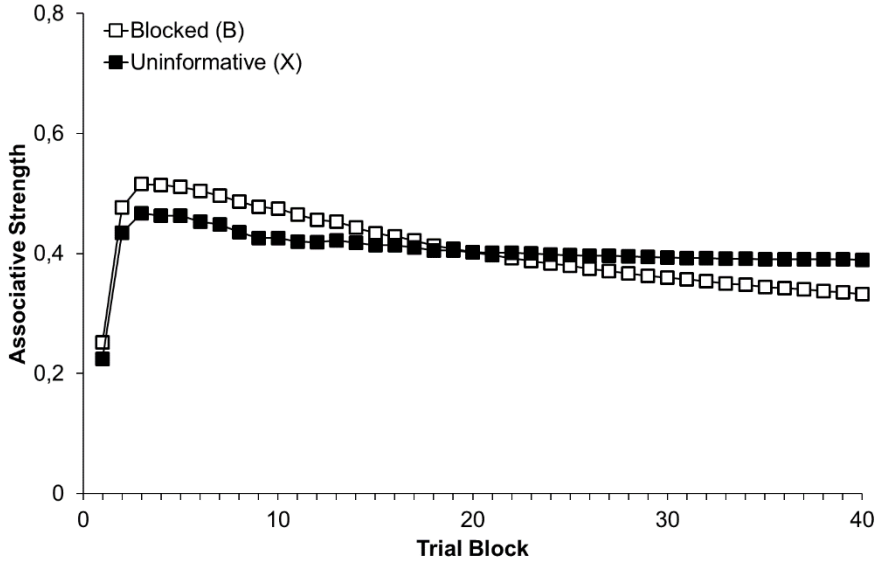

Figure 8. Acquisition of associative strengths for the blocked and uninformative cues trained in Stage 1 of Experiment 3 according to Vogel and Wagner (2017). The associative strength of each cue is characterised by the combination of three elements: one element representing the unique characteristics of the cue, one element representing the characteristics of the stimulus dimension, and one element representing the characteristics of the cue that were shared by all other cues.