Outcome Predictability:

Does associative history of outcomes bias subsequent learning in a human goal-tracking paradigm?

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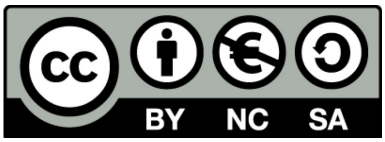

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Abstract

In 1975, Mackintosh proposed that a cue previously experienced to be a better predictor of the outcome than the other cues present possesses greater associability. More recently, a study using a human causal learning task demonstrated better learning about the outcome which has been consistently predictable in the past, as compared to the outcome previously experienced to be unpredictable, namely the *outcome predictability effect* (Griffiths, Mitchell, Bethmont and Lovibond, 2015). The present study aimed to examine the generality of the effect with a novel goal tracking paradigm and determine if the learned predictability of an outcome can shape the *associability* of this outcome to be entered into novel associations, which is similar to the Mackintosh theory proposed for cues. Seven experiments were conducted by approaching three different designs to manipulate outcome predictability. For the first four experiments, one outcome was consistently predictable in the initial training phase, while the other two outcomes were less predictable because each of them is preceded by cue C half of the time and cue D on the other half (Design 1). In the second phase, each outcome was fully predictable by a novel cue. We firstly observed the outcome predictability effect in the first experiment. The previously predictable outcome was more readily associated with a novel cue than the previously less predictable outcomes. However, this finding could not be reproduced in the following three experiments. All these results indicate that the finding from Experiment 1 is not replicable and this manipulation of outcome predictability in the present paradigm cannot reliably exert an effect on novel learning about this outcome. Based on the results of the first four experiments, we approached two other manipulations to differentiate the outcomes' predictability (Design 2 and 3) in Phase 1 to detect if the different manipulations can influence the demonstration of the outcome predictability effect. Moreover, these two manipulations differ in the formation of contextual

associations with outcomes. A stronger contextual association should be formed to the less predictable outcome with Design 3, but not with Design 2. In Phase 2, each outcome is, again, fully predictable by novel cues. Thus, through the comparison of data between two designs, we are able to determine whether context can mediate the demonstration of the outcome predictability effect. Experiment 5 to 7 examined these two designs. We observed once that the conduction of Design 2 demonstrated more rapid learning about the prior predictable than the prior less predictable outcome in Phase 2. However, through additional analyses we found that such a difference is based on a stronger association between context and the prior less predictable outcome showed in Phase 2, which is inconsistent with our expectation. Moreover, Experiment 7 with the additional instructional manipulations did not replicate this finding. Participants did not show a preference for the prior predictable outcome in Phase 2 learning, even though we explicitly informed them that the previous predictable outcome would also be predictable in Phase 2. Furthermore, the execution of Design 3 did not establish an effect of outcome predictability on subsequent learning, indicating that context cannot mediate the demonstration of the outcome predictability effect. Overall, our data suggest that the manipulation of the outcome's predictability in the initial training phase cannot affect subsequent learning about the outcome in the present paradigm and processing of outcomes may differ from cues on the basis of predictability/predictiveness. We discussed that the different features between cues and outcomes might be responsible for the difference in cues and outcomes processing. Furthermore, we carefully reviewed the studies which have reported the outcome predictability effect and speculate that their findings might be paradigm-dependent.

Zusammenfassung

Im Jahr 1975 hat Mackintosh vorgeschlagen, dass ein Cue, das zuvor als besserer Prädiktor für den Outcome im Vergleich zu anderen präsentierten Cues gelernt wurde, eine größere Assoziabilität besitzt. Kürzlich hat eine Studie unter Anwendung einer Human Kausallernen Aufgabe das bessere Lernen über den Outcome, das in der Vergangenheit gut vorhersagbar war, im Vergleich zu den vorher unvorhersagbaren Outcomes, gezeigt, nämlich der *Outcome Predictabililty Effect* (Griffiths, Mitchell, Bethmont and Lovibond, 2015). Das Ziel der vorliegenden Studie ist es, die Allgemeingültigkeit des Effekts mit einer neuen Goal-Tracking Aufgabe zu überprüfen, und festzustellen, ob die gelernte Vorhersagbarkeit eines Outcomes die Assoziabilität dieses Outcomes beim Eintreten in die neue Assoziation formen kann, was der Mackintosh Theorie für Cues ähnelt. Sieben Experimente unter Anwendung drei verschiedener Designs, in der die Vorhersagbarkeit des Outcomes manipuliert wurde, wurden durchgeführt. Für die ersten vier Experimente war ein Outcome vollständig vorhersagbar in der ersten Trainingsphase, während die zwei anderen Outcomes weniger vorhersagbar waren, weil jeder der beiden Outcomes in 50% der Trials von das Cue C und in der anderen Hälfte der Trials von das Cue D vorhergesagt wurde. In der zweiten Phase wurde jeder Outcome vollständig von einem neuen Cue vorhergesagt (Design 1). Wir haben zunächst den Outcome Predictability Effekt im ersten Experiment beobachtet. Der früher vorhersagbare Outcome wurde leichter mit einem neuen Cue assoziiert als die früher nur teilweise vorhersagbaren Outcomes. Allerdings konnte dieser Befund nicht in den folgenden drei Experimenten reproduziert werden. Alle diese Ergebnisse zeigen, dass die Befunde des Experiments 1 nicht replizierbar sind und diese Manipulation der Vorhersagbarkeit eines Outcomes im vorliegenden Paradigma keine zuverlässige Wirkung auf das nachfolgende Lernen über diesen Outcome ausüben kann. Aufgrund der

Ergebnisse der ersten vier Experimente haben wir zwei weitere Manipulationen für die Differenzierung der Vorhersagbarkeit des Outcomes (Design 2 und 3) in Phase 1 nachgeprüft, um festzustellen, ob die verschiedenen Manipulationen die Demonstration des Outcome Predictability Effects beeinflussen kann. Zudem unterscheiden sich diese zwei Manipulationen im Formen der kontextuellen Assoziation mit Outcomes. Eine stärkere kontextuelle Assoziation sollte mit Design 3 geformt werden, aber nicht mit Design 2. In der Phase 2 war jeder Outcome wiederum vollständig von neuen Cues vorhersagbar. So können wir durch den Vergleich der Daten zwischen zwei Designs feststellen, ob der Kontext die Demonstration des Outcome Predictability Effekt vermitteln kann. Experimente 5 bis 7 untersuchten diese beiden Designs. Wir haben einmal beobachtet, dass die Durchführung des Designs 2 ein schnelleres Lernen über den früher vorhersagbaren Outcome als den früher weniger vorhersagbaren Outcome in der Phase 2 gezeigt hat. Jedoch finden wir durch die zusätzlichen Analysen, dass ein solcher Unterschied auf einer stärkeren Assoziation zwischen dem Kontext und den früher weniger vorhersagbaren Outcome, was in Phase 2 gezeigt wurde, beruht. Diese ist nicht mit unserer Erwartung vereinbar. Zudem hat Experiment 7 mit den zusätzlichen Instruktionsmanipulationen diesen Befund nicht repliziert. Versuchspersonen haben keine Präferenz für den früher vorhersagbaren Outcome beim Lernen der zweiten Phase gezeigt, obwohl wir ihnen explizit erläutert haben, dass der zuvor gut vorhersagbare Outcome auch in der Phase 2 gut vorhersagbar ist. Darüber hinaus hat die Ausführung des Designs 3 keine Auswirkung der Outcomes Vorhersagbarkeit auf das nachfolgende Lernen hergestellt. Dies indiziert, dass der Kontext die Demonstration des Outcome Predictability Effekts nicht vermitteln kann. Insgesamt deuten unsere Daten darauf hin, dass die Manipulation der Vorhersagbarkeit des Outcomes in der ersten Trainingsphase im unserem Paradigma das nachfolgende Lernen über diesen Outcome nicht beeinflussen

kann und der Verarbeitungsprozess für Outcomes sich mit dem für Cues im Rahmen der Vorhersagbarkeit/Vorhersagekraft unterscheidet. Wir diskutierten, dass der Unterschied der Merkmale zwischen Cues und Outcomes möglicherweise für den unterschiedlichen Verarbeitungsprozess verantwortlich ist. Darüber hinaus haben wir die Studien, die über den Outcome Predictability Effekt berichtet haben, sorgfältig geprüft und spekulieren, dass ihre Befunde Paradigmen-spezifisch sein könnten.

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Chapter 1: Introduction

In everyday life, we can experience that one event often reliably predicts another. A big dark cloud will be followed by rain, and eating rotten meat will cause illness. Learning about the relationships between events is a fundamental ability of humans and other animals that enables organisms to prepare for future events and adapt to their environment. A famous example of this ability is Pavlovian conditioning (Pavlov, 1927). When a neutral stimulus (the conditioned stimulus, CS, or cue), is repeatedly paired with a biologically significant event (the unconditioned stimulus, US, or outcome), it comes to elicit a response (the conditioned response, CR) that is appropriate to the imminent delivery of the outcome. Pavlovian conditioning is considered one of the most basic learning forms that plays a significant role not only in associative learning studies, but also in other research fields, such as clinical psychology, neuroscience and educational psychology. For instance, Pavlovian conditioning has been used to explain pathological behavior, such as drug abuse (e.g., Siegel, 1989) and anxiety disorders (e.g., Bouton, Mineka, & Barlow, 2001). Many contemporary theories assume that the CR reflects the organism's prediction of the outcome based on the accumulation of knowledge about the sequential structure of its environment during Pavlov conditioning (see Pearce & Bouton, 2001 for a review). Associative learning models like the Rescorla-Wagner theory (Rescorla & Wagner, 1972) assume that this knowledge takes the form of associations that connect mental representations of events, and that learning results in changes to the association of the cue with the outcome (ΔV). In the Rescorla-Wagner Model, these changes are directly determined by variations in the processing of the outcome (Equation 1), as the outcome loses its capacity to surprise when the discrepancy between the actual outcome (λ) and its prediction based on the associations with the cues (ΣV) decreases during learning (i.e., minimizing *prediction error*). Thus, learning occurs when the

presence or absence of the outcome does not match the expectation of the organism and the expectation on a given trial is based on the predictive value of all of the stimuli present.

$$\Delta V_A = \alpha_A \beta (\lambda - \Sigma V) \quad (1)$$

Moreover, the Rescorla-Wagner Model includes two fixed parameters that alter the rate of learning and are referred to as the associability of cue A (α_A) and the outcome (β). According to Rescorla and Wagner, the associabilities of both cue and outcome were considered to be a function of physical characteristics of the stimuli that do not change during learning. For instance, when electric shock serves as outcome, the rate of learning and the level of conditioned response are greater with a shock obtaining higher intensity than a low shock intensity (e.g., Annau & Kamin, 1961). Likewise, when rats are trained with the same magnitude of the outcome but with different intensities of a white noise for the cue, the rate of learning is greater with a stronger noise than with a weak noise (e.g., Kamin & Schaub, 1963). As the most influential theory of associative learning, the Rescorla-Wagner model is successful in interpreting many conditioning phenomena, such as blocking (Kamin, 1969) and overshadowing (e.g., Kamin, 1969; Mackintosh, 1976). However, the Rescorla-Wagner model is still not perfect and there are some learning phenomena that cannot be explained by this model (Miller, Barnet & Grahame, 1995). One example is the CS preexposure effect, also called "latent inhibition" (Lubow & Moore, 1959). This effect refers to the retarded acquisition of a cue-outcome relationship that occurs if subjects are exposed to a cue alone prior to cue-outcome pairing. According to the Rescorla-Wagner model, since there is no outcome present during the preexposure phase, nothing should be learnt about the cue and the associative status of the cue should not be changed. Consequently, the subjects preexposed to the cue should learn the cue-outcome association at the same rate as the subjects that did not receive the preexposure training. Such a prediction based on the Rescorla-Wagner model is incompatible with the

actual observation. On the contrary, an explanation of the CS preexposure effect proposed by Mackintosh (Mackintosh, 1975) suggests that the nonreinforced exposure to the cue in the pretraining phase reduces the associability of the cue, that consequently impairs the acquisition of the cue-outcome association. Moreover, Mackintosh (1975) argued that it is not only the cue's physical characteristics, but rather its learning history that can influence its associability (for details on the theory, see 1.1 Learned Predictiveness and Associability of Cues). Based on this assumption, Mackintosh theory provides an explanation of many behavior phenomena that cannot be predicted by the Rescorla-Wagner model, such as the CS-exposure effect (e.g., Lubon & Moore, 1959) and learned irrelevance (e.g., Baker, 1976; Baker & Mackintosh, 1977). However, less research has addressed how the associability of the outcome β is affected by prior learning. Griffiths, Mitchell, Bethmont and Lovibond (2015) approached this issue, demonstrating that the extent to which an outcome has been consistently predicted by the same set of cues, that is its previous *predictability*, influences the rate of new learning about that outcome in a human causal learning task. Moreover, they proposed that the associability of an outcome may vary based on its associative history. In the present studies, we applied a novel conditioning paradigm with measurements of eye fixation to determine if and how manipulating outcome predictability could affect the subsequent learning about the outcome. Furthermore, our data provided a great opportunity to discuss if the learning history of an outcome, in particular its previous predictability, can influence its associability (β).

1.1 Learned Predictiveness and Associability of Cues

In contrast to the assumption of the Rescorla-Wagner Model that α for a specific cue is constant, Mackintosh (Mackintosh, 1975) allows α of a cue to change depending on how accurately it predicts reinforcement (Equation 2).

$$\Delta\alpha_A > 0 \qquad \text{if } |\lambda - V_A| < |\lambda - V_X| \tag{2}$$

$$\Delta\alpha_A < 0 \qquad \text{if } |\lambda - V_A| \geq |\lambda - V_X|$$

If the mismatch between the actual outcome λ on a given trial and the anticipation of the outcome based on cue A (V_A) is smaller than the mismatch between λ and the other cue X (V_X) present at the same time, cue A is regarded as a better predictor than X and its α will increase. Conversely, α of A will decrease if other cues can predict the outcome at least as well as A. Thus, according to Mackintosh, learning both results in changes to the association and to the processing of the cues involved. Moreover, Mackintosh (Mackintosh, 1975) suggested that the associability of cue represents attention allocated to the stimulus. Subjects will learn to attend to the predictive cue and ignore the nonpredictive cues across learning trials, that results in better learning about the predictive than the nonpredictive cues. Powerful evidence for a role of associability processes is provided by the studies that have compared the effects of intradimensional (ID) and extradimensional (ED) shifts on the acquisition of discriminations (e.g., George & Pearce, 1999; Mackintosh & Little, 1969; Shepp & Eimas, 1964). In these experiments, subjects were trained on a discrimination between stimuli that varied on two independent dimensions, say color and shape. Initially, the occurrence of reward was predicted by the stimuli from one dimension, say color, but not from the other dimension, say shape. Thus, one dimension (i.e. color) was predictive and the second dimension (i.e. shape) was nonpredictive. For the subsequent phase, a second discrimination between novel stimuli, that also differed in color and shape, was given. It has been demonstrated that subjects for which the previously predictive dimension (i.e. color) remained predictive (ID shift), acquired the second discrimination more rapidly than those for which the previously nonpredictive dimension (i.e. shape) became predictive (ED shift). Such an advantage for ID shifts over ED shifts can be explained by assuming that the first phase training

encouraged subjects to pay more attention to the predictive than nonpredictive dimension. This interpretation is in keeping with the predictiveness principles of the Mackintosh theory (Mackintosh, 1975). However, there is still an issue based on the ID-ED shift effect regarding the level at which associability applies to stimuli. One view is that associability applies to the level of cues' dimensions, such that subjects may learn to attend to one dimension (e.g., color) rather than another (e.g., shape) as a result of experience (Sutherland & Mackintosh, 1971). The alternative view, embodied by the Mackintosh theory (Mackintosh, 1975), suggests that associability applies to individual cues or features rather than whole dimensions. Moreover, Mackintosh proposed that associability could generalize from one stimulus to another based on their similarity. In the case of the ID-ED shift, it seems reasonable to assume that features from the same dimension have greater similarity (e.g., red and yellow) than the features from the different dimensions (e.g., red and triangle). As a result, there will be a greater generalization of associability from the predictive cues of Phase 1 to the predictive cues of Phase 2 in the ID group (as the predictive cues from the two phases have higher similarity) than in the ED group (as the predictive cues from Phase 1 have lower similarity to the predictive cues from Phase 2). The ID-ED shift effect can be explained by either of these accounts. Further, another less ambiguous phenomenon that provides strong support for the predictiveness principle embodied by the Mackintosh theory is the learned predictiveness effect.

When people learn novel predictive relations between cues and an outcome, they will learn more rapidly about the cues that have been shown to be better predictors of other outcomes in the past. This is referred to as *the learned predictiveness effect* (see Le Pelley, 2004, for a review). In contrast to the studies on the ID- and ED-shift effects that manipulated the predictiveness of the cues' dimensions and changed the cues between two phases, the studies on the learned predictiveness effect directly manipulated the cues'

predictiveness and changed the outcomes between two phases. These manipulations can be seen in the study conducted by Le Pelley and McLaren (2003). On each trial of their study, human subjects were required to predict the type of allergic reaction that a fictitious patient would suffer after eating different foods. Immediate feedback was given after each prediction allowing participants to learn the relationships between foods (cues) and different types of allergic reactions (outcomes). In the initial training phase, each trial featured a pair of foods, one of which (e.g., apple) could consistently predict which reaction would occur, and the other of which (e.g., banana) was paired equally often with two reactions (sweating and dizziness) and so were nonpredictive. In particular, cues A-D were predictive and cues R-U were nonpredictive. In the second training phase, participants were informed that a new patient ate the same foods as the previous patient, but suffered different types of reactions (nausea and itching). During this phase, new compounds were presented, each of which consisted of one previously predictive cue and one previously nonpredictive cue. Specifically, compounds AT and CR were paired with o3, and compounds BU and DS with o4. Crucially, all cues present in Phase 2 were equally predictive of the outcomes with which they were paired. In the final test phase, participants were asked to rate how likely each of o3 and o4 would appear after eating the foods AC, BD, RT, and SU. As a result, participants rated compound AC as a stronger predictor of o3 than RT, and compound BD as a stronger predictor of o4 than SU. Since all cues did not differ in their predictiveness from one another in Phase 2, this finding indicates a difference in the processing of cues A-D and R-U due to the difference in the learned predictiveness of these cues during Phase 1. The Mackintosh theory predicts that cues A-D will possess greater associability than cues R-U at the end of Phase 1, since they are better predictors relative to R-U. These associabilities will be transferred to Phase 2 learning, resulting in more rapid learning about associations between cues A-D and the

novel outcomes than between cues R-U and the novel outcomes. Thus, participants will show better learning about cues A-D than R-U in the test phase. These predictions are consistent with the results of the study. Moreover, this learned predictiveness effect has been reliably demonstrated in a series of animal learning experiments and human learning studies (e.g., Beesley & Le Pelley, 2010; Dopson, Esber, & Pearce, 2010; Le Pelley & McLaren, 2003; Livesey & McLaren, 2007; Lochmann & Wills, 2003; Mackintosh & Turner, 1971). Further, several studies investigated attentional bias with respect to cues' predictiveness by directly measuring overt attention with eye gaze to the different cues (e.g., Beesley, Nguyen, Person, & Le Pelley, 2015; Le Pelley, Beesley, & Griffiths, 2011; Mitchell, Griffiths, Seetoo, & Lovibond, 2012). Eye-tracking data have demonstrated that participants spent a longer time looking at the cue experienced to be a better predictor in the previous training phase than the cues previously experienced to be a poor predictor, indicating that the previous predictive cue captured more visual attention than the previous nonpredictive cue. Such results fit well with the attentional assumptions for the learned predictiveness effect suggested by Mackintosh (1975).

According to the Mackintosh theory (Mackintosh, 1975), the learned predictiveness effect is based on a comparison of the *relative predictiveness* of simultaneously presented cues. That is, the associability of a good predictor increases through a comparison with the poorer predictor present on the same trial, while the associability of the poorer predictor declines as a result of the same comparison with the better predictor of the outcome. In this sense, the *absolute predictiveness* of a given cue that is determined by the mismatch between λ and the anticipation based on this cue (V_A) on each trial has no direct influence on $\alpha_{A,}$ since α_A only changes through comparison with other cues on each trial. Furthermore, Le Pelley (2004) suggested that the experiments, whose procedure emphasizes absolute predictiveness, are expected to

demonstrate faster learning about the stimuli previously established as poor predictors in comparison to those previously experienced as better predictors. Thus, it seems that the learned predictiveness effect cannot be demonstrated by manipulating the absolute predictiveness. However, some studies cast doubt on this assumption (e.g., Kattner, 2015; Livesey, Thorwart, De Fina & Harris, 2011; Le Pelley, Turnbull, Reimers and Knipe, 2010). For instance, the study conducted by Le Pelley et al. (2010) established the learned predictiveness effect by using the single-cue training paradigm to human subjects. In the first training phase, each of six cues signaled the occurrence of the outcome, in which cues A and D were consistently paired with outcome 1, and B and C with outcome 2. In contrast, cues X and Y were followed by either of o1 or o2, and were henceforth referred to as nonpredictive cues. Crucially, because all the cues were trained individually, they differed in the *absolute predictiveness*. In the second training phase, every cue was consistently paired with a novel outcome, in which cue A, C and X were followed by a positive consequence (i.e. profit), while cue B, D and Y were followed by a negative consequence (i.e. loss). In the final test phase, every two cues were presented together and participants had to choose one of them. As a result, both the data of Phase 2 learning and the choice data from the test phase indicated that participants leaned more readily about the cues which had been predictive in Phase 1, compared to the previously nonpredictive cues. These results are consistent with the Mackintosh theory (1975). Notably, it has been shown that the presentation of a single cue, without the direct comparison of simultaneous present cues on every trial, can still successfully establish the learned predictiveness effect in humans. Furthermore, Kattner (2015) conducted the studies by using a human-contingency learning paradigm emphasizing the relative predictiveness and the absolute predictiveness in different groups. Notably, he manipulated the absolute predictiveness of compound of cues (e.g., AB-o1, XY-o1/o2)

in one group. Crucially, all groups demonstrated more rapid learning about the previous predictive cues than the previous nonpredictives, irrespective of which type of predictiveness had been emphasized during Phase 1. Considering all these data, it has been argued that at least with respect to human associative learning, manipulating the absolute predictiveness can exert the same influence on associability as the relative predictiveness (Kattner, 2015; Le Pelley et al., 2010).

1.2 Outcome Predictability

Not only can the cue be more or less predictive - the outcome can also be more or less predictable. For example, if either of two outcomes follows the same cue, both can be regarded as being less predictable than an outcome that has been consistently paired with one particular cue (e.g., A-o1, B-o2/o3, C-o2/o3). Moreover, if an outcome appears only half of the time when a given cue is presented, this outcome is less predictable than another outcome that has been consistently preceded by a certain cue (e.g., A-o1, B-o2/Ø). However, it has been less investigated in prior literature whether a general processing of an outcome can be affected by associative history of outcomes. Moreover, the term *outcome predictability* used in the present article describes how reliably an outcome has been predicted by other cues learned in the past. It is noteworthy that such influences of outcome predictability differ from those captured in calculations of prediction error, which form part of the Rescorla-Wagner model and many others like it (Bush and Mosteller, 1955; Doya, Samejima, Katagiri & Kawato, 2002; Pearce, 1987; Rescorla and Wagner, 1972; Sutton and Barto, 1990). Prediction error results in changes to the association between the outcome and certain cues and its influence is therefore confined to situations where these cues, or at least similar cues that support strong generalization, are present and the association has been re-activated. It reflects how well an outcome is predicted on a *specific trial* by a *specific cue* configuration. In contrast, we discuss a

general influence of outcome predictability on changes to the processing of the outcome itself, independently of the presence of other cues, and will therefore transfer to all new learning situations. This impact of outcome predictability can be reflected by the associability of the outcome (β). Considering that the learned predictiveness of cues changes α (in line with the Mackintosh theory, Mackintosh, 1975), we questioned whether β of an outcome is also variable based on its predictability learned in the past. If this is the case, it would be expected that a difference in the predictability of the outcomes experienced in the past will impact subsequent learning about novel cues associated with these outcomes.

Notably, traditional formal models of associative learning, like the Rescorla-Wagner model and the Mackintosh theory (see above), predict the effects of two components on the formation of cue-outcome associations: (1) prediction error that involves the learned associative strength of certain cue-outcome relationships on a given trial, and (2) the associability of cues modulated by the learned predictiveness (see Pearce & Bouton, 2001 for a review). However, none of these models approached the possibility that the outcomes' predictability learned in the past may shape β of these outcomes and, consequently, modulate the degree to which these outcomes will enter into novel associations with other cues in the future. If such an assumption about the impact of outcome predictability on β is true, it will constitute a challenge to the assumptions of many traditional associative models of learning and offer new understandings about the role of outcome-processing in associative learning.

1.2.1 US Preexposure Effect

The influence of prior predictability of an outcome on later learning can be linked to the studies addressing the US preexposure effect, and it has been shown in a variety of learning paradigms (e.g., Kamin, 1961; Kimble & Dufort, 1956; Siegel & Domjan, 1971;

Taylor, 1956). For instance, when subjects are exposed to an outcome alone prior to cue-outcome pairing, subsequent learning about the cue-outcome relationship is impaired. In other words, subjects experience that the outcome is unpredictable, and this results in a deceleration of later learning about that outcome. From a perspective of associative account, the US preexposure effect is normally interpreted as the effect of context blocking: an association between the outcome and contextual stimuli was learned during the preexposure phase and thus blocks learning about the relationship between a novel cue and this outcome during the subsequent phase (Randich and LoLordo, 1979). Thus, if the context has changed or the association between context and outcome has been extinguished prior to the cue-outcome pairing, the effect should (and does) vanish (Baker, Mercier, Gabel and Baker, 1981; Randich, 1981). Notably, such an explanation of the US preexposure effect relies *not* on changes to the outcome's associability, but only on changes to its associations with the context, which reduce prediction errors during subsequent conditioning, thus slowing down learning about the predictive cue.

1.2.2 Outcome Predictability Effect

More recently, Griffiths et al. (2015) demonstrated an influence of the manipulation of the outcomes' predictability on later learning with new stimuli by extrapolating an experimental design from Le Pelley and McLaren's (2003) study on the learned predictiveness effect. In a human causal learning task, subjects were required to learn about the causal relationships between cues (foods) and outcomes (allergic reactions) in a hypothetical scenario (i.e. a fictitious patient) and give the judgment of the outcome's occurrence based on the cues present. In the initial training phase, each participant experienced that some outcomes were predicted exactly by one particular cue; other outcomes were less predictable because they were preceded (and only *partially* signaled) by a cue that could be followed by one of two outcomes. In a second training phase, a

previously predictable outcome and a previously less predictable outcome were always presented simultaneously and consistently predicted by a novel cue and an additional unpredictive cue Y, which was present in every trial in Phase 2. Thus, all outcomes in the second phase were entirely predictable and differed from one another only in their Phase 1 predictability. A test phase followed in which participants were asked to rate the likelihood that each cue in Phase 2 would lead to each of the outcomes. As a result, participants demonstrated better learning about the cues associated with the previous predictable outcomes, as compared to the cues associated with the previous unpredictable outcomes, namely *the outcome predictability effect*. The authors interpreted their findings as evidence that an outcome's associability varies based on its previous predictability. In particular, the outcome that has been experienced as predictable in the past possesses greater associability than the outcome which has been unpredictable. Moreover, they argued that subjects encoded an outcome's predictability during the initial training phase and used that information to shape subsequent learning about this outcome.

However, their data did not provide any direct evidence to rule out the possibility that outcome predictability may affect subsequent learning via blocking by the context. For instance, participants may have learned an association between contextual stimuli and the unpredictable outcomes in Phase 1, when the corresponding cues were less predictive. Such an association would then block learning about the novel cue in association with the previously less predictable outcomes in Phase 2. Moreover, Griffiths et al. did not observe an attentional bias for the predictable outcome category over the unpredictable category in Phase 2 training by capturing eye fixation during tasks, while observing attentional differences for the predictive and the nonpredictive cues. This leaves open whether their effect is related to changes to overt attention which is consistent with the attentional viewpoint for the learned predictiveness effect suggested by Mackintosh for cues. Further,

the data from the test phase indicated that the novel unpredictive cue Y was more readily associated with the previous unpredictable outcomes than with the previous predictable outcomes. Such a finding is inconsistent with the explanation that predictable outcomes are higher in associability than unpredictable outcomes. On the contrary, it invites an alternative interpretation that their effect may be based to some degree on inferential reasoning rather than an associative account. Hence, further investigations are required to determine if an influence of outcome predictability on subsequent learning observed in their study relies on a change to the outcome's associability, which is similar to the mechanisms for the learned predictiveness effect for cues.

1.3 Present Research

Considering the potential theoretical significance of the effect described by Griffiths et al. (2015), the present experiments aimed to examine the generality of their effect with a different learning paradigm and determine if outcome predictability can exert an effect on β that is similar to the learned predictiveness effect for cues. The learned predictiveness effect on α was not only examined in human causal learning paradigms (e.g., Le Pelley & McLaren, 2003; Lochmann & Wills, 2003), but also extensively with the conditioning magazine approach in animals and other learning paradigms in humans (e.g., Beesley & Le Pelley, 2010; Dopson et al., 2010; Le Pelley et al., 2010; Livesey & McLaren, 2007; Mackintosh & Turner, 1971). If both effects rely on a similar mechanism, we would expect that the effect of outcome predictability would be observed in different learning paradigms as well. More specifically, it was expected that our experiments would demonstrate more readily learning about the outcome that has been fully predictable by certain cues in the previous training phase, as compared to the previous less predictable outcomes.

The present experiments used a novel paradigm (Thorwart, Uengoer, Livesey & Harris, 2017) that applies a goal-tracking task to human subjects and, hence, builds a bridge between animal and human learning paradigms. In a typical goal-tracking task in rats, subjects learn to poke their nose into the magazine in anticipation of the food outcome when a cue signaling food delivery is presented; in the following experiments, human participants learn to gaze at a certain goal area in anticipation of a task-relevant outcome. It is well known that eye movements are influenced by predictions and both anticipatory and smooth pursuit eye-movements have been actively investigated in research addressing sequence and motion learning, as well in action and motor control (e.g., Bulloch, Prime, & Marotta, 2015; Mennie, Hayhoe, & Sullivan, 2007). Furthermore, Koenig and Lachnit (2011) reported how the trajectories of saccadic eye movements are affected by memory interference acquired during associative learning. In the present experiments, overt attention was used as an indicator for discrimination learning about cue-outcome relationships where cues preceded different outcomes and predicted their location.

Moreover, we captured the motor responses as participants placed the cursor towards the goal area in anticipation of the outcome during the signaling. This type of conditioned response is considered an additional indicator for discrimination learning about cue-outcome relationships. It has been shown in natural behavior that fixations are allocated on objects prior to initiation of the object-related act and these early fixations are considered to facilitate planning an action in the near future (e.g., Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Mennie et al., 2007; Pelz & Canosa, 2001). Thus, we would expect a temporal difference between anticipatory gaze and the initiation of mouse movements in the present experiments. Further, some literatures proposed that a mechanism responsible for the selection of motor responses is not necessary for control

over the focus of visual attention (e.g., Pashler, 1991; Reimer, Strobach, Frensch, & Schubert, 2015). In line with this argument, conditioned responses at the two behavior levels measured in our experiments are not necessarily to be consistent. Hence, measuring two types of responses can provide broader evidence to determine how behavior changes due to the acquisition of cue-outcome associations.

Our experiments proceeded as a computer game, so that participants were not informed about the experimental hypotheses. Moreover, they were instructed that the primary task of the experiment was to earn points for "fishing" by clicking on the fish that appeared in a river on the left side of the screen (see Figure 1.1). The secondary task asked participants to feed multiple animals living in different caves on the right side of the screen. Each animal lived in a particular cave and appeared sporadically in its cave's entrance. To earn points, participants had to click on the cave's entrance each time the animal's eyes appeared. Different eye symbols were located at the same distance from the center of the fish area. The appearance of the eyes lasted for only about a second and was difficult to detect using peripheral vision alone, making overt monitoring necessary for performing the task. The appearance of the eyes was signaled by visual or auditory cues, such as a change in the color of the river or a certain sound. The primary task was designed to attract the participants' attention to the river, while the secondary task was the actual conditioning task. Since participants were unable to attend the river and the cave at the same time, learning about the relationship between the cue and outcome (animal's eyes) could be determined by their gazing at the cave's entrance in anticipation of an outcome during the corresponding cue. By having multiple, clearly distinguishable outcomes and caves, we can manipulate and compare their predictability in a single subject. Such a within-subjects design can reduce the error variance caused by individual differences.

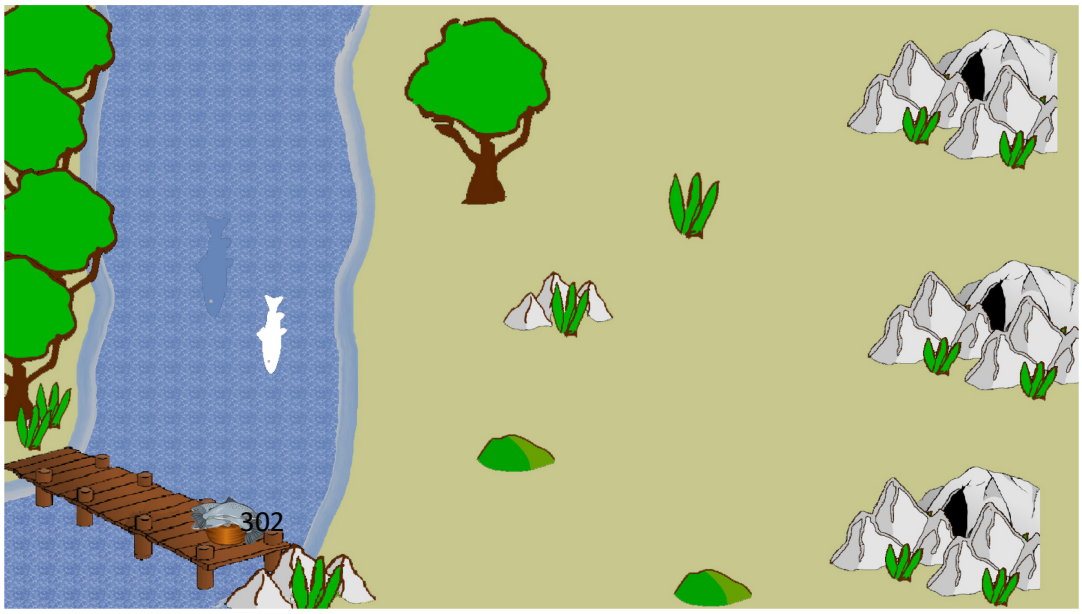


Figure 1.1. Visual stimuli used in the experiments. Note that not all stimuli shown were present at the same time during the actual experiment.

We conducted seven experiments in which three different designs were applied to manipulate the outcome's predictability in the initial training (for an overview of all seven experiments, see Table 1.1). Study I (Experiment 1 to 4) aimed to investigate if and how manipulating outcome predictability with Design 1 would affect subsequent learning about these outcomes in our goal-tracking paradigm. Particularly, in four experiments, outcome o1 was consistently preceded by cue A, while the other two outcomes o2 and o3 were each preceded by cue C half of the time, and cue D the other half in the first training phase (Design 1). In this way, o1 was fully predictable, while o2 and o3 were less predictable. In the second phase, each outcome was fully predicted by novel cues. If learning about o1's novel relationship would differ from learning about o2 and o3 in Phase 2, it should be due to the difference in the outcomes' predictability learned in Phase 1.

Table 1.1
Overview of seven Experiments

		Research question	Manipulation of the predictability in Phase1
Study I			
Exp.1		Does learned predictability bias subsequent learning in our paradigm?	*Design 1* (A→o1, C→o2, C→o3, D→o2, D→o3)
Exp. 2	Group 1 (same context)	Replication of the outcome predictability (OP) effect found in Exp.1	
	Group 2 (context switch)	Does the OP effect rely on a change in the outcome's associability or an influence of context?	
	Group 3 (context switch & outcome removal)		
Exp. 3	Group 1 (same context)	Replication of the OP effect observed in Exp.1	
	Group 2 (context switch)	Does the OP effect rely on an influence of context?	
	Group 3 (same context & outcome removal)	Does a change in number of the outcomes influence the OP effect?	
	Group 3 (context switch & outcome removal)	Does the OP effect is context-dependent?	
Exp. 4	(same context)	Is the effect found in Exp.1 replicable?	
Study II			
Exp. 5	Group 1	Does learned predictability impact subsequent learning via a change in the outcome's associability?	*Design 2* (A→o1, C→o2, C→Ø)
	Group 2	Does learned predictability impact subsequent learning via a blocking effect caused by context?	*Design 3* (A→o1, C→o2, Ø→o2)
Exp. 6	(no interruption between phases)	Does learned predictability impact subsequent learning via a blocking effect caused by context?	*Design 3*
Exp. 7	Group 1 (Instruction consistent)	Can the manipulation of the predictability with Design 2 reliably demonstrate an effect on subsequent learning? Does higher cognitive control influence the effect?	*Design 2*
	Group 2 (Instruction inconsistent)		

Note. Letters A and C denote cues that were always followed by one of three outcomes, donated as o1, o2 and o3. The absence of the stimuli is denoted as Ø.

The aim of Experiment 1 was to access whether the prior predictability of outcomes affected the rate at which they were learned about, when they were predicted by novel cues in a subsequent training phase. If an effect of outcome predictability on subsequent learning is comparable to the leaned predictiveness effect for cues, we would expect that learning about the prior predictable outcome o1 proceeds more rapidly than the prior less predictable outcome o2 and o3, namely *the outcome predictability effect*.

Since the first experiment successfully demonstrated the outcome predictability effect that the prior predictable outcome was more rapidly learned about than the prior less predictable outcome, Experiment 2 aimed to replicate the key findings from Experiment 1 (Group 1) and, further, detect the possible mechanism underlying the effect (Group 2 and 3). In line with the Mackintosh theory, one possibility is that learned predictability alters the associability of the outcome with which it will enter into a novel association. However, with the consideration of the US pre-exposure effect, another possibility is that the outcome predictability effect is mediated by a blocking effect caused by the association between context and the less predictable outcomes. Experiment 2 particularly investigated whether the observed effect was mediated or modulated by context by conducting a context shift between two phases. Moreover, having observed a strong bias towards the outcome placed in the middle cave in Experiment 1, Group 3 employed an additional manipulation besides the context switch to reduce the interference of the middle cave advantage during Phase 2 learning. We placed outcome o3 in the middle cave during the first training phase for all participants of Group 3, and then removed o3 (animal eyes) and the middle cave in the second phase. If the outcome predictability effect is not due to an influence of context, we would expect to observe more rapid learning about the prior predictable outcome than the prior less predictable outcome in Group 2 and 3 as well.

Having observed that none of the three groups in Experiment 2 demonstrated the outcome predictability effect, we found that a counterbalancing manipulation might interfere with the data of Experiment 2. Further, since the third group of Experiment 2 contained the context switch and the outcome's removal at the same time, it is unclear if its results should be due to a context shift or/and a change in number of the outcomes. Thus, Experiment 3 developed the counterbalancing manipulations and examined whether the outcome predictability effect is context-dependent by using a complex design. The first group of Experiment 3 aimed to replicate the effect observed in Experiment 1. The second group investigated whether the effect is based on an influence of context by conducting a context switch between two training phases. If the effect relies on a change in the outcome's associability rather than an impact of context, we would expect that the prior predictable outcome is learned more rapidly about than the prior less predictable outcomes during the second phase in Group 2. The third group aimed to examine whether a change in number of the outcomes impairs the effect of outcome predictability. If so, it would be expected that learning about the prior predictable outcome does not differ from the prior less predictable outcome in Group 3. Group 4 executed both the context switch and the outcome removal. Thus, if the effect of outcome predictability is context-dependent, we should not observe any difference in learning about the prior predictable and the prior less predictable outcome in Group 4.

As Study I revealed that manipulating outcome predictability with the first design cannot reliably establish an effect on subsequent learning about this outcome, we considered the possibility that the demonstration of the effect depends on how outcome predictability is specifically manipulated. Thus, Study II consisting of three experiments approached two other manipulations of the predictability.

For Design 2, a partial reinforcement procedure was applied to reduce the outcome's predictability in the initial training. In particular, outcome o2 appeared half of the time when cue C was presented in Phase 1, and therefore was regarded as partly predictable, while o1 was fully predictable by cue A. In Phase 2, each outcome was consistently predicted by novel cues. According to a computational simulation based on the Rescorlar-Wagner model, it was expected that both outcomes should be less likely to be associated with context during the initial training phase. Further, if outcome predictability can shape the associability of the outcome which is consistent with the learned predictiveness effect for cues, we would expect learning about the cue associated with the prior predictable outcome proceeds more rapidly than the cue associated with the prior less predictable outcome in the second training phase.

For Design 3, outcome o2 was less predictable because it preceded by cue C half of the time and presented *without* any cue the other half of the time in the first training phase, while o1 was fully predictable by cue A. In the second phase, each outcome was consistently predicted by a novel cue. Based on the simulation, we expect a stronger contextual association formed with the less predictable outcome (o2) than with the predictable outcome (o1) after Phase 1 training. Moreover, such a strong context-o2 association should then impair the formation of associations between novel cues and o2 in Phase 2.

Experiment 5 consisted of two groups in which Design 2 and 3 were conducted respectively. The purpose of this experiment is to investigate whether the new manipulations of outcome predictability could exert an effect on subsequent learning about this outcome. Further, by comparing the data between two groups, we are able to detect the possible mechanisms underlying the effect. More specifically, if the outcome predictability effect is mediated by a change in the outcome's associability, rather than a

blocking effect caused by context, we would expect more rapid learning about the prior predictable outcome than the prior less predictable outcome during Phase 2 training observed in Group 1. On the contrary, if the effect relies on an influence of context blocking rather than a change to the outcome's associability, the effect should be only observed in Group 2, but not in Group 1.

The data of the second Group in Experiment 5 suggested a possibility that the strong contextual association formed in Phase 1 might not be able to successfully transfer to Phase 2 learning. Thus, Experiment 6 executed Design 3 with an additional manipulation (i.e. removing the break between the phases) to encourage the transfer of contextual associations from Phase 1 to Phase 2 learning. Further, if a strong contextual association formed with the less predictable outcome retards subsequent learning about this outcome, we would expect that the prior less predictable outcome is less readily learned about than the prior predictable outcome in Experiment 6.

Moreover, as the first group in Experiment 5 with Design 2 demonstrated better learning about the prior predictable than the prior less predictable outcome, Experiment 7 aimed to replicate the effect and, further, examine whether the effect relies on a higher cognitive control. Considering that the outcome predictability effect on subsequent learning reported by Griffiths et al. (2015) was assessed via a likelihood rating in the subsequent test phase with a causal learning task, it is possible that their effect is to some degree based on inferential reasoning. Furthermore, it has been shown that the learned predictiveness effect is sensitive to instructed top-down control (Mitchell et al., 2012; Shone, Harris & Livesey, 2015; Don & Livesey, 2015). Thus, an instructional manipulation on learned predictability was applied to both groups in Experiment 7. For Group 1, an instruction about the outcome's predictability was presented prior to the second training phase that was consistent with the actual manipulation. In contrast, Group

2 received another instruction prior to Phase 2 which reversed the actual manipulation. We expected that Group 1 would demonstrate better learning about the prior predictable than the prior less outcome in Phase 2. Further, if the effect is governed by a higher cognitive control, we would expect a difference in Phase 2 learning between the two groups.

Chapter 2: Empirical Study I

The four experiments described in this chapter aimed to determine if the manipulation of outcome predictability can bias subsequent learning about the outcome in a goal-tracking task to human subjects. For all the experiments, the three outcomes were preceded by the different cues and differed in their predictability in the initial training phase. In particular, outcome o1 was consistently predicted by cue A while the other two outcomes o2 and o3 were each partially signaled by two cues C and D, such that both C and D were followed by o2 half of the time and o3 on the other half. In this way, o2 and o3 were only partially predictable. If the effect of the learned predictability is comparable to the learned predictiveness effect for cues, we would expect that the prior predictable outcome would be learned more rapidly about than the prior less predictable outcomes, when each of them was fully predictable by novel cues. Furthermore, our paradigm enabled us to investigate in particular the influence of context on the learned predictability effect, as the experimental layout (i.e., learning context) can be easily manipulated (Experiment 2 and 3).

2.1 Experiment 1

The present experiment was expected to demonstrate an effect of the leaned predictability of outcomes on subsequent learning. In the initial training phase, outcome o1 was consistently predictable and the other outcome o2 and o3 were only partly predictable (see Table 2.1.1). Cue B predicted the absence of any outcome to ensure that participants did not simply shift their attention to the caves at the onset of *any* discrete cue, without learning about the particular relationships between cues and outcomes. During the second phase, each outcome was fully predictable via one of three novel cues (W, X and Y). If the different predictability of outcomes perceived in the first learning

phase transferred to the second phase, learning about o1's new relationship on the one hand should differ from learning about o2 and o3 on the other hand. The Z- trial had the same function as B- trial in the first Phase.

Table 2.1.1
Design of Experiment

Phase 1	Phase 2
A → o1, A → o1, B → Ø, B → Ø	W → o1, X → o2
C → o2, C → o3, D → o2, D → o3	Y → o3, Z → Ø

Note. Letters A-Z denote visual and auditory cues that were always followed by one of three outcomes (i.e., the eyes of one of the animals in the experimental task): o1 was the fully predictable outcome, o2 and o3 were less predictable as they were equally likely to appear after cues C and D. Cues B and Z were followed by the absence of any outcome, denoted as Ø.

2.1.1 Methods

Participants. Twenty-four undergraduate students from Philipps-Universität Marburg, Germany participated in this experiment (M_{age}=23.38 years, age range 19-48 years) in exchange for course credit or payment (EUR € 7). They were allocated equally to the counterbalancing conditions as they arrived in the experimental room. Exclusion criteria of the study were (a) missing or invalid data for more than 10% of the total measurements across all training trails and (b) participants did not attend to one of three outcome areas at all during the corresponding cues. In the present experiment, data from two additional participants were excluded from analysis due to ignoring the feeding task.

Apparatus and Stimuli. All written instructions and visual stimuli were presented on a 23‘‘computer screen with a frame rate of 60 Hz. Two stereo loud speakers were placed on the left and right side of the screen and used to present auditory stimuli. Participants interacted with the computer via mouse and keyboard. The experiment was written in Matlab by using of Psychophysics Toolbox extensions (Kleiner, Brainard & Pelli, 2007). A Tobii Tx300 Eye Tracker measured the eye fixation during the experiment

with a frame rate of 300 Hz for both eyes. We used the Matlab language binding of Tobii Analytics SDK to operate the eye tracker.

Presentation of stimuli on screen during the learning tasks is illustrated in Figure 1.1. The main components were a river on the left side of the screen and three caves on the right side. The river changing from blue to one of four different colors (red, yellow, green and white) served as visual cues. Auditory cues were a white noise, a pure tone, a clicking ringtone, and pulsating "wah-wah" sound. Within one learning phase the cues were from the same modality. The order of the two modalities was counterbalanced. Three symbols (“oo”, “xx” and “++”) were displayed on the entrance of the different caves as outcomes. The positions of the predictable outcomes were counterbalanced, resulting in three experimental conditions (see Table 2.1.2).

Table 2.1.2
Cave conditions of Experiment 1

	condition 1	condition 2	condition 3
upper cave	**o1**	o2	o2
middle cave	o2	o3	**o1**
lower cave	o3	**o1**	o3

Note. Each outcome was presented in one of three caves (upper cave, middle cave and lower cave). Positions of predictable outcome o1 were counterbalanced across participants.

The experimental task also required additional visual and auditory stimuli. Blue fish were presented randomly in different positions in the river and turned white by clicking on them. When an animal was successfully released from its cave, cartoon images of one of three animals (a pig, dog, or rabbit) were shown in animation running from the cave to the river, while the sound of running footsteps was played. If the participant failed to release the animal, the image of a fence (pictured in Figure 1.1) appeared above the cave and fell down on the cave, accompanied by the sound of a slamming door.

Procedure. Participants were informed that the experiment was going to examine their eye movements during the task. They were asked to sit in front of the computer and put their head on the chin rest positioned 65 cm from the eye tracker with a maximum 35° gaze angle to any point on the screen to ensure the optimal measurement position. At the start of the experiment, calibration and validation were done using a series of nine dots arranged in a square grid. After successful calibration of the eye tracker, participants were told to read the following instructions (in German) on the computer screen:

In the following experiment you are going to play a computer game.

In this game, you are standing on a bridge over a stream on the left side of the screen and catching fish by clicking on them with the LEFT mouse button.

For each fish you catch, you will earn 2 points. For each fish you miss, you will lose 1 point.

At the same time, you also need to feed the fish to a pig, a dog, or a rabbit that each live in one of three caves on the right side of the screen. Most of the time the animals are sleeping, but from time to time they will wake up hungry. Then an animal will appear in the cave's entrance and you will see its eyes: either two circles, or two small crosses, or two "x".

Whenever the eyes appear, you must keep the cave open by clicking with the LEFT MOUSE BUTTON ON THE EYES in cave's entrance. Then, the pig, the dog, or the rabbit can run over from its own cave and eat the fish, and you will earn 100 points. However, if you miss the animal and don't click on the eyes, the cave will be closed. A fence will fall down and you will lose 100 points.

Remember that you have to accomplish both tasks – catching the fish and feeding the animals – at the same time.

In between the games there will be breaks so that you can take a break and relax your eyes and hands for a moment. Just follow the instructions on the screen when you are ready to resume playing.

If you have any questions, please ask them now. Otherwise, you can press the space bar to start the game.

The experiment consisted of 132 trials. The Phase 1 trials were arranged into 12 blocks of eight trials (A→o1, A→o1, B→ Ø, B→ Ø, C→o2, C→o3, D→o2, D→o3). The trial order was randomized within every three blocks and no more than three trials in a row had the same outcome. The eye symbols and the animal types of outcomes were randomized across participants. Phase 2 contained 36 trials grouped into nine blocks, with the same outcomes as in Phase 1. However, this time each outcome was consistently preceded by a novel cue (W→o1, X→o2, Y→o3, Z→ Ø).

A drift check controlled the validity of the calibration after each training phase. A white dot was progressively presented on the gray screen randomly in nine positions (upper left, upper middle, upper right, middle left, center, middle right, below left, below middle, below right), participants were required to press the space bar while looking at the dot. After the drift check, participants could take a break before recommencing. They were instructed to press the space bar to continue the game.

Each learning trial began with an ITI that varied between 10 and 15 seconds. Participants experienced the events within each phase in a continuous fashion such that the start and end of each trial was not explicitly signaled. Cues were presented for 3.66 to 4.66 seconds, and the outcome appeared during the final second of the cue presentation. If participants clicked on the outcome while it was being presented (the eyes appearing in the cave), the corresponding animal would run from the cave to the basket with fish on the lower left of the screen in 3.33 seconds. If participants missed the outcome, a fence

would descend over the cave's entrance and remain there for 2.83 seconds. The game score displayed was constantly updated above the basket of fish throughout the experiment.

During the entire experiment, two fish were always present simultaneously in randomly chosen positions for a maximum of 1.5 seconds. There were 25 possible positions for the fish in total. If participants clicked on a fish during its presentation, it would turn white and remain on the screen for 0.83 second. Otherwise, it would disappear and a new blue fish would appear in a new position.

Data analysis. Single measurements were excluded based on the validity code provided by the Tobii eye tracker. We considered only the measurements with validity code 0, which means that both eyes were tracked and identified, as valid. The measurements for the left and right eyes were averaged to obtain the final gaze position. Participants with more than 10% of missing or invalid measurements were excluded completely from the analyses (see above). We defined three goal areas as areas of interest (AoI): each goal area was an invisible rectangle around one of the three caves measuring 384 pixels long and 302 pixels wide, centered on the animal eyes' position (the outcome), located in that cave. We then calculated the proportion of valid measurements during a specific time window for which the eye gaze fell within a certain goal area (relative dwell time). Consistent with magazine training experiments, we compared this response rate during the presentation of a cue with the response rate immediately before its presentation which represented the baseline response rate since the cue still did not appear (pre-cue period). The final dependent variable used in our statistical analyses was therefore the proportion of measurements participants spent looking at the correct goal area during the cue presentation but before outcome onset (cue interval) minus the relative dwell time at the same goal area during an equally long interval before cue onset (pre-cue interval) to

indicate the anticipatory responses. This measurement is henceforth referred as "dwell time". In this manner, the participants' dwell time represents successful learning about the relationship between a particular cue and outcome.

In addition, we also measured the position of mouse cursor with a rate of 6 Hz during the tasks. The dependent variable with mouse data was calculated as the proportion of time the cursor was inside the goal area (AoI) during the cue interval minus the percentage of time during the pre-cue interval. These mouse movements also reflected the anticipation of the outcome and therefore provide additional evidence how well participants learn about the relationship between a certain cue and an outcome.

2.1.2 Results

Gaze data. *Phase 1.* Trials were grouped according to their outcome, resulting in three trial types (o1-trial, o2-trial, o3-trial). Dwell time in each trial type was averaged across the two trials within each block. Figure 2.1.1 (left) shows the mean proportion of dwell time that participants spent looking at the correct outcome area per block across the 12 blocks of Phase 1. Dwell time towards the o1 area in o1 trials increased across blocks, and reached the peak of 0.33 on Block 8, while the correct response to the cues associated with o2 and o3 remained relatively low.

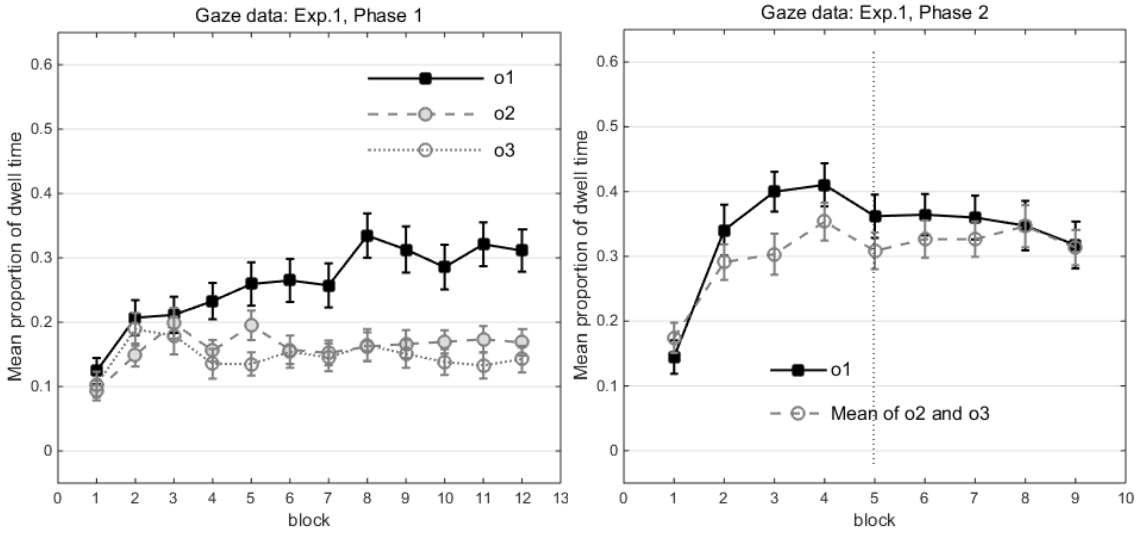


Figure 2.1.1. Gaze data of Experiment 1. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of dwell time across nine blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

We analyzed data using a 3 (outcome: o1, o2, or o3) ×3 (cave condition: o1 in top, bottom, or middle cave) × 12 (block: 1-12) ANOVA in which outcome and block were within-subjects factors. This analysis revealed a main effect of outcome, $F(2,42)=7.74$, $p<.01$, $\eta^2=.269$, with significant contrasts regarding the comparison between o1 and both o2 and o3 trials, but not o2 versus o3 ($F_{o1vs.o2}=11.03$, $p<.01$, $F_{o1vs.o3}=8.92$, $p<.01$, $F_{o2vs.o3}<1$), indicating that participants gazed longer at the outcome o1 cave during cue A presentation than they did to the outcome o2 or o3 caves during presentation of cues C and D. We also noted a significant main effect of block $F(11,231)=3.39$, $p<.01$, $\eta^2=.139$, showing that the accuracy of the anticipatory gaze increased across blocks. More importantly, a significant outcome × block interaction became apparent, $F(22,462)=2.31$, $p<.05$, $\eta^2=.099$, linear contrast $F_{o1vs.o2}=13.72$, $p<.01$, $F_{o1vs.o3}=16.9$, $p<.001$, reflecting that the increase in dwell time proceeded differently according to the outcome's predictability. Additionally, a significant outcome × cave condition interaction, $F(4,42)=4.3$, $p<.01$, $\eta^2=.291$, indicated that participants looked at the middle cave generally longer than at the other two. None of the other main effects and interactions were significant (largest $F=1.26$, corresponding $p=.264$).

Phase 2. Figure 2.1.1 (right) shows the Phase 2 dwell time. It was averaged based on the predictability of each outcome during Phase 1. The anticipatory gaze towards the cave of the previously predictable outcome o1 increased more rapidly across the first four blocks and remained higher than the averaged dwell time towards the caves of the previously less predictable outcomes o2 and o3. The reactions of the both trial types reached the peak on Block 4, indicating that the learning process in Phase 2 was

completed in the first half phase. Hence, we analyzed the data of the first five blocks of Phase 2.

A 2 (outcome predictability: previously predictable or less predictable) × 3 (cave condition: o1 in top, bottom or middle cave) × 5 (block: 1-5) ANOVA with repeated measures on outcome predictability and block revealed a significant main effect of the previous predictability of outcome, $F(1,21)=5.83$, $p<.05$, $\eta^2=.217$, showing that the dwell time towards the o1 cave was generally longer than dwell times towards o2 and o3 cave. The main effect of block was significant $F(4,84)=12.83$, $p<.001$, $\eta^2=.379$. The outcome predictability × block interaction was not significant $F(4,84)=1.81$, $p=.149$. None of the other main effects and interactions were significant (largest $F=1.17$, corresponding $p=.329$).

As expected from the learned predictability effect, participants exhibited overall longer dwell times towards the cave of previously predictable outcome o1 during the corresponding cue (W) than toward the caves of the previously less predictable outcomes o2 and o3 during their cues (X and Y). However, one would also expect this result if participants had developed a general preference for the o1 cave, independently of learning about the novel relationship in Phase 2. To exclude this possibility, we compared the dwell time toward three caves during cue Z in Phase 2 which signaled the absence of any outcome. If a general preference was the reason for the different dwell times in Phase 2, we would anticipate a difference in dwell time between o1 and o2/o3 during Z. A 3 (outcome: o1, o2, o3) × 3 (cave condition: o1 in top, bottom or middle cave) × 9 (block) ANOVA analysis was conducted. Neither the main effect of outcome, $F(2,42)<1$, $p=.449$, nor its interaction with block, $F(16,236,)<1$, $p=.443$, was significant, showing no general bias towards any outcome. We also observed a significant effect of block, $F(8,168)=9.61$, $p<.001$, $\eta^2=.314$. In addition, an outcome × cave condition interaction was significant

$F(4,42)=3.56$, $p<.05$, $\eta^2=.253$, reflecting longer dwell time towards the middle cave. No further main effects or interactions were significant (largest $F=1.11$, corresponding $p=.349$).

To further discover whether participants had other systematic biases towards a particular outcome, we analyzed the dwell time towards caves o1, o2, and o3 during the cue which did *not* precede them. In particular, we wondered whether participants would prefer caves o3 and o2 to the o1cave during cues X and Y while learning that the latter predicted o2 and o3, respectively. Figure 2.1.2 shows how long participants gazed at the o1cave during cue X and Y, gazed at the o3 cave during cue X, and at the o2 cave during Y, respectively, across all the Phase 2 blocks. A 2 (cue: X vs. Y) × 2 (previous predictability: o1 vs. o2/o3) × 3 (cave condition: o1 in top, bottom or middle cave) × 9 (block) ANOVA was conducted in which cue, previous predictability of outcome, and block were within-subjects factors. The factor previous predictability demonstrated a non-significant trend that participants spent longer looking at the area of the previously predictable outcome than previously less predictable outcome during the cue that was not associated with them, $F(1,21)=4.08$, $p=.056$, $\eta^2=.163$. The interaction between previous predictability and block was not significant, $F(8,168)=.588$, $p=.688$. A significant main effect of block, $F(8,168)=3.85$, $p<.01$, $\eta^2=.155$, indicated that dwell time decreased across blocks during the irrelevant cues. In addition, we observed a significant previous predictability × cave condition interaction $F(2,21)=23.92$, $p<.001$, $\eta^2=.695$, and a significant cue × previous predictability × cave condition interaction $F(2,21)=4.55$, $p<.05$, $\eta^2=.302$. Note that these significant interactions are all consistent with a general gaze bias towards the middle cave. No further main effect or interaction was significant (largest $F=2.77$, corresponding $p=.111$).

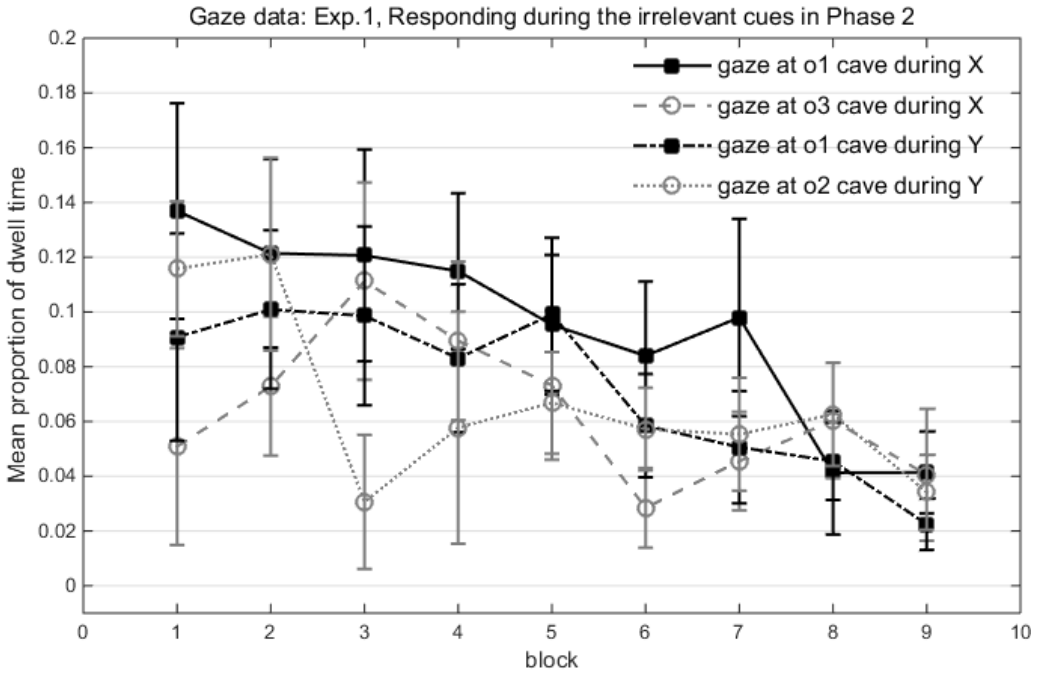


Figure 2.1.2. Additional analysis of Gaze data for Experiment 1: Mean dwell time towards o1, o2 and o3 caves during the cues that had *not* signaled them across nine blocks in Phase 2 (i.e., gaze at the o1 cave during cues X and Y, gaze at the o3 cave during X and at the o2 cave during Y).

Mouse data. Mouse movements during the tasks were captured and used as an additional indicator of learning as participants placed the cursor towards the goal area in anticipation of the outcome during the presentation of the corresponding cue.

Phase 1. It was similar to the analyses of gaze data that three trial types were calculated based on the outcome (o1-trial, o2-trial, o3-trial). Figure 2.1.3 (left) shows the mean proportion of time that participants positioned the cursor at the correct outcome area per block across the 12 blocks of Phase 1. The time towards the o1 area during the corresponding cue increased across blocks, and reached the peak of 0.28 on the last block, while the correct response to the cues associated with o2 and o3 remained relatively low.

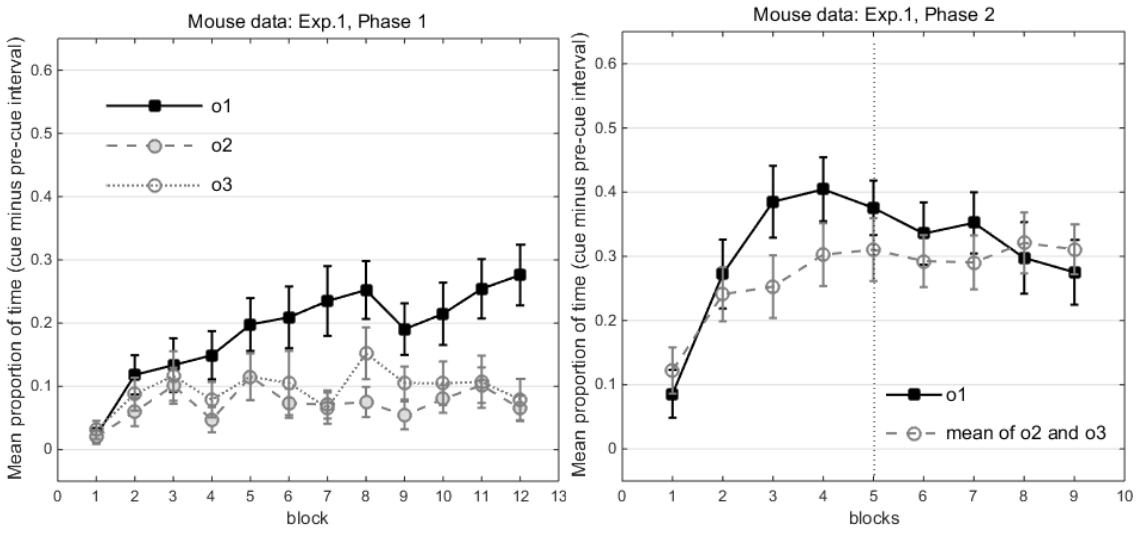


Figure 2.1.3. Mouse data of Experiment 1. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of time across nine blocks in Phase 2, wherein mouse time was averaged based on the predictability of each trial's outcome during Phase 1.

We conducted a 3 (outcome: o1, o2, or o3) ×3 (cave condition: o1 in top, bottom, or middle cave) × 12 (block: 1-12) ANOVA in which outcome and block were within-subjects factors. The main effect of outcome was significant, $F(2,42)=9.41$, $p<.001$, $\eta^2=.309$, and it yielded a significant contrasts regarding the comparison between o1 and both o2 and o3 trials, ($F_{o1vs.o2}=16.38$, $p<.01$, $F_{o1vs.o3}=8.02$, $p=.01$, $F_{o2vs.o3}<1$). This indicated that participants positioned the cursor longer at the outcome o1 cave during cue A than they did to the outcome o2 or o3 caves during presentation of cues C and D. A significant main effect of block $F(11,231)=5.51$, $p<.001$, $\eta^2=.208$, reflexed that the accuracy of the responding based on mouse movements increased across blocks. More importantly, the outcome × block interaction was significant, $F(22,462)=2.22$, $p<.05$, $\eta^2=.096$, linear contrast $F_{o1vs.o2}=17.28$, $p<.001$, $F_{o1vs.o3}=10.32$, $p<.01$, reflecting that the reaction of different trial types increased differently. None of the other main effects and interactions were significant (largest $F=2.45$, corresponding $p=.061$).

Phase 2. Figure 2.1.3 (right) shows the mouse data of Phase 2. It was averaged based on the predictability of each outcome during Phase 1. The tendency of mouse movements was similar to the gaze data. Responding during o1 trials increased rapidly and reached the peak of 0.41 on Block 4, whereas the anticipatory mouse movements towards the cave of the previously less predictable outcomes increased slowly and reached the peak of 0.32 on Block 8. In line with the analyses of gaze data, we examined the mouse data from Block 1 to Block 5.

We used a 2 (outcome predictability: previously predictable or less predictable) × 3 (cave condition: o1 in top, bottom or middle cave) × 5 (block: 1-5) ANOVA with repeated measures on predictability and block. The previous predictability showed a non-significant trend, $F(1,21)=4.16$, $p=.055$, $\eta^2=.165$, that participants placed cursor longer at the o1 cave than at the o2 and the o3 cave during the corresponding cues. The main effect of block was significant $F(4,84)=11.53$, $p<.001$, $\eta^2=.354$. The outcome predictability × block interaction did not reach the significance, $F(4,84)=1.84$, $p=.135$. None of the other main effects and interactions were significant (largest $F=1.46$, corresponding $p=.256$).

2.1.3 Discussion

Participants learned the cue-outcome relationships in the first training phase successfully, where outcomes differed in their predictability. In the second phase, even though all outcomes were completely predictable, participants spent longer time to look at the o1 area than at the o2/o3 area during the corresponding cue. This result suggested that the previously predictable outcome associated more readily with a novel cue during learning, as compared to the previously less predictable outcomes (o2 and o3). In addition, the mouse movements in Phase 1 demonstrated the same results as the gaze data that participants showed stronger responses in anticipation of the predictable outcome than the less predictable outcomes. However, the difference in Phase 2 learning between two

outcome types did not reach significance with mouse data. Some researchers pointed out that the mechanism responsible for the selection of motor responses is not necessary for control over the focus of visual attention (Pashler, 1991; Reimer et al., 2015). Thus, it is possible that gaze allocation and the mouse movements in the present paradigm are based on some different cognitive processing and the impact of the outcome predictability on subsequent learning might more strongly manifest in gaze allocation than in the motor responses. Considering the task used in the present experiment that participants were explicitly asked to click on the eye symbols to gain points, it is possible that shifting cursor from the fishing area to the outcome areas requires more cognitive control than gaze movements.

The finding based on gaze data represents an effect of outcome predictability on later learning. In particular, an outcome with higher predictability in the past can be more rapidly associated to novel cues in subsequent learning as compared to the less predictable outcomes. This effect seems to be consistent with the findings of Griffiths et al. (2015). If our finding relied on similar mechanisms to those proposed by Mackintosh and thought to underlie the learned predictiveness effect, where changes in a cue's associability depend on its relevance or irrelevance to an outcome, then an outcome's predictability should be encoded as a particular feature of that outcome and its processing, and subsequent learning would be altered according to this feature.

Nevertheless, given the fact that the outcome's previous predictability revealed a significant main effect across Phase 2 training, but the previous predictability × block interaction was not significant, it is arguable whether the discrepancy in dwell time between o1 and o2/o3 in Phase 2 was based on a general bias toward the previously predictable outcome, rather than a difference in the rate of learning about previously predictable and less predictable outcomes. Importantly, none of our additional analyses

were consistent with this explanation in terms of a general looking bias. We found no evidence of a general bias towards any outcome in Phase 2, for instance the participants did not spend longer looking at o1 than o2 or o3 during cue Z. Thus, it seems very likely that the difference in dwell time in Phase 2 reflects a difference in learning about the previously predictable outcome compared to the previously less predictable outcomes.

It is noteworthy that the cave condition (i.e. the counterbalancing of o1, o2, and o3 to the top, middle, and bottom caves) interacted significantly with other factors. The results consistently suggest that participants generally favored the outcome in the middle cave. Some participants also reported that they looked at the middle cave and placed the cursor above it once the cue appeared, so that they could easily move the cursor from the middle to one of the other two caves during the outcome's presentation. Importantly, since the allocation of outcome to cave position was fully counterbalanced, this preference for the middle cave cannot explain our key finding. In fact, the predicable outcome o1 occupied the middle cave for only a third of participants and thus if anything, this preference would have worked against observing the effect. Thus, differences in preferential looking behavior reflect faster learning about o1 than o2/o3 *despite* a bias for the middle cave. Nevertheless, the general preference for the middle cave suggests that the paradigm could be improved in future experiments.

In the first training phase, two less predictable outcomes (o2 and o3) were associated with the same cues. In this context, we have to consider two possible consequences. One possibility is that such "overlapping" relationships might form an inhibitory association between o2 and o3. If that is the case, we should expect an improved performance on the cues associated with those outcomes in Phase 2, since their associated outcomes would be less likely to be confused with one another. However, the present experiment revealed the opposite result – learning about o2 and o3 in Phase 2

proceeded more slowly. Hence, it seems unlikely that o2 and o3 inhibit each other in Phase 2 learning.

Another possible consequence of o2 and o3 being associated with the same cues is acquired equivalence (Hall, Ray, & Bonardi, 1993). Hall and his colleagues reported that when human subjects were required to make the same response to stimuli that had shared a common consequence during a previous training phase, their performance was enhanced, as compared to the condition in which different responses were required to these stimuli (Hall, Mitchell, Graham & Lavis, 2003). Those results indicated that initially distinct stimuli that have shared a common antecedent will eventually be treated as equivalent. Such an effect is called "acquired equivalence". Applied to the present experiment, because o2 and o3 were functionally identical in Phase 1, they might become equivalent during training and, hence, less discriminable in Phase 2. If that is the case, subjects should exhibit a longer gaze in anticipation of o2 than o1 during cue Y, and/or a longer gaze in anticipation of o3 than o1 during cue X in Phase 2, since o2 and o3 would be more easily confused with one another. However, we did not observe such a tendency in an additional analysis. It thus seems less likely that acquired equivalence played a role in the present experiment.

Another alternative explanation for the present result can be attributed to a blocking effect caused by associations between the context and outcomes rather than a change in the processing of the outcome itself. In the present experiment, the presented layout contained many elements that could also be associated with each outcome. These incidental elements can be regarded as the context having the potential to compete for learning. Because o1 was consistently predicted by a cue in Phase 1, the cue is a much stronger predictor of o1 and the association between the context and o1 should therefore be relatively weak. In contrast, o2 and o3 were less predictable in Phase 1 based on the

cues, and thus the cues that preceded those outcomes are only marginally more predictive than the context; they provide some information about the imminent presentation of an outcome, but are far less informative than the cue paired with o1. Therefore, participants may establish a stronger association between the context and each of those two less predictable outcomes. These context associations could transfer to Phase 2 learning and preferentially block learning about the novel relationships with o2 or o3, since the context is more strongly associated with o2 and o3 than with o1. As a result, learning about the previously less predictable outcomes in Phase 2 may proceed more slowly compared to the previously predictable outcome. This possibility suggests that the outcome predictability effect is highly context-specific and thus motivated the design of Experiment 2.

2.2 Experiment 2

This experiment aimed to replicate the outcome predictability effect (Group 1) and to further investigate the context blocking account of the findings in Experiment 1 (Group 2 and 3). For Group 2 and 3, two different layouts ("summer" versus "winter") were used for the two training phases. In this way, learning in Phase 2 would not be influenced by any associations acquired through the context in Phase 1. Furthermore, having observed a strong bias towards the outcome placed in the middle cave in Experiment 1, we conducted a third group with a manipulation to reduce the interference of the middle cave advantage on learning in Phase 2. For this group, three outcomes were presented in the first training phase, in which o1 was fully predicted by cue A, and both cue C and D were followed by o2 half of the time and o3 half of the time. Moreover, we placed the less predictable outcome o3 in the middle cave throughout the first training phase for all participants, and counterbalanced the positions of o1 and o2 (top vs. bottom

cave). In the second phase, we removed o3 (animal eyes) and the middle cave (see Fig. 5) and only presented the outcome o1 and o2, which were both fully predictable by the novel cue. Another advantage of using only one of the less predictable outcomes in Phase 2 is that any effect of acquired equivalence between them would not play a role in this group.

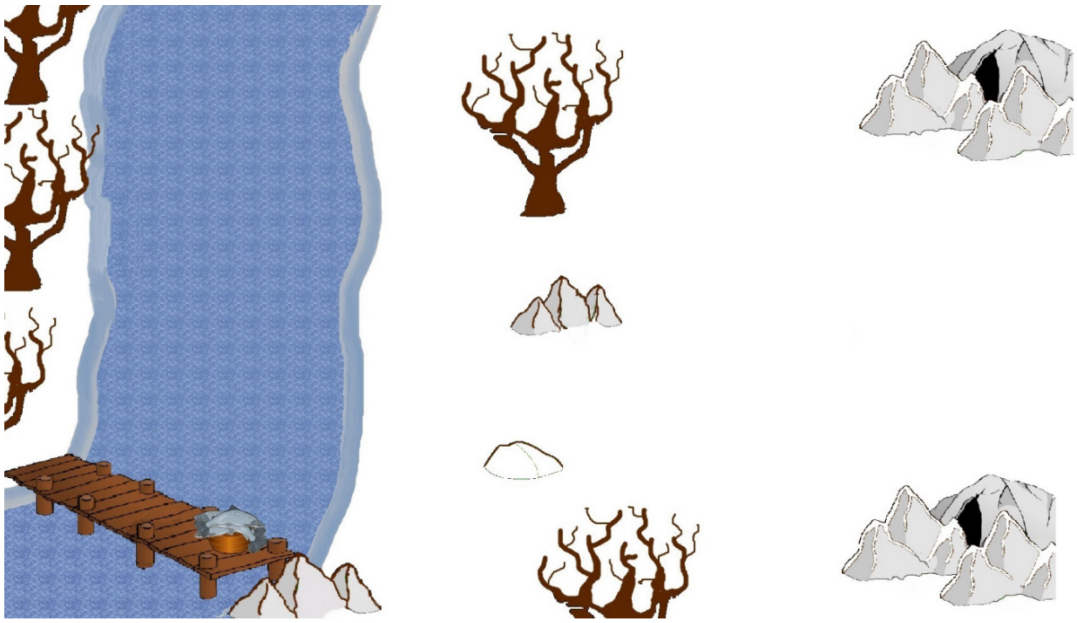


Figure 2.2.1. Novel context "winter" used in Experiment 2. Note that contexts differed between these two phases ("summer" vs. "winter") for Group 2 and 3. For Group 3, there were three caves present in Phase 1, but just two caves in Phase 2.

Participants were assigned the same tasks during the first phase of training as in Experiment 1. However, we lowered the contrast between the eye symbols and cave entrance so that the outcome became less salient. In this way, participants were forced to focus on the cave's entrance to actually perceive the outcome and thereby also reduce the advantage of the "middle cave strategy" in Phase 1.

2.2.1 Methods

Participants. Fifty-six undergraduate students from the Philipps-Universität Marburg, Germany (40 females, 16 males; M_{age}=22.29 years, age range 18-34 years; 12 participants for Group 1, 12 participants for Group 2, 32 participants for Group 3) participated in this experiment and received course credit or payment (EUR € 7). Data

from ten additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used in Experiment 2 were very similar to those in Experiment 1 with a few exceptions. First, besides the "summer" layout" used in Experiment 1, a "winter" layout was displayed (see Fig. 5). Half participants in Group 1 received the summer context in the experiment and another half received the winter context. In Group 2 and 3, the different contexts were presented in two training phases for each participant. Second, only two caves were presented (top and bottom caves) for Group 3 during Phase 2, and the middle cave was omitted. Third, the eye symbols used as outcomes were less salient than those in Experiment 1 because they were darker.

For Group 1 and 2, the cave condition was the same as in Experiment 1 so that three outcome's positions were counterbalanced. Moreover, the sequence of outcomes' presentation during the first two trials in Phase 2 was manipulated. Since o2 and o3 are both less predictable and functionally identical, we only counterbalanced the sequence of o1 and o2 in the first two Phase 2 trials (i.e. either W-o1 for Trial 1 and X-o2 for Trial 2, or X-o2 for Trial 1 and W-o1 for Trial 2), so that the prior predictable and the prior less predictable outcome could be equally frequently presented during the first two trials. In Group 3, outcome o3 was always located in the middle cave during Phase 1; it was omitted in Phase 2. Outcomes o1 and o2 were placed in other two caves, and their positions were counterbalanced. The sequence of o1 and o2 in the first two Phase 2 trials was also counterbalanced (i.e. either X-o1 for Trial 1 and Y-o2 for Trial 2, or Y-o2 for Trial 1 and X-o1 for Trial 2). Lastly, the order of two contexts and two modalities of cues in every group was counterbalanced as well.

Design and Procedure. Table 2.2 shows the design of Experiment 2. Group 1 and 2 maintain the same design as Experiment 1. For Group 3, the initial training phase was

identical to Experiment 1. However, only o1 and o2 were presented during the second phase, and each was consistently predicted by a novel cue.

Table 2.2

Design of Experiment 2

	Phase 1	Phase 2
Group 1	***Cont. 1***: A → o1, A → o1, B → Ø, B → Ø C → o2, C → o3, D → o2, D → o3	***Cont. 1***: W → o1, X → o2 Y → o3, Z → Ø
Group 2	***Cont. 1***: A → o1, A → o1, B → Ø, B → Ø C → o2, C → o3, D → o2, D → o3	***Cont. 2***: W → o1, X → o2 Y → o3, Z → Ø
Group 3	***Cont. 1***: A → o1, A → o1, B → Ø, B → Ø C → o2, C → o3, D → o2, D → o3	***Cont. 2***: X → o1, Y → o2 Z → Ø

Note. Letters A-Z denote visual and auditory cues that were always followed by one outcome (i.e., the eyes of one of the animals in the experimental task): o1 was the fully predictable outcome, o2 and o3 were less predictable as they were equally likely to appear after cues C and D. Cues B and Z were followed by the absence of any outcome, denoted as Ø. For Group 2 and 3, two different layout as context were presented during two phases, denoted as Cont..

In the first two groups, every participant completed 132 trials with 96 trials grouped into 12 blocks in Phase 1 and 36 trials grouped into nine blocks in Phase 2. The third group consisted of 123 trials. The Phase 1 trials were the same as in Phase 1 of Experiment 1. Phase 2 contained 27 trials grouped into nine blocks (X→o1, Y→o2, Z→ Ø). The trial order was randomized.

Data analyses. we applied the Bayesian method to ANOVA designs for the non-significant results to state evidence for an invariance (Rouder, Morey, Speckman, & Province, 2012; also see Wetzels, Grasman, & Wagenmakers, 2012). A Bayes factor is calculated by directly comparing two models of special interest, in which one includes additional predictors (i.e. those of interest) that are not included in the other, to test for the effect of these predictors. All Bayes factor ANOVA analyses were computed with an uninformative default prior by using the software platform JASP. According to Jeffreys (1961), a BF between one and three provides anecdotal (or "worth no more than a bare

mention") in favor of the first model which in our analyses is always the null hypothesis without the predictor of interest. Moreover, a BF between three and ten provides substantial evidence, between 10 and 30 provides strong evidence, between 30 and 100 very strong evidence, and above 100 decisive evidence in favor of the null hypothesis.

2.2.2 Results

Gaze data. The anticipatory gaze behavior of three groups was illustrated in Figure 2.2.2 to 2.2.4 respectively. In following, we would present the data of Phase 1 and Phase 2 training separately.

Phase 1. Figure 2.2.2 (left) demonstrates the averaged proportion of time participants spent looking at the cave of the correct outcome per block across the 12 blocks of Phase 1 in Group 1. As we expected, dwell time towards the o1 area increased rapidly across blocks and maintained a higher level than dwell time towards o2 and o3 area. Figure 2.2.3 (left) shows the Phase 1 learning in Group 2 that also reflects a higher level of dwell time during the o1 trials than during o2 and o3 trials. Figure 2.2.4 (left) illustrates learning across all 12 blocks during Phase 1 in Group 3. As we expected, dwell time towards the o1 area increased rapidly across blocks while dwell time towards o2 area remained relatively low. Notably, responses to the cave associated with o3 were stable across all blocks and were comparable to the high level that responses to the cave associated with o1 reached by the end of the phase. Given the fact that o3 was always presented in the middle cave, such a response indicates that participants did indeed tend to favor the middle cave, and that the dwell time towards o3 area did not merely reflect specific learning about o3.

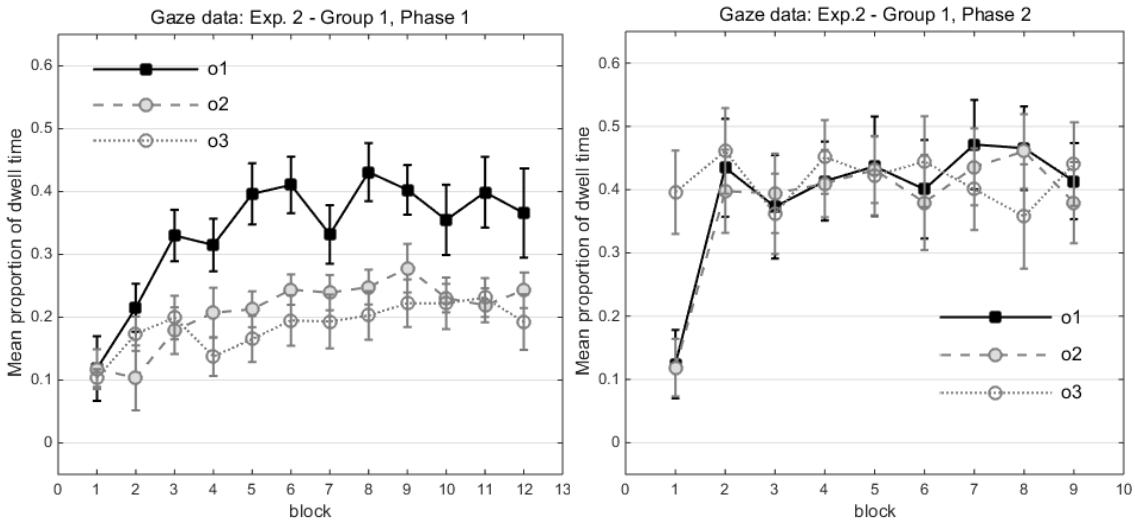


Figure 2.2.2. Gaze data of Group 1 in Experiment 2. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1 and the right panel shows mean proportion of dwell time across nine blocks in Phase 2.

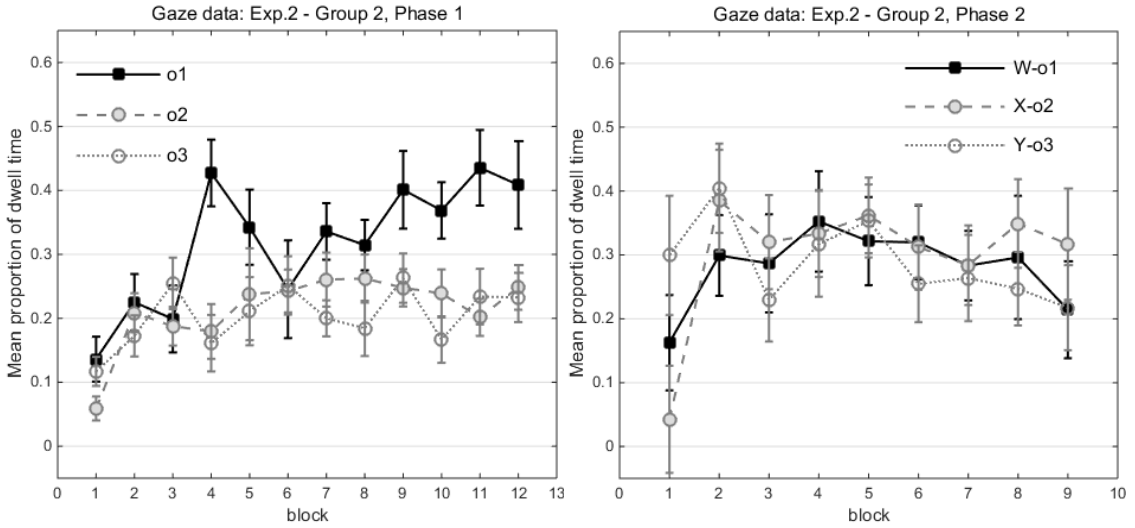


Figure 2.2.3. Gaze data of Group 2 in Experiment 2. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1 and the right panel shows mean proportion of dwell time across nine blocks in Phase 2.

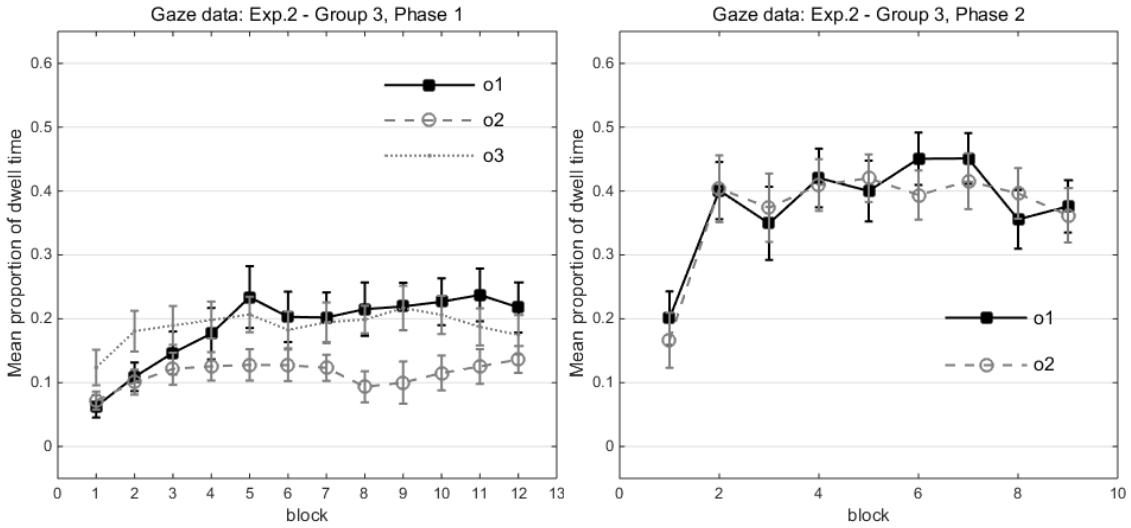


Figure 2.2.4. Gaze data of Group 3 in Experiment 2. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that the dwell time towards o3 cave was not entered into analysis. The right panel shows mean proportion of dwell time across nine blocks in Phase 2.

For Group 1 and 2, we conducted a 2 (outcome: o1 vs. o2 vs. o3) × 3 (cave condition: o1 in top or middle or bottom cave) ×12 (block) ANOVA separately in which outcome and block were within-subjects factors. For Group 3, because the position of o3 was not counterbalanced and gaze allocation towards the o3 area was interfered with the middle cave advantage, we only analyzed the eye gaze towards o1 and o2 area during the corresponding cues. Thus, the data of Group 3 were entered into a 2 (outcome: o1 vs. o2) × 2 (cave condition: o1 in top or bottom cave) × 12 (block) ANOVA in which outcome predictability and block were within-subjects factors.

For Group 1, we found a significant main effect of outcome, $F(2,18)=17.48$, $p<.001$, $\eta^2=.66$, $F_{o1 \text{ vs. } o2}=21.39$, $p<.001$, $F_{o1 \text{ vs. } o3}=22.31$, $p<.001$, $F_{o2 \text{ vs. } o3}=1.12$, $p>.1$, and a significant main effect of block, $F(11,99)=9.11$, $p<.001$, $\eta^2=.503$. However, the outcome × block interaction was not significant, $F(22,198)=1.68$, $p=.141$. In addition, the outcome × cave condition interaction was significant, $F(4,18)=6.22$, $p<.01$, $\eta^2=.580$. No

further main effects or interactions was significant (largest F=1.82, corresponding p=.095).

For Group 2, the analyses also revealed a significant main effect of outcome, $F(2,18)=14.58$, $p<.001$, $\eta^2=.618$, $F_{o1 \text{ vs. } o2}=14.49$, $p<.01$, $F_{o1 \text{ vs. } o3}=25.10$, $p<.01$, $F_{o2 \text{ vs. } o3}<1$, and a significant main effect of block, $F(11,99)=4.39$, $p<.05$, $\eta^2=.328$. The outcome × block interaction demonstrated a non-significant trend, $F(22,198)=2.52$, p=.061, that the responses towards o1 cave increased more rapidly than o2 and o3 cave during the corresponding cues. We again found a significant outcome × cave condition interaction, $F(4,18)=3.30$, $p<.05$, $\eta^2=.423$. No further main effects or interactions was significant (largest F=3.58, corresponding p=.072).

For Group 3, the analysis revealed a significant main effect of predictability, $F(1,30)=10.74$, $p<.01$, $\eta^2=.26$, reflecting that participants spent longer looking at the o1cave than the o2 cave during the corresponding cues. There was a significant main effect of block $F(11,330)=4.89$, $p<.001$, $\eta^2=.14$, showing that the dwell time at the goal area rose across blocks. Notably, a significant predictability × block interaction $F(11,330)=2.87$, $p<.01$, $\eta^2=.09$, linear contrast $F_{o1 \text{ vs. } o2}=14.98$, $p<.01$, revealed that dwell time in anticipation of o1 increased faster across training phases than it did in anticipation of o2. We again noted effects from the counterbalancing factor: cave condition interacted with outcome predictability and demonstrated a significant effect, $F(1,30)=4.98$, $p<.05$, $\eta^2=.14$. No further main effects or interactions was significant (largest F=1.05, corresponding p=.386).

Phase 2. The right panels of Figure 2.2.2 and 2.2.3 demonstrate the Phase 2 learning during the three trial types (o1 trial, o2 trial and o3 trial) in Group 1 and Group 2 respectively. None of them showed that the prior predictable outcome had an advantage over the prior less predictable outcomes in Phase 2 learning. For Group 1, dwell time

during o1 and o2 trials already reached a very high level of about 0.4 on Block 2 and their development overlapped each other. Notably, the anticipatory gaze towards the o3 area started with a high level of 0.4 on Block 1 and consistently remained high across the rest blocks. For Group 2 which contained a context shift, responses during the o2 trials increased rapidly from Block 1 to Block 2 while reactions during the o1 trials rose gently. During the rest blocks, dwell time of these two trial types proceeded similar. Moreover, gaze time towards the o3 cave during the novel cue Y started with a relatively high level of 0.3 from the beginning and reached the peak of 0.4 on Block 2. It is noteworthy that we did not expect such great accurate responses to the novel cue associated with o3 on the first block for Group 1 and 2. In order to direct compare learning about the previously predictable versus the previously less predictable outcome, dwell time was averaged in the following analyses based on the predictability of each outcome during Phase 1. Figure 2.2.4 (right) represents the Phase 2 learning of Group 3 across the nine blocks. The increment of responses in anticipation of o1 did not differ substantially from that of o2 across training phase.

Because Group 1 and 2 obtained the same cave condition and the same number of outcomes in Phase 2, we are able to compare their Phase 2 learning by using a 2 (outcome predictability: previously predictable versus less predictable) × 2 (Group 1 vs. 2) × 2 (cave condition: o1 in top or bottom cave) × 9 (block: 1-9) ANOVA in which the previous predictability of outcome and block were within-subjects factors. We did not observe a significant main effect of outcome predictability, $F(1,18) < 1$, nor a significant predictability × block interaction, $F(8,144) < 1$. This suggests that learning about the prior predictable outcome o1 did not differ from the prior less predictable outcomes o2 and o3 in Phase 2. Moreover, neither the group × predictability interaction, $F(1,18) < 1$, nor the group × predictability × block interaction, $F(8,144) < 1$, appeared significant, showing

that there was no difference in Phase 2 learning between Group 1 and 2 based on the different outcome predictability learned in Phase 1. A significant main effect of block indicated a general increment across blocks, $F(8,144)=7.98$, $p<.001$, $\eta^2=.307$. In addition, we observed a significant predictability × cave condition interaction, $F(2,18)=5.64$, $p<.05$, $\eta^2=.385$, reflecting the influence of outcome position on the performances. No further main effects or interactions was significant (largest $F=2.80$, corresponding $p=.112$). In the analog Bayesian repeated measures ANOVA, a BF of 7.86 provided substantial evidence for the model including the main effect of group, cave condition and block over the main effects model with all four main effects (i.e. including the factor outcome predictability), and a BF of 64.22 very strongly supported the main effects model over the model including an additional predictability × block interaction. Furthermore, a BF of 7 substantially favored the main effects model over the model including an additional group × predictability interaction. And a BF of 17.34 provided strong evidence for the model with all main effects and all two-way interactions within factor group, predictability and block over the model including an additional group × predictability × block interaction.

The data of Group 3 were entered into a 2 (outcome predictability: previously predictable versus less predictable) × 2 (cave condition: o1 in top or bottom cave) × 9 (block: 1-9) ANOVA in which the previous predictability of outcome and block were within-subjects factors. We observed a significant main effect of block $F(8,240)=7.72$, $p<.001$, $\eta^2=.21$, showing that dwell time at the goal area increased across blocks. However, neither the main effect of outcome predictability, $F(1,30)<1$, nor its interaction with block, $F(8,240)<1$, was significant, as there was no difference in dwell time between o1-trials and o2-trials in Phase 2. An analog Bayesian repeated measures ANOVA provided strong evidence for the model including the factor cave condition and block over the

model with all three main effects with a BF of 10.61. In addition, a BF of 173.91 provided strong evidence for the main effects model over the model containing an additional predictability × block interaction.

Mouse data. Mouse movements of three groups were further analyzed to determine whether an outcome predictability effect would be observed with another measurement.

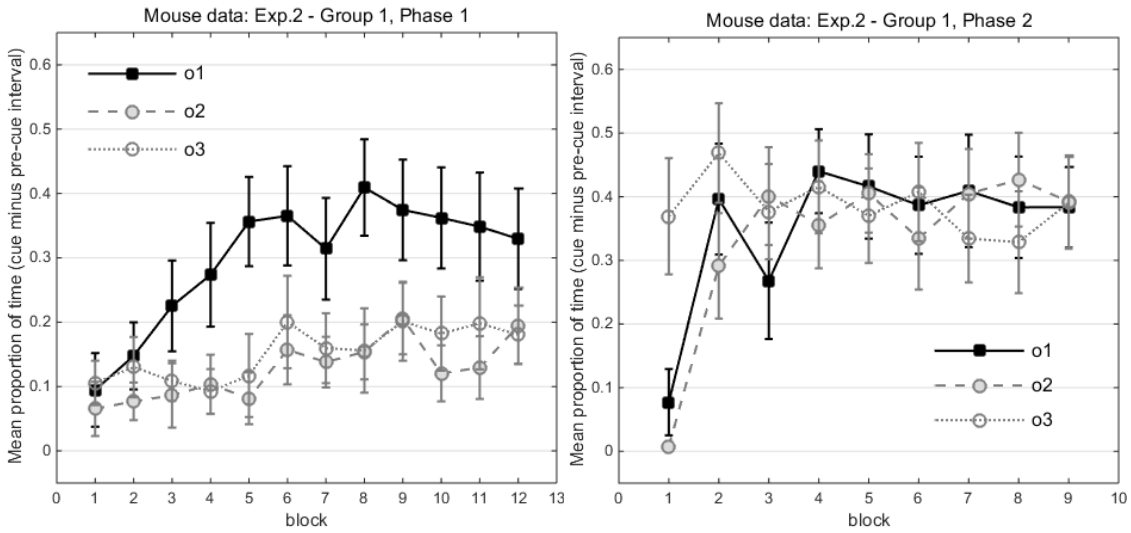


Figure 2.2.5. Mouse data of Group 1 in Experiment 2. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave per block across the 12 blocks in Phase 1 and the right panel shows mean proportion of mouse time across nine blocks in Phase 2.

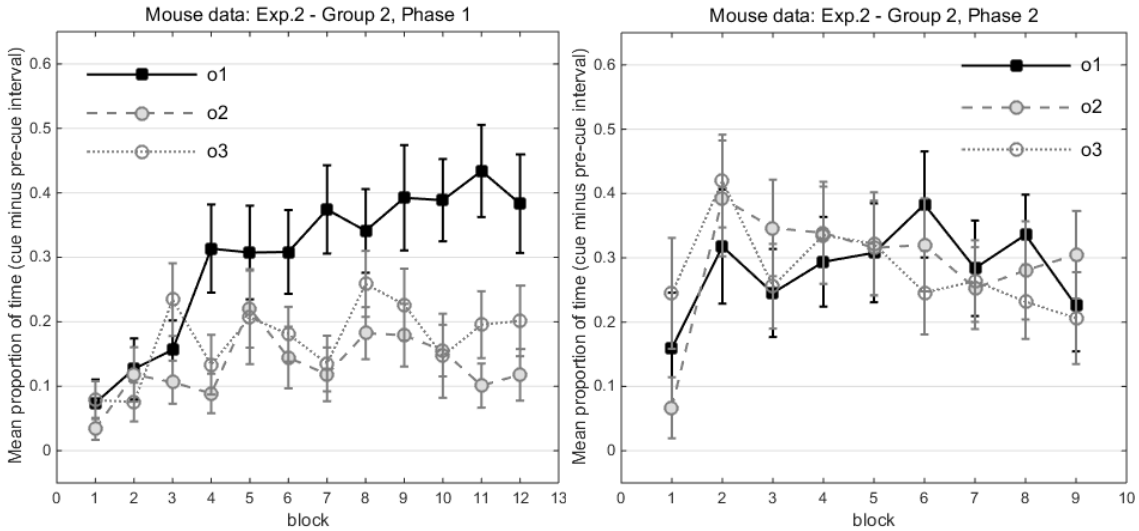


Figure 2.2.6. Mouse data of Group 2 in Experiment 2. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave per

block across the 12 blocks in Phase 1 and the right panel shows mean proportion of mouse time across nine blocks in Phase 2.

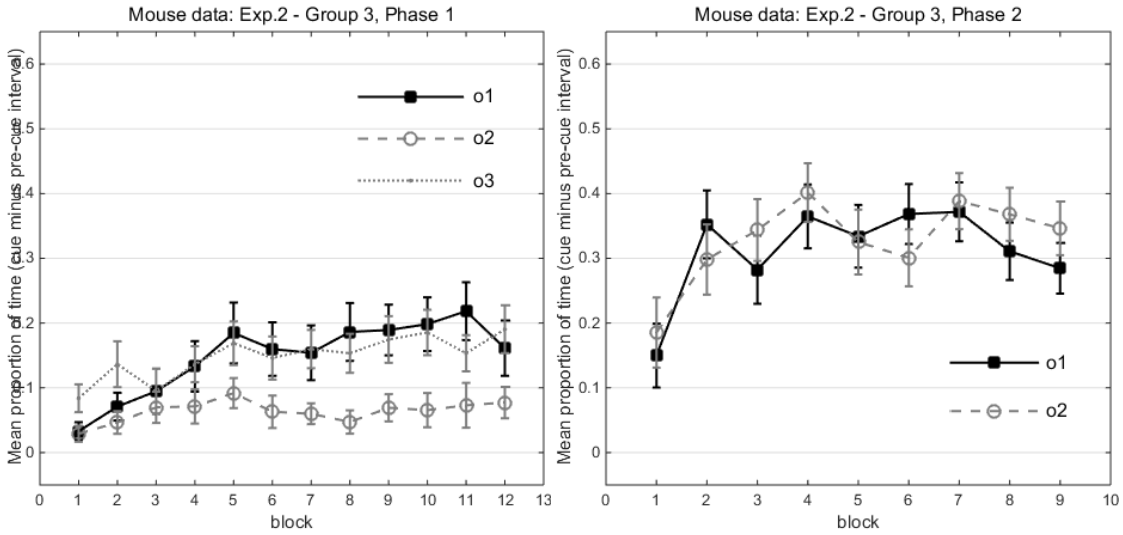


Figure 2.2.7. Mouse data of Group 3 in Experiment 2. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that response on o3-trial was not entered into analysis. The right panel shows mean proportion of mouse placements' time across nine blocks in Phase 2.

Phase 1. The left panels of Figure 2.2.5 and 2.2.7 illustrate the averaged proportion of time participants positioned their cursor at the goal area per block across the 12 blocks of Phase 1 for three groups respectively. For Group 1 and 2, the learning curve of Phase 1 based on mouse movements was consistent with that displayed by gaze data: The time participants placed the cursor towards the o1 area rose more rapidly across blocks and maintained higher than they placed the cursor towards o2 and o3 area during the corresponding cues. Further, the left panel of Figure 2.2.7 for Group 3 shows that participants positioned their cursor longer towards the area of the predictable outcome o1 across blocks during cue A, while the responding towards the area of the less predictable outcome o2 during cue C and D maintained a lower level. Moreover, a strong preference for the middle cave was indicated by the responses during the o3 trials.

The two-way repeated measures ANOVA with factor outcome (for Group 1 and 2: o1 vs. o2 vs. o3; for Group 3: o1 vs. o2), cave condition (for Group 1 and 2: o1 in top vs. middle vs. bottom cave; for Group 3: o1 in top vs. bottom cave) and block (1-12) was conducted for three groups respectively, in which outcome and block were within-subjects factors.

For Group 1, the test revealed a significant main effect of outcome, $F(2,18)=6.23$, $p<.01$, $\eta^2=.409$, $F_{o1 \text{ vs. } o2}=10.30$, $p<.05$, $F_{o1 \text{ vs. } o3}=6.37$, $p<.05$, $F_{o2 \text{ vs. } o3}<1$, showing that participants generally placed the cursor longer towards the o1 cave than the o2 and o3 cave during the corresponding cue. Furthermore, we also observed a significant main effect of block, $F(11,99)=4.09$, $p<.01$, $\eta^2=.312$. However, the outcome × block interaction was not significant, $F(22,198)=1.14$, $p=.350$. No further main effects or interactions was significant (largest $F=2.08$, corresponding $p=.052$).

For Group 2, we again observed a significant main effect of outcome, $F(2,18)=13.32$, $p<.01$, $\eta^2=.597$, $F_{o1 \text{ vs. } o2}=14.85$, $p<.01$, $F_{o1 \text{ vs. } o3}=13.65$, $p<.01$, $F_{o2 \text{ vs. } o3}=4.63$, $p=.06$, and a significant main effect of block, $F(11,99)=5.02$, $p<.01$, $\eta^2=.358$. The outcome × block interaction demonstrated a non-significant trend, $F(22,198)=2.20$, $p=.062$, that the difference in responses between the different trial types increased across blocks. No further main effects or interactions was significant (largest $F=2.61$, corresponding $p=.128$).

For Group 3, both the main effect of predictability, $F(1,30)=11.61$, $p<.01$, $\eta^2=.279$, and its interaction with block, $F(11,330)=2.87$, $p<.01$, $\eta^2=.081$, appeared significant. The main effect of block was also significant, $F(11,330)=3.81$, $p<.01$, $\eta^2=.113$. No further main effects or interactions was significant (largest $F=.882$, corresponding $p=.517$).

Phase 2. The right panels of Figure 2.2.5 and 2.2.6 demonstrate Phase 2 learning based on mouse data during the three trial types (o1 trial, o2 trial and o3 trial) for Group

1 and 2 respectively. It is consistent with the gaze data, neither Group 1 nor Group 2 showed a preference for the prior predictable outcome over the prior less predictable outcomes in Phase 2 learning, when each outcome was fully predicted by a novel cue. Notably, participants of both groups placed the cursor longer towards o3 cave during the novel corresponding cue on the first block. For Group 3, there was no apparent difference in learning between the o1 and the o2 trials in the second phase (right panel of Figure 2.2.7). In the following analyses for Group 1 and 2, the time participants spent placing the cursor towards the goal area was averaged based on the predictability of each trial's outcome during Phase 1.

We, again, compared Phase 2 learning between Group 1 and 2 by using a 2 (outcome predictability: prior predictable versus prior less predictable) × 2 (Group 1 vs. 2) × 3 (cave condition: o1 in top or middle or bottom cave) × 9 (block: 1-9) ANOVA in which the previous predictability of outcome and block were within-subjects factors. We only observed a significant main effect of block, $F(8,144)=6.69$, $p<.001$, $\eta^2=.271$, showing a general increment of accurate responding across blocks. Neither the main effect of predictability, $F(1,18)<1$, nor its interaction with group, $F(1,18)<1$, nor the predictability × block interaction, $F(8,144)=1.143$, $p=.344$, nor the group × predictability × block interaction, $F(8,144)<1$, reached significance. No further main effects or interactions was significant (largest $F=2.71$, corresponding $p=.094$). In the analog Bayesian repeated measures ANOVA, a BF of 9.11 provided substantial evidence for the model including the main effect of group, cave condition and block over the main effects model with all four main effects, and a BF of 25.70 very strongly supported the main effects model over the model including an additional predictability × block interaction. Furthermore, a BF of 9 substantially favored the main effects model over the model including an additional group × predictability interaction. And a BF of 16.08 provided

strong evidence for the model with all main effects and all two-way interactions within factor group, predictability and block over the model including an additional group × predictability × block interaction.

For Group 3, we conducted a 2 (outcome predictability: previously predictable versus less predictable) × 2 (cave condition: o1 in top or bottom cave) × 9 (block: 1-9) ANOVA in which the previous predictability of outcome and block were within-subjects factors. Only the factor block demonstrated a significant effect, $F(8,240)=4.51$, $p<.01$, $\eta^2=.131$. Neither the main effect of outcome predictability, $F(1,30)<1$, $p=.771$, nor its interaction with block, $F(8,240)<1$, $p=.89$, was significant. No further main effects or interactions was significant (largest $F=3.08$, corresponding $p=.09$). In the analog Bayesian repeated measures ANOVA, a BF of 8.04 provided substantial evidence for the model including the main effect of cave condition and block over the model with all three main effects. In addition, a BF of 65.46 provided strong evidence for the main effects model over the model containing an additional predictability × block interaction.

2.2.3 Discussion

None of three groups in the present experiment replicated the key finding from Experiment 1. These results were revealed by both the gaze and the mouse data. In the replication group (Group 1), although participants successfully learned about the outcomes' different predictability in Phase 1, they did not show any preference for the previously predictable outcome over the previously less predictable outcomes in learning about the outcomes' novel relationships during Phase 2. One possible reason for these results is the small sample size. It is also questionable whether the effect of outcome predictability on subsequent learning is strong enough or even robust. However, given the fact that participants already showed a highly accurate prediction of o3 on the first block of Phase 2, it is necessary to review our manipulations carefully. For the first two

trials of Phase 2, we counterbalanced the sequence of o1 and o2 (either W-o1 for Trial 1 and X-o2 for Trial 2, or X-o2 for Trial 1 and W-o1 for Trial 2), so that the prior predictable and the prior less predictable outcome could be equally frequently presented at the beginning of Phase 2. In this way, Phase 2 learning could be less likely to be influenced by the first presentation of one outcome. However, because we only have tree outcomes, after experiencing the first two trials, participants could simply infer that the next novel cue would most possibly predict the last outcome. In this case, this rapid learning about the o3's relationship might cover any disadvantage of its prior unpredictability.

The second group aimed to investigate the context blocking account of the outcome predictability effect. For the first training phase, participants successfully discriminated between the predictable and the less predictable outcome. However, we did not observe any bias towards the prior predictable outcome during novel learning in Phase 2, when the context was changed between two phases. This indicates that an effect of the outcome predictability on subsequent learning relies on the presentation of the same context, whose associations with the outcome might block learning about the novel relationship with this outcome. However, since we manipulated the sequence of the outcome's presentation in Phase 2 in the same way as for Group 1, we cannot rule out the possibility that this manipulation may interfere with any influence of the prior predictability of an outcome on Phase 2 learning.

For the third group, the context was changed between two training phases and one outcome was removed in Phase 2, in order to investigate the impact of context on the outcome predictability effect with the reduction of the influence of the middle cave advantage. We did not find any difference in learning about the prior predictable and the prior less predictable outcome in Phase 2, although participants successfully discriminated the outcome's predictability in Phase 1. Such a result is inconsistent with

the findings from Experiment 1. One explanation can be attributed to the blocking effect caused by associations between context and the outcomes. During the first training phase, o2 and o3 were partially predicted by discrete cues (cue C and D). Thus, cues C and D were only marginally more predictive than the context, and less informative about the emergence of outcomes than cue A, which had consistently predicted o1. When context acts as an additional cue competing with discrete cues to predict the same outcome, participants may form stronger associations between context and the less predictable outcomes o2 and o3, since cues C and D were less predictive. If Phase 2 learning maintains the same context as in Phase 1 (as in Experiment 1), such associations between context and less predictable outcomes can be transferred to the predictions made on Phase 2 trials and block learning about relationships between novel cues and previously less predictable outcomes (o2 and o3). As a result, novel cues paired with previously less predictable outcomes in Phase 2 are learned more slowly than the novel cue associated with the previously predictable outcome. On the other hand, if the learning context in Phase 2 differs from that in Phase 1 (as in Group 3), the novel context in Phase 2 provides no information on the emergence of outcomes or learned associations between the Phase 1 context and the less predictable outcomes that cannot affect subsequent learning about those outcomes. In Group 3, the possible contribution of the Phase 1 context to Phase 2 learning was eliminated. The data revealed no difference in subsequent learning based on the previous predictability of the outcomes, implying that the outcome predictability effect we found in Experiment 1 may have been mediated by a blocking effect induced by context–outcome associations in Phase 1.

However, because the first group failed to replicate the outcome predictability effect and the results of the second group cannot rule out the impact of the counterbalancing manipulation, it is too soon to draw any conclusion. In addition, since

the third group contained the context shift and the outcome's removal at the same time, it is unclear whether the results should be due to a context switch or/and a change in the number of outcomes. Based on those considerations, the next experiment investigated every possible account with a complex design.

2.3 Experiment 3

The present experiment improved the design and the counterbalancing manipulations of Experiment 2 and consisted of four groups. The first group was the replication of Experiment 1. The second group received a context change between two phases to examine the context blocking account of the outcome predictability effect. The cue-outcome pairings for the first two groups in the present experiment were the same as in Group 1 and 2 of Experiment 2. Furthermore, we considered that the counterbalancing manipulation of Experiment 2, as o1 and o2 were presented for the first two trials of Phase 2 across all participants, might interfere with the influence of the outcome's prior predictability. Thus, we improved this manipulation in the present experiment. Four trial types (either o1-, or o2-, or o3- or no outcome trial) were counterbalanced for the first trial of Phase 2 across all participants.

For the third and the fourth group, we presented the less predictable outcome o3 in the middle cave across all participants in Phase 1, and then removed it as well as the middle cave in Phase 2. Considering that it is impossible to determine whether the failed observation of the outcome predictability effect in the third group of Experiment 2 is due to the change of the outcome's number or/and the context shift, the context switch was conducted for Group 4, but not for Group 3, in the present experiment. If changes in the outcome's number cannot impair the outcome predictability effect, we would observe more rapid learning about the prior predictable outcome than the prior less predictable

outcome in Group 3. Moreover, if the outcome predictability effect is context-dependent, we should not observe any difference in learning about the prior predictable and the prior less predictable outcome in Group 4. Further, having observed that participants have learned about the outcome's relationships extremely quickly when each of the two outcomes was fully predictable by a discrete cue, we added three additional pairs (R-o1, S-o2, T- Ø) to Group 3 and 4 in the present experiment to slow down acquisitions in Phase 2.

Table 2.3
Design of Experiment 3

	Phase 1	Phase 2
Group 1	***Context 1***: A→o1, A→o1, B→Ø, B→Ø C→o2, C→o3, D→o2, D→o3	***Context 1***: W→o1, X→o2 Y→o3, Z→Ø
Group 2	***Context 1***: A→o1, A→o1, B→Ø, B→Ø C→o2, C→o3, D→o2, D→o3	***Context 2***: W→o1, X→o2 Y→o3, Z→Ø
Group 3	***Context 1***: A→o1, A→o1, B→Ø, B→Ø C→o2, C→o3, D→o2, D→o3	***Context 1***: X→o1, R→o1, Y→o2, S→o2, Z→Ø, T→Ø
Group 4	***Context 1***: A→o1, A→o1, B→Ø, B→Ø C→o2, C→o3, D→o2, D→o3	***Context 2***: X→o1, R→o1, Y→o2, S→o2, Z→Ø, T→Ø

Note. Letters A-Z denote visual and auditory cues that were always followed by one outcome (i.e., the eyes of one of the animals in the experimental task): o1 was the fully predictable outcome, o2 and o3 were less predictable as they were equally likely to appear after cues C and D. Cues B and Z were followed by the absence of any outcome, denoted as Ø. For Group 1 and 3, the same context (Summer layout) was presented for both training phases; For Group 2 and 4, a context switch was conducted between two phases (Winter layout in Phase 1 and Summer layout in Phase 2).

2.3.1 Methods

Participants. Ninety-six undergraduate students from the Philipps-Universität Marburg, Germany (70 females, 26 males; M_{age}=22.28 years, age range 18-31 years; 24 participants in each group) participated in the experiment and received course credit or payment (EUR € 7). Data from ten additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used in Experiment 3 were similar to those in Experiment 2: In Group 1 and 2, three outcomes were presented in two training phases so that three outcome's positions were counterbalanced (o1 in top vs. middle vs. bottom cave). In Group 3 and 4, o3 was always located in the middle cave during Phase 1; o1 and o2 were placed in other two caves (top vs. bottom), and their positions were counterbalanced. However, some counterbalancing manipulations in the present experiment were different from Experiment 2: First, every trial type (o1-trial or o2-trial or o3-trial or no outcome trial) was equally frequently presented on the first trial of Phase 2 across all participants in the present experiment; Secondly, the summer context was presented for both phases in Group 1 and 3, while the winter context was displayed for Phase 1 and the summer context for Phase 2 to all participants in Group 2 and 4; Lastly, all participants received auditory cues in Phase 1 and visual cues in Phase 2. In Experiment 2, we observed participants tended to show better learning performances with the summer context than the winter context. Moreover, some researchers suggested that responses to auditory stimuli are faster than to visual stimuli (Jain, Bansal, Kumar, & Singh, 2015; Shelton & Kumar, 2010). Since we aimed to establish better acquisitions of Phase 1 pairings and slow down the Phase 2 acquisitions, the Phase 1 training contained the summer context and the auditory cues, while the Phase 2 training obtained the winter context and the visual cues.

Design and Procedure. Table 2.3 shows the design of Experiment 3. Group 1 and 2 maintain the same design as the first two groups of Experiment 2. In Group 3 and 4, the initial training phase was identical to the third group of Experiment 2. However, each outcome (o1 or o2) was preceded by two novel cues in the second training phase.

For Group 1 and 2, each participant completed 12 blocks (132 trials) in Phase 1 and 12 blocks (48 trials) in Phase 2. For Group 3 and 4, there were 123 trials grouped into

12 blocks in Phase 1 and 72 trials grouped into 12 blocks in Phase 2. The trial order was randomized.

2.3.2 Results

Gaze data. Figure 2.3.1 to 2.3.4 illustrate dwell time that participants spent looking at the goal areas per block across all blocks of Phase 1 and 2 in all four groups, respectively. In the first training phase of all groups (left panel of Figure 2.3.1 to 2.3.4), as we expected, a difference in anticipatory gaze for the predictable and the less predictable outcome became apparent. In addition, in Group 3 and 4, responses during o3 trials increased quickly and maintained relatively high since o3 was always presented in the middle cave. This confirmed the bias towards the middle cave and therefore did not merely reflect specific learning about o3. For the second training phase of all groups, dwell time was averaged based on the predictability of each outcome during Phase 1 (prior predictable or prior less predictable), resulting in two trial types. In Group 1 which was the replication group (right panel of Figure 2.3.1), it is inconsistent with our expectation as participants did not spent longer looking at the area of the prior predictable than the prior less predictable outcome across all blocks of Phase 2. Furthermore, participants of Group 2 which contained context shift between two phases did not show a great difference in responses between two trial types in Phase 2 (right panel of Figure 2.3.2). In Group 3 with outcome removal and Group 4 containing both context shift and outcome removal, learning curve for two trial types overlapped each other across all blocks of Phase 2 (right panel of Figure 2.3.3 and 2.3.4).

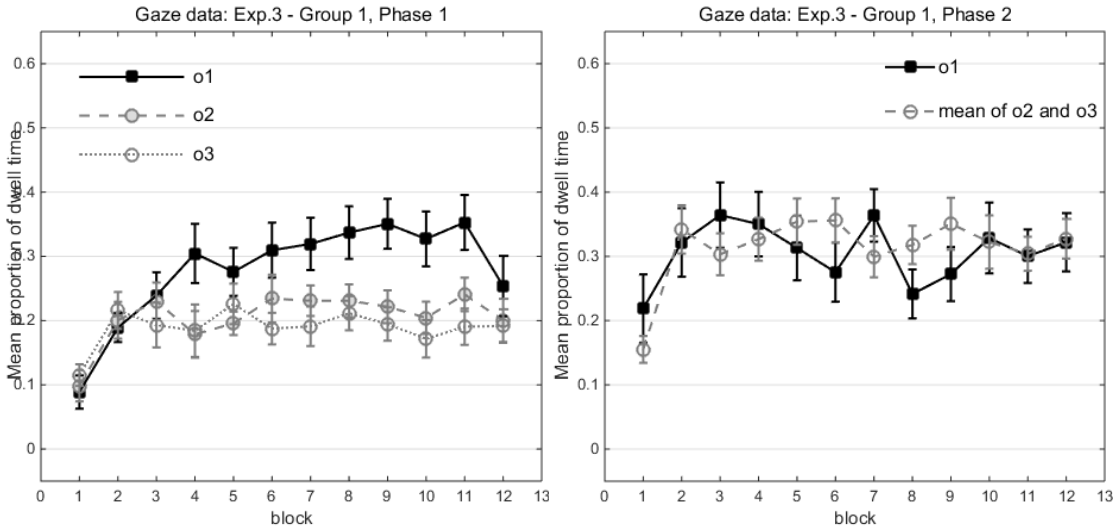


Figure 2.3.1. Gaze data of Group 1 in Experiment 3. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of dwell time across 12 blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

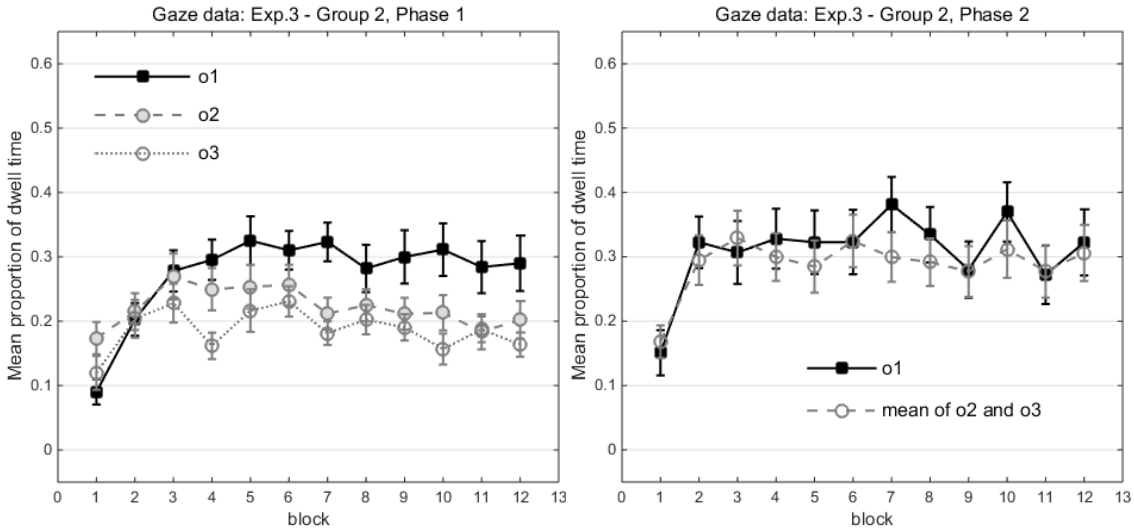


Figure 2.3.2. Gaze data of Group 2 in Experiment 3. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of dwell time across 12 blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

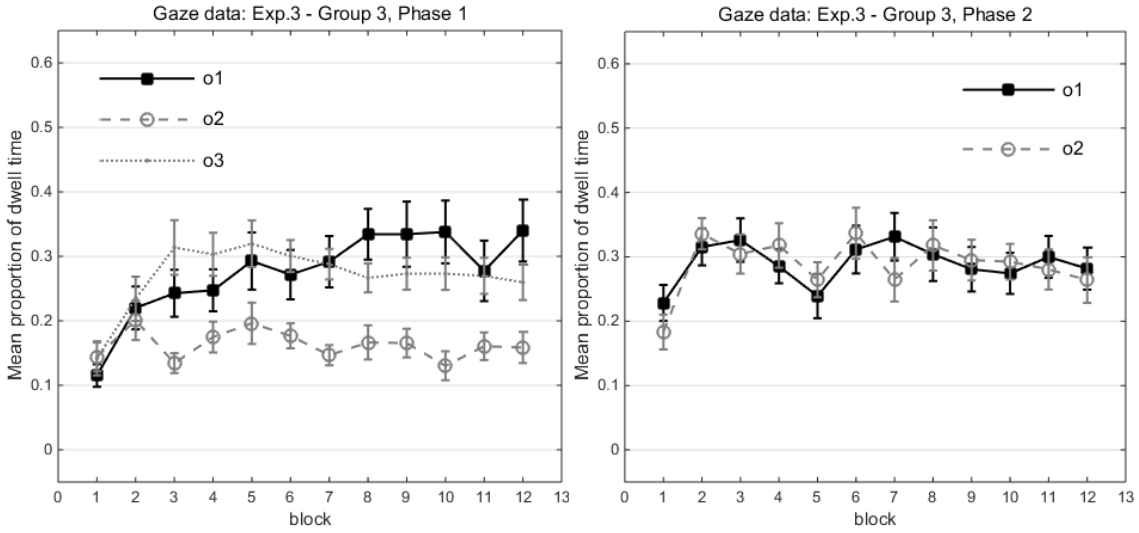


Figure 2.3.3. Gaze data of Group 3 in Experiment 3. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that the dwell time towards o3 cave was not entered into analysis. The right panel shows mean proportion of dwell time across 12 blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

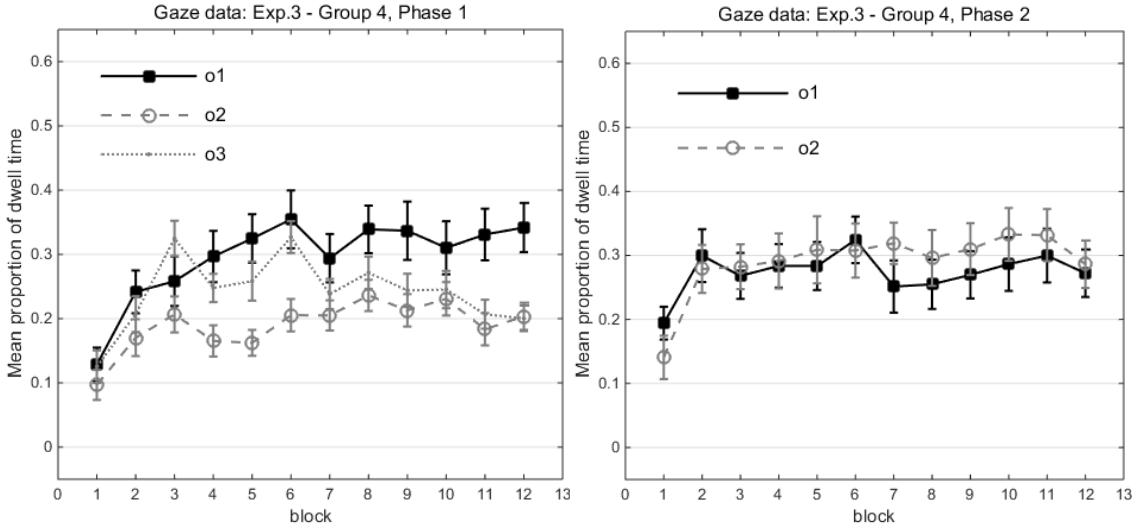


Figure 2.3.4. Gaze data of Group 4 in Experiment 3. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that the dwell time towards o3 cave was not entered into analysis. The right panel shows mean proportion of dwell time across 12 blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

Phase 1. We analyzed performance of each group during the first training phase.

For Group 1 and 2, a two-way repeated measures ANOVA with factor outcome (o1 vs.

o2 vs. o3), cave condition (o1 in top or middle or bottom cave) and block (1-12) in which outcome and block were within-subjects factors, was conducted respectively.

For Group 1, the main effect of outcome, $F(2,42)=9.08$, $p<.01$, $\eta^2=.302$, $F_{o1 \text{ vs. } o2}=9.10$, $p<.01$, $F_{o1 \text{ vs. } o3}=12.43$, $p<.01$, $F_{o2 \text{ vs. } o3}<1$, and its interaction with block, $F(22,462)=2.40$, $p<.05$, $\eta^2=.103$, became significant. The test also revealed a significant main effect of block, $F(11,231)=5.58$, $p<.001$, $\eta^2=.210$. In addition, the outcome × cave condition interaction was significant, $F(4,42)=9.84$, $p<.001$, $\eta^2=.484$. No further main effects or interactions was significant (largest $F=.96$, corresponding $p=.506$).

For Group 2, the main effect of outcome, $F(2,42)=12.47$, $p<.001$, $\eta^2=.373$, $F_{o1 \text{ vs. } o2}=7.66$, $p<.05$, $F_{o1 \text{ vs. } o3}=30.13$, $p<.001$, $F_{o2 \text{ vs. } o3}=3.59$, $p=.072$, and its interaction with block, $F(22,462)=2.43$, $p<.05$, $\eta^2=.104$, were significant. We also noted a significant main effect of block, $F(11,231)=6.98$, $p<.001$, $\eta^2=.249$. Again, the outcome × cave condition interaction became significant, $F(4,42)=9.91$, $p<.001$, $\eta^2=.486$. No further main effects or interactions was significant (largest $F=1.03$, corresponding $p=.429$).

In following, we conducted a two-way repeated measures ANOVA with factor predictability (predictable vs. less predictable), cave condition (o1 in top vs. bottom cave) and block (1-12) with within-subjects factor predictability and block for Group 3 and 4 respectively.

For Group 3, predictability demonstrated a significant main effect, $F(1,22)=28.07$, $p<.001$, $\eta^2=.561$, and significantly interacted with block, $F(11,242)=4.80$, $p<.001$, $\eta^2=.179$. The main effect of block appeared significant, $F(11,242)=2.84$, $p<.05$, $\eta^2=.114$. In addition, the counterbalancing factor cave condition showed effects on participants' performance: The outcome × cave condition interaction, $F(1,22)=6.36$, $p<.05$, $\eta^2=.224$. and the cave condition × block interaction, $F(11,242)=3.11$, $p<.05$, $\eta^2=.124$, became

significant. No further main effects or interactions was significant (largest F=4.21, corresponding p=.052).

For Group 4, the test revealed the significant main effect of predictability, $F(1,22)=32.58$, $p<.001$, $\eta^2=.597$, and the significant main effect of block, $F(11,242)=5.78$, $p<.001$, $\eta^2=.208$. However, the outcome × block interaction did not reach the significance, $F(11,242)=1.39$, $p=.215$. In addition, the factor cave condition interacted significantly with outcome, $F(1,22)=10.84$, $p<.01$, $\eta^2=.330$. No further main effects or interactions was significant (largest F=1.90, corresponding p=.077).

Phase 2. Because Group 1 and Group 2 differed only in the application of the context switch between two phases, as well as Group 3 and 4, we firstly compared two pairs of groups (Group 1 vs. 2, Group 3 vs. 4), to determine whether a change in the context resulted in any difference in Phase 2 learning. A two-way repeated measurements ANOVA with factor outcome predictability (prior predictable vs. prior unpredictable outcome), group (either Group 1 vs. 2 or Group 3 vs. 4), cave condition (o1 in top vs. middle vs. bottom cave for Group 1 and 2; o1 in top vs. bottom cave for Group 3 and 4) and block (1-12) in which outcome predictability and block were within-subjects factors, was conducted for each pairs.

For the comparison of Phase 2 learning between Group 1 and 2, the test did not reveal a significant main effect of outcome predictability, $F(1,41)<1$, nor a significant outcome predictability × block interaction, $F(11,451)=1.13$, p=.338. These results suggest that learning about the prior predictable outcome did not differ from the prior less predictable outcome across all participants of Group 1 and 2 in Phase 2. Furthermore, we did not observe any difference in learning about the prior predictable and the prior less predictable outcomes between two groups: Neither the group × outcome predictability interaction, $F(1,41)<1$, nor the group × outcome predictability× block interaction,

$F(11,451)=1.34$, $p=.221$, reached significance. The main effect of block appeared significant, $F(11,451)=7.02$, $p<.001$, $\eta^2=.146$, showing a general increment of dwell time across blocks for two groups. The counterbalancing factor cave condition significantly interacted with outcome predictability, $F(2,41)=16.09$, $p<.001$, $\eta^2=.440$, indicating the middle cave preference. No further main effects or interactions was significant (largest $F=1.43$, corresponding $p=.093$). In the analog Bayesian repeated measures ANOVA, a BF of 14.03 provided strong evidence for the model including the main effect of group, cave condition and block over the main effects model with all four main effects (i.e. outcome predictability, group, cave condition and block), and a BF of 265.39 decisively supported the main effects model over the model including all four main effects and an additional outcome predictability × block interaction. Moreover, a BF of 2.39 provided anecdotal evidence for the model containing main effects of all factors over the model including the additional group × outcome predictability interaction. A BF of 40.68 provided very strong evidence for the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including the additional group × outcome predictability × block interaction.

For the comparison of Phase 2 learning between Group 3 and 4, we did not observe a significant main effect of outcome predictability, $F(1,44)<1$, nor a significant outcome predictability × block interaction, $F(11,451)<1$, indicating that learning about the prior predictable outcome did not differ from the prior less predictable outcome across all participants of Group 3 and 4 in Phase 2. Moreover, neither the group × outcome predictability interaction, $F(1,44)<1$, nor the group × outcome predictability × block interaction, $F(11,484)<1$, reached significance. Thus, Phase 2 learning of Group 3 did not differ from Group 4 based on the predictability of outcomes learned in Phase 1. Moreover, the test revealed a significant main effect of block, $F(11,484)=6.73$, $p<.001$, $\eta^2=.133$. In

addition, the counterbalancing factor also showed some effects: the cave condition × outcome predictability interaction, $F(1,44)=15.19$, $p<.001$, $\eta^2=.257$, and the cave condition × outcome predictability × group interaction, $F(1,44)=5.36$, $p<.05$, $\eta^2=.109$, appeared significant. No further main effects or interactions was significant (largest $F=2.02$, corresponding $p=.057$). In the analog Bayesian repeated measures ANOVA, a BF of 9.19 substantially favored the model including the main effects of factor group, cave condition and block over the main effects model including the main effects of all four factors, and a BF of 329.61 decisively supported the main effects model over the model including the additional outcome predictability × block interaction. Furthermore, a BF of 4.84 provided substantial evidence for the model containing all main effects over the model including the additional group × outcome predictability interaction. In addition, a BF of 29.12 strongly supported the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including the additional group × outcome predictability × block interaction.

Secondly, we compared all four groups with each other to investigate if there is any difference in Phase 2 performance between groups based on the predictability of outcomes leaned in Phase 1. Because outcome o1 was presented either in the top or the bottom cave for Group 3 and 4, we removed data from the subjects of Group 1 and 2 who received the cave condition 3 in which o1 was placed in the middle cave. Thus, we only entered the anticipatory gaze towards o3 under cave condition 1 (o1 in top and o3 in bottom cave) and towards o2 under cave condition 2 (o1 in bottom and o2 in top cave) into analyses. In this way, four groups could maintain the same counterbalancing of the outcome's position.

We conducted a 2 (outcome predictability: previously predictable versus less predictable) × 4 (Group: 1 - 4) × 2 (cave condition: o1 in top or bottom cave) × 12 (block:

1-12) ANOVA in which outcome predictability and block were within-subjects factor. The data did not show any difference in Phase 2 learning between groups based on the predictability of outcomes learned in Phase 1: Neither the group × outcome predictability interaction, $F(3,71)<1$, nor the group × outcome predictability × block interaction, $F(11,781)=1.34$, $p=.098$, reached significance. The factor block showed a significant main effect, $F(11,781)=10.80$, $p<.001$, $\eta^2=.132$. In addition, we observed the influences of the counterbalancing factor: the outcome predictability × cave condition interaction $F(1,71)=21.30$, $p<.001$, $\eta^2=.231$, and the cave condition × block × group interaction, $F(33,781)=2.14$, $p<.01$, $\eta^2=.084$, were significant. No further main effects or interactions was significant (largest $F=1.68$, corresponding $p=.178$). An analog Bayesian repeated measures ANOVA was conducted to state the evidence for the invariance between groups. A BF of 42.2 provided very strong evidence for the model containing all main effects over the model including the additional group × outcome predictability interaction. Moreover, a BF of 149152 showed decisive evidence for the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including the additional group × outcome predictability × block interaction.

Mouse data. We additionally analyzed the anticipatory mouse movements which described proportion of time participants placed the cursor at the goal area during the corresponding cues. Figure 2.3.5 to 2.3.8 illustrate the performance of four groups. For all groups, participants showed stronger responses towards the area of the predictable outcome than the less predictable outcomes across all blocks of Phase 1 (left panel of Figure 2.3.5 to 2.3.8). Moreover, we noted that participants placed the cursor longer towards the o3 area for Group 3 and 4 due to a general preference of the middle cave, since o3 was always presented on the middle cave. The right panel of Figure 2.3.5 to 2.3.8 represents Phase 2 learning for four groups respectively: For Group 1, the anticipatory

mouse movements towards the area of the prior predictable outcome reached the peak of 0.3 on Block 2 and then dropped down across the rest blocks, while learning about the prior less predictable outcome gradually increased and maintained stable. For Group 2, responses to the cue associated with the prior predictable outcome reached the peak on Block 4 and maintained a relatively higher level than the prior less predictable outcomes across all blocks of Phase 2. For Group 3, the time participants spent placing the cursor around the o1 area rapidly increased from Block 1 to 3 and then oscillated across the rest block of Phase 2, while the responses in anticipation of o2 increased slowly and stayed at a relatively lower level. For Group 4, learning curves for two trial types overlapped each other across blocks in Phase 2. The mouse data were analyzed by the same ANOVA tests as the gaze data.

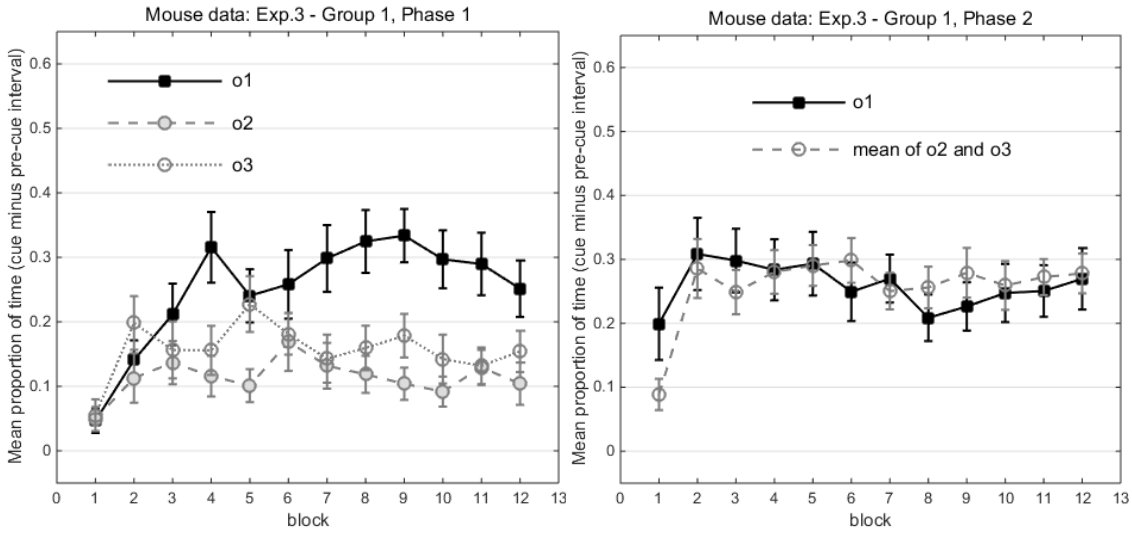


Figure 2.3.5. Mouse data of Group 1 in Experiment 3. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of mouse time across 12 blocks in Phase 2, wherein it was averaged based on the predictability of each trial's outcome during Phase 1.

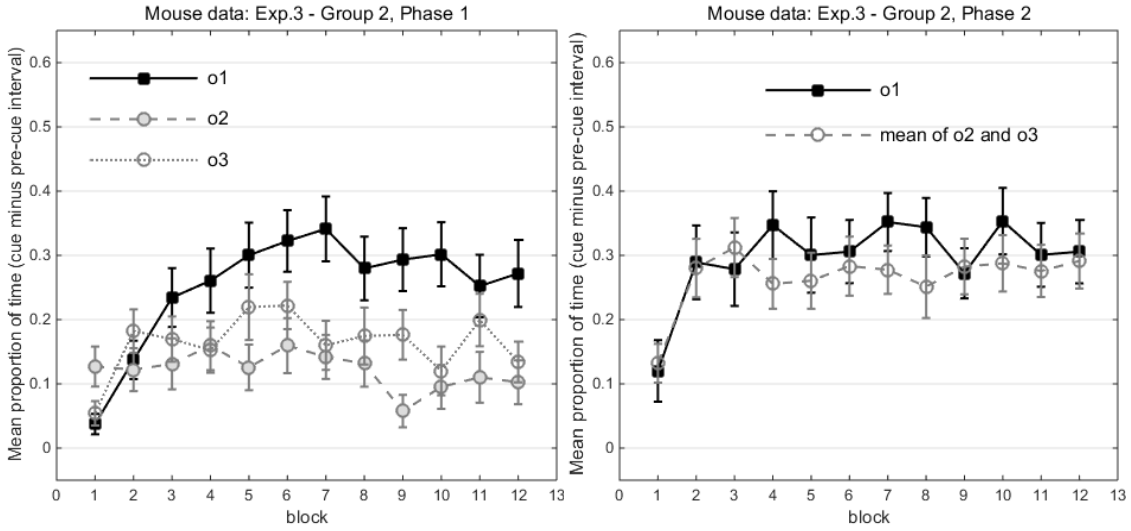


Figure 2.3.6. Mouse data of Group 2 in Experiment 3. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of mouse time across 12 blocks in Phase 2, wherein it was averaged based on the predictability of each trial's outcome during Phase 1.

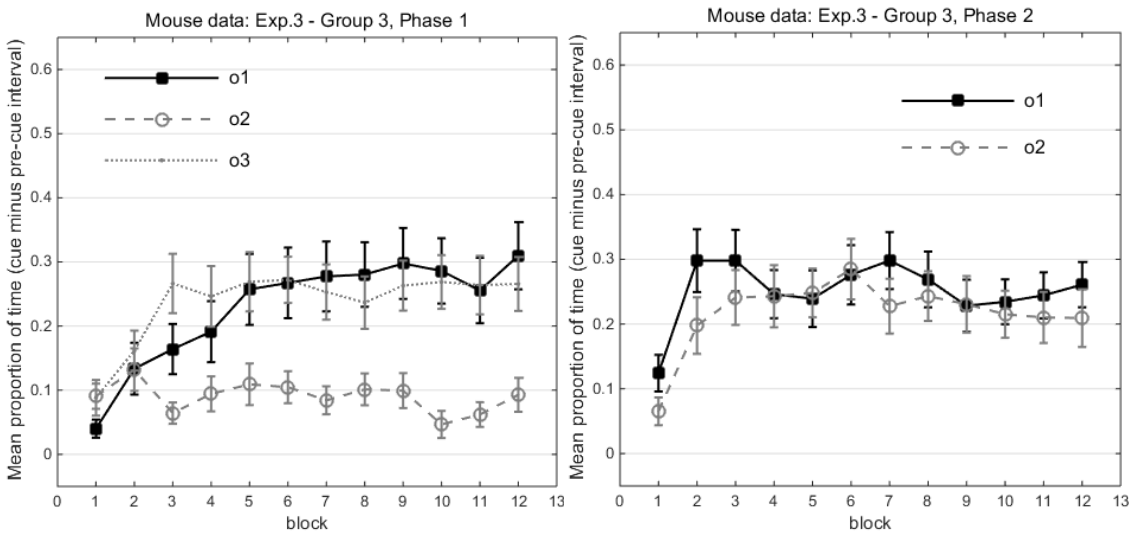


Figure 2.3.7. Mouse results of Group 3 in Experiment 3. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that response on o3-trial was not entered into analysis. The right panel shows mean proportion of mouse time across 12 blocks in Phase 2, wherein mouse time was averaged based on the predictability of each trial's outcome during Phase 1.

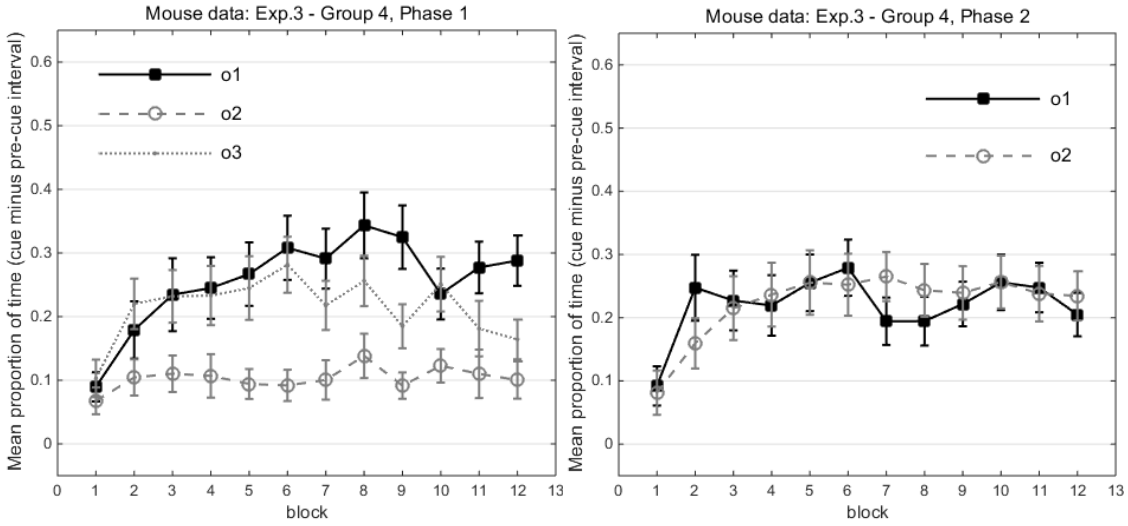


Figure 2.3.8. Mouse results of Group 4 in Experiment 3. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. Note that response on o3-trial was not entered into analysis. The right panel shows mean proportion of mouse time across 12 blocks in Phase 2, wherein mouse time was averaged based on the predictability of each trial's outcome during Phase 1.

Phase 1. The test of Phase 1 learning for Group 1 revealed a significant main effect of outcome, $F(2,42)=10.90$, $p<.001$, $\eta^2=.342$, $F_{o1 \text{ vs. } o2}=18.31$, $p<.001$, $F_{o1 \text{ vs. } o3}=7.76$, $p<.01$, $F_{o2 \text{ vs. } o3}=3.451$, $p=.77$, and a significant outcome × block interaction, $F(22,462)=2.40$, $p<.05$, $\eta^2=.102$. The factor block showed a significant main effect, $F(11,231)=6.01$, $p<.001$, $\eta^2=.222$. In addition, the outcome × cave condition interaction was significant, $F(4,42)=6.82$, $p<.001$, $\eta^2=.394$. No further main effects or interactions was significant (largest $F=1.06$, corresponding $p=.398$).

For Group 2, the main effect of outcome, $F(2,42)=9.34$, $p<.001$, $\eta^2=.308$, $F_{o1 \text{ vs. } o2}=24.23$, $p<.001$, $F_{o1 \text{ vs. } o3}=5.52$, $p<.05$, $F_{o2 \text{ vs. } o3}=2.42$, $p=.135$, and its interaction with block, $F(22,462)=2.95$, $p<.01$, $\eta^2=.103$, became significant. Block revealed a significant main effect, $F(11,231)=5.38$, $p<.001$, $\eta^2=.204$. Again, the outcome × cave condition interaction appeared significant, $F(4,42)=4.85$, $p<.01$, $\eta^2=.316$. No further main effects or interactions was significant (largest $F=1.21$, corresponding $p=.263$).

For Group 3, the test demonstrated a significant main effect of predictability, $F(1,22)=17.92$, $p<.001$, $\eta^2=.449$, and the significant predictability × block interaction, $F(11,242)=6.53$, $p<.001$, $\eta^2=.229$. The main effect of block became significant, $F(11,242)=2.84$, $p<.05$, $\eta^2=.114$. In addition, we noted the counterbalancing factor cave condition significantly interacted with block, $F(11,242)=4.80$, $p<.01$, $\eta^2=.179$. No further main effects or interactions was significant (largest $F=3.08$, corresponding $p=.093$).

For Group 4, the main effect of predictability, $F(1,22)=37.60$, $p<.001$, $\eta^2=.631$, and its interaction with block, $F(11,242)=2.37$, $p<.05$, $\eta^2=.097$, became significant. Moreover, the main effect of block was also significant, $F(11,242)=3.45$, $p<.01$, $\eta^2=.136$. No further main effects or interactions was significant (largest $F=2.04$, corresponding $p=.073$).

Phase 2. We analyzed the mouse data of Phase 2 learning in the same way as we analyzed the gaze data: First, we compared the responding across all the blocks of Phase 2 between Group 1 and 2, as well as between Group 3 and 4; Second, a comparison of Phase 2 learning between four groups were conducted.

For the comparison between Group 1 and 2, neither the main effect of outcome predictability, $F(1,42)=1.3$, $p=.260$, nor the outcome predictability × block interaction, $F(11,462)<1$, reached significance, suggesting that learning about the prior predictable outcome did not differ from the prior less predictable outcome across all participants of Group 1 and 2 in Phase 2. Moreover, the test did not reveal the significant group × outcome predictability interaction, $F(1,42) =1.08$, $p=.304$, nor the group × outcome predictability × block interaction, $F(11,462)=1.46$, $p=.144$, indicating that learning about the prior predictable and the prior less predictable outcome did not differ between Group 1 and 2. Further, the main effect of block appeared significant, $F(11,462)=6.64$, $p<.001$, $\eta^2=.137$. Additionally, we also noted the influences of the counterbalancing factor: The

cave condition × outcome predictability interaction, $F(2,42)=9.26$, $p<.001$, $\eta^2=.306$, and the cave condition × block × group interaction, $F(22,462)=2.37$, $p<.01$, $\eta^2=.102$, became significant. No further main effects or interactions reached significance (largest $F=1.17$, corresponding $p=.270$). In the analog Bayesian repeated measures ANOVA, a BF of 3.74 provided substantial evidence for the model including the main effect of factor group, cave condition and block over the main effects model including the main effect of all four factors, and a BF of 1040.74 decisively supported the main effects model over the model including the additional outcome predictability × block interaction. Moreover, a BF of 3.63 provided substantial evidence in favor of the main effects model over the model including the additional group × outcome predictability interaction. In addition, a BF of 21.07 strongly favored the model with all main effects and all two-way interactions within factor group, predictability and block over the model including the additional group × outcome predictability × block interaction.

For the comparison between Group 3 and 4, we only observed a significant main effect of block, $F(11,484)=8.55$, $p<.001$, $\eta^2=.163$. Notably, neither the main effect of outcome predictability, $F(1,44)=1.26$, $p=.268$, nor the outcome predictability × block interaction, $F(11,484)=1.53$, $p=.144$, nor the group × outcome predictability interaction, $F(1,44)=1.8$, $p=.182$, nor the group × outcome predictability × block interaction, $F(11,484)<1$, reached significance (largest $F=1.8$, corresponding $p=.182$). Thus, learning about the prior predictable and the prior less predictable outcome did not differ from one another across all participants of Group 2 and 4, and these two groups did not differ in Phase 2 learning based on the predictability of outcomes learned in Phase 1. In the analog Bayesian repeated measures ANOVA, a BF of 2.44 provided anecdotal evidence in favor of the model including the main effects of factor group, cave condition and block over the main effects model including the main effects of all four factors, and a BF of 160.14

decisively supported the main effects model over the model including the additional outcome predictability × block interaction. Furthermore, a BF of 1.06 provided anecdotal evidence for the main effects model over the model including the additional group × outcome predictability interaction. In addition, a BF of 110.99 decisively supported the model including all main effects and all two-way interactions within factor group, predictability and block over the model including the additional group × outcome predictability × block interaction.

For the comparison between four groups, the test confirmed that there was no difference in Phase 2 learning between groups based on the outcome predictability learned in Phase 1: Neither the group × outcome predictability interaction, $F(3,71)=1.25$, $p=.296$, nor the group × outcome predictability × block interaction, $F(11,781)=1.07$, $p=.375$, was significant. The test only showed a significant main effect of block, $F(11,781)=10.56$, $p<.001$, $\eta^2=.128$. No further main effects or interactions was significant (largest $F=1.68$, corresponding $p=.178$). The analog Bayesian repeated measures ANOVA was conducted to state the evidence for the invariance between groups. A BF of 13.54 provided strong evidence for the model containing all main effects over the model including the additional group × outcome predictability interaction. Furthermore, a BF of 83823 showed decisive evidence for the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including the additional group × outcome predictability × block interaction.

2.3.3 Discussion

The present experiment consisted of four groups which contained the different manipulations. During the first training phase, participants of all groups successfully learned the different predictability of the outcomes. However, none of the four groups

demonstrated an effect of previous predictability on Phase 2 learning. Such results were provided by both the gaze and the mouse data.

For the first group, the original design of Experiment 1 was applied and it aimed to replicate the outcome predictability effect observed in Experiment 1. Nonetheless, it was inconsistent with our expectation, learning about the prior predictable outcome did not differ from the prior less predictable outcome in Phase 2. Because the experimental design for Group 1 was exactly the same as for Experiment 1, their inconsistent results are not attributed to the manipulation of the outcome's predictability in Phase 1. Through Experiment 2 we noticed that the manipulation of the outcome presentation during the first two trials of Phase 2 can strongly affect learning in this phase. In particular, presenting o1- and o2-trial on the first two trials of Phase 2 could result in rapid learning about the o3's relationship. Thus, we carefully manipulated the presentation in the present experiment so that all trial types (o1-trial, o2-trial, o3-trial and no outcome trial) were equally frequently presented on the first trial of Phase 2 for all participants. Moreover, we considered that the manipulation of outcome presentation during only one single trial at the beginning should not be able to influence the whole phase learning. Hence, the results of the first group raised the question of whether the finding from Experiment 1 is replicable or if the effect really exists.

However, given that Group 1 received two trial types including the prior less predictable outcome (o2- and o3-trial) and one trial type including the prior predictable outcome (o1-trial), the prior predictable outcome was presented half as often as the prior less predictable outcome on the first trial in Phase 2. Thus, we cannot completely rule out an influence of the counterbalancing manipulation.

For the second group, the context was changed from Phase 1 to Phase 2. Based on our hypothesis, if the outcome predictability effect is context-dependent, we should not

observe the outcome predictability effect. In fact, the effect did not appear during the Phase 2 learning. According to the graphic, mouse data illustrated a relatively stronger preference for the prior predictable outcome in Phase 2. However, such a preference was not confirmed by the significance test. Because of the lack of the effect's replication in Group 1, it is impossible to conclude whether the results of Phase 2 learning in Group 2 were due to the context shift or the inexistence of the effect with our paradigm.

In the third group, one of the two less predictable outcomes was presented in the middle cave during Phase 1 and then removed from Phase 2 training. This manipulation aimed to reduce the interference of the middle cave preference since the other two outcomes were presented in the top and the bottom cave. This group determined whether a change of the outcome's number would affect the demonstration of the outcome predictability effect. Again, we did not observe a significant difference in Phase 2 learning based on the outcomes' predictability in Phase 1. In addition, we also noted the difference in graphs between the gaze data and mouse data. It seems that participants generally placed the cursor longer towards the o1 area than o2 area across blocks during the corresponding cues. Nonetheless, the discrepancy shown in the graph was not confirmed statistically. Since Group 1 did not replicate the outcome predictability effect observed in Experiment 1, it is unclear whether the results of Group 3 was due to the change of the outcome's number in Phase 2 or the inexistence of the effect.

The fourth group replicated Group 3 of Experiment 2, which executed both the outcome removal and the context shift. Neither the gaze data nor the mouse data revealed a difference in Phase 2 learning between two trial types.

In summary, because all four groups, in particular the first group, did not demonstrate a difference in Phase 2 learning about the outcomes that differed in the predictability in Phase 1, we noted the possibility that manipulating the predictability of

an outcome in our paradigm is not able to bias forming a novel association with this outcome in a subsequent training phase. Possibly, the finding of the outcome predictability effect observed in Experiment 1 is incidental and not replicable. Regarding this matter, it is pointless to discuss the impact of the context or the outcome removal on the outcome predictability effect if it still leaves open whether the finding of Experiment 1 is replicable and whether the effect does exist. Hence, it is essential to answer this question in the following experiment. Considering there are still some differences in manipulations between the present experiment and Experiment 1, such as counterbalancing manipulations and the outcome removal, the next experiment would remove all the additional manipulations.

2.4 Experiment 4

Since both Experiment 2 and 3 did not demonstrate the effect of outcome predictability on subsequent learning, we considered the possibility that the effect might be vulnerable. Possibly, some additional manipulations applied in Experiment 2 and 3, such like the counterbalancing of the outcome presentation in Phase 2, or the change in the number of outcomes, which had already shown some impacts on performances, might be responsible for the failed observation. Following this idea, we presented three outcomes for two training phases in the present experiment, in which one outcome (o1) was predictable in Phase 1 and the other two outcomes (o2 and o3) only partially predictable, and subsequently paired each of them with one novel cue in Phase 2. Moreover, the present experiment obtained the summer context for both training phases, and the outcome presentation for the early trials of Phase 2 were not explicitly manipulated. Instead, the order of trials was fully randomized by MATLAB which was exactly the same as Experiment 1.

2.4.1 Methods

Participants. Twenty-four undergraduate students from the Philipps-Universität Marburg, Germany (17 females, 7 males; M_{age}=22.88 years, age range 19-28) participated in this experiment and received course credit or payment (EUR € 7). Data from four additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used in Experiment 4 were the same as in Experiment 1 with only one exception: The auditory cues were presented for Phase 1 with a headset and the visual cues were showed for Phase 2 across all participants.

Design and Procedure. The design of Experiment 4 was exactly the same as Experiment 1. The experiment consisted of 132 trials. The Phase 1 trials were arranged into 12 blocks of eight trials (A→o1, A→o1, B→ Ø, B→ Ø, C→o2, C→o3, D→o2, D→o3), and Phase 2 contained 36 trials grouped into nine blocks, with the same outcomes as in Phase 1. However, this time each outcome was consistently preceded by a novel cue (W→o1, X→o2, Y→o3, Z→ Ø). A drift check was introduced to participants after the second training phase.

2.4.2 Results

Gaze data*. Phase 1.* Trials were grouped according to their outcome, resulting in three trial types (o1-trial, o2-trial, o3-trial). Dwell time in each trial type was averaged across the two trials within each block. Figure 2.4.1 (left) shows the mean proportion of dwell time that participants spent looking at the correct outcome area per block across the 12 blocks of Phase 1. The dwell time towards the o1 area during o1 trials increased across blocks, and reached the peak of 0.4 on Block 8 and then declined to the level of 0.34 on the last block, while the correct responses to the cues associated with o2 and o3 remained relatively low.

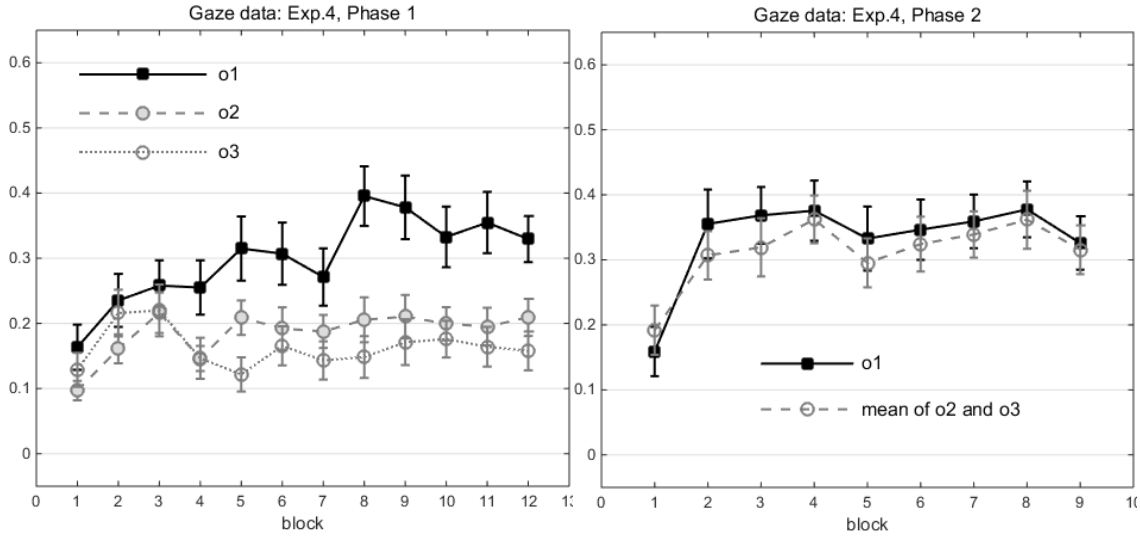


Figure 2.4.1. Gaze data of Experiment 4. The left panel shows mean proportion of dwell time that participants gazed at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of dwell time across nine blocks in Phase 2, wherein dwell time was averaged based on the predictability of each trial's outcome during Phase 1.

We analyzed data using a 3 (outcome: o1, o2, or o3) × 3 (cave condition: o1 in top, bottom, or middle cave) × 12 (block: 1-12) ANOVA in which outcome and block were within-subjects factors. This analysis revealed a main effect of outcome, $F(2,42)=21.22$, $p<.001$, $\eta^2=.503$, with significant contrasts regarding the comparison between o1 and both o2 and o3 trials, but not o2 versus o3, $F_{o1vs.o2}=19.68$, $p<.001$, $F_{o1vs.o3}=28.41$, $p<.001$, $F_{o2vs.o3}=2.55$, $p=.125$, indicating that participants gazed longer at the o1 cave than they did to the o2 or o3 caves during the corresponding cues. We also noted a significant main effect of block $F(11,231)=4.49$, $p<.01$, $\eta^2=.176$, showing that the accuracy of the anticipatory gaze increased across blocks. More importantly, a significant outcome × block interaction became apparent, $F(22,462)=2.81$, $p<.01$, $\eta^2=.118$, reflecting that the increase in dwell time proceeded differently according to the outcome's predictability. Additionally, a significant outcome × cave condition interaction, $F(4,42)=12.09$, $p<.001$, $\eta^2=.535$, suggested that participants looked at the middle cave

generally longer than at the other two. None of the other main effects and interactions were significant (largest F=1.42, corresponding p=.143).

Phase 2. The right panel of Figure 2.4.1 shows the Phase 2 dwell time. It was averaged based on the predictability of each outcome during Phase 1. The anticipatory gaze towards the cave of the previously predictable outcome o1 seems to be higher than the dwell time towards the caves of the previously less predictable outcomes.

We analyzed data with 2 (outcome predictability: previously predictable or less predictable) × 3 (cave condition: o1 in top, bottom or middle cave) × 9 (block: 1-9) ANOVA with repeated measures on predictability and block. In contrast to the descriptive analyses, neither outcome predictability, $F(1,21)=1.04$, p=.320, nor its interaction with block, $F(8,168)<1$, reached significance. The main effect of block became significant $F(8,168)=7.05$, $p<.001$, η^2=.251. In addition, the counterbalancing factor cave condition interacted with outcome predictability, $F(2,21)=4.03$, $p<.05$, η^2=.277, indicating longer dwell time towards the middle cave. None of the other main effects and interactions were significant (largest F=2.05, corresponding p=.154). In an analog Bayesian repeated measures ANOVA, a BF of 3.95 substantially supported the model containing the main effect of cave condition and block over the model with all three main effects. Moreover, a BF of 122.09 provided very strong evidence for the main effects model over the model including the additional outcome predictability × block interaction.

Mouse data. *Phase 1.* Mouse movements during the tasks were captured and used as an additional indicator of learning. It was similar to the analyses of gaze data that three trial types were calculated based on the outcome (o1-trial, o2-trial, o3-trial). Figure 2.4.2 (left) shows the mean proportion of time that participants positioned the cursor at the goal area per block across the 12 blocks of Phase 1. The time towards the o1 area during cue

A increased across blocks, and reached the peak on Block 8, while the correct responses to the cues associated with o2 and o3 remained relatively low.

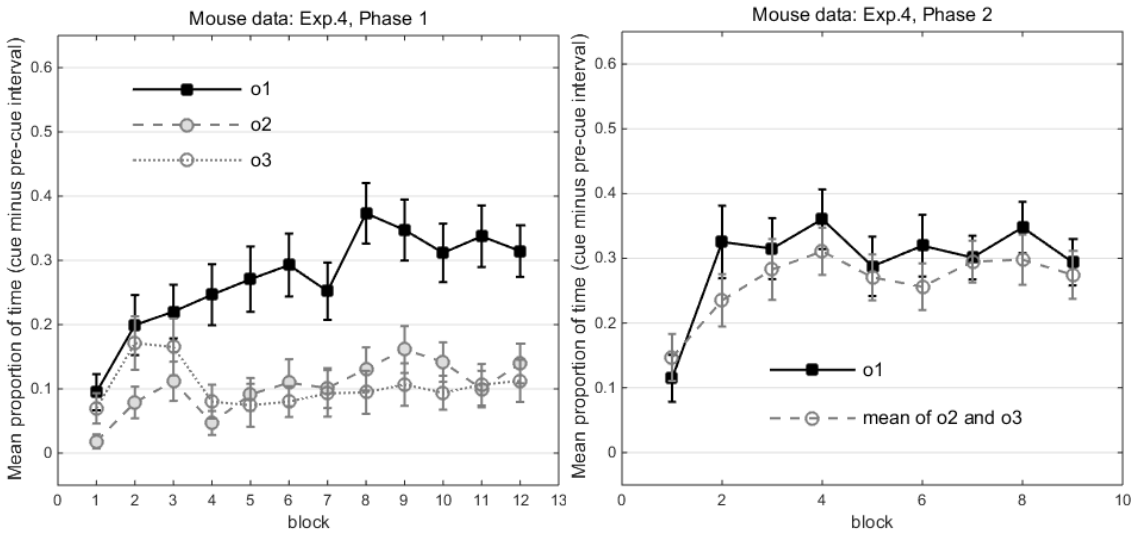


Figure 2.4.2. Mouse data of Experiment 4. The left panel shows mean proportion of time that participants placed cursor at the correct outcome's cave per block across the 12 blocks in Phase 1. The right panel shows mean proportion of mouse time across nine blocks in Phase 2, wherein it was averaged based on the predictability of each trial's outcome during Phase 1.

The data were entered into a 3 (outcome: o1, o2, or o3) × 3 (cave condition: o1 in top, bottom, or middle cave) × 12 (block: 1-12) ANOVA in which outcome and block were within-subjects factors. The main effect of outcome was significant, $F(2,42)=30.42$, $p<.001$, $\eta^2=.592$, and it yielded a significant contrasts regarding the comparison between o1 and both o2 and o3 trials, $F_{o1vs.o2}=34.25$, $p<.001$, $F_{o1vs.o3}=33.69$, $p<.001$, $F_{o2vs.o3}<1$. This suggested that participants positioned the cursor longer at the o1 cave during cue A than they did to the outcome o2 or o3 caves during cues C and D. A significant main effect of block $F(11,231)=5.75$, $p<.001$, $\eta^2=.215$, indicated that the accurate responses increased across blocks. More importantly, the outcome × block interaction was significant, $F(22,462)=2.94$, $p<.01$, $\eta^2=.123$, reflecting that the reaction during different trial types increased differently across blocks. In addition, we noted a significant cave

condition × outcome interaction, $F(4,42)=10.53$, $p<.001$, $\eta^2=.501$. None of the other main effects and interactions were significant (largest $F=1.03$, corresponding $p=.432$).

Phase 2. Figure 2.4.2 (right) shows Phase 2 learning based on mouse data. The time participants positioned the cursor around the goal area was averaged based on the predictability of each outcome during Phase 1. It is similar to the gaze data, responses during o1 trials increased rapidly and remained relatively higher than responses during o2 and o3 trials.

We conducted a 2 (outcome predictability: previously predictable or less predictable) × 3 (cave condition: o1 in top, bottom or middle cave) × 9 (block: 1-9) ANOVA with repeated measures on outcome predictability and block. In contrast to the descriptive analyses, the main effect of outcome predictability did not reach significance, $F(1,21)=1.72$, $p=.203$, nor its interaction with block, $F(8,168)<1$. The main effect of block was again significant $F(8,168)=6.79$, $p<.001$, $\eta^2=.244$. None of the other main effects and interactions were significant (largest $F=3.27$, corresponding $p=.058$). In the analog Bayesian repeated measures ANOVA, a BF of 1.22 provided only anecdotal evidence for the model containing the main effect of cave condition and block over the model with all three main effects. In addition, a BF of 65.45 provided very strong evidence for the main effects model over the model including an additional outcome predictability × block interaction.

2.4.3 Discussion

The present experiment executed the replication of Experiment 1. In line with Experiment 2 and 3, we did not observe a significant difference in subsequent learning about the outcomes which differed in predictability in the previous training phase.

According to both the gaze and the mouse data, participants successfully learned the cue-outcome relationships and performed differently in anticipation of the predictable

and the less predictable outcome in the first training phase. For the second phase, data based on both measurements showed a tendency that the prior predictable outcome was more readily associated with a novel cue than the prior less predictable outcomes. However, such a difference was not statistically confirmed. Such results suggest a possibility that the effect of outcome predictability on subsequent learning is not robust enough to be reliably observed in the present paradigm.

Further, considering that Griffiths et al. (2015) reliably demonstrated the same effect in their all experiments which contained the completely different designs as ours, it is arguable whether the paradigm or the manipulation of the predictability can have a strong influence on the demonstration of the effect. For instance, in their experiment, the predictable and the unpredictable outcome were presented in compound which might encourage the competition between outcomes, which can lead to the greater subjective discrepancy in the predictability of outcomes and demonstrate a stronger effect on subsequent learning. Moreover, some manipulations in their experiments, like adding additional nonpredictive cues in the second phase, can also lead to inferential reasoning to some degree, resulting in a better discrimination of the previous predictability of the outcome in the rating test. In fact, Thorwart, Livesey, Wilhelm, Liu & Lachnit (2017) also successfully demonstrated the effect of outcome predictability on later learning with the same design as applied by Griffiths and colleagues (2015). Thus, it is possible that the reliable observation of the outcome predictability effect depends on how we manipulate the outcome predictability. Based on this consideration, we approached the different manipulations of the outcome predictability in the next experiments.

Chapter 3: Empirical Study II

According to the first four experiments, it seems that the manipulation of outcome predictability applied in the previous experiments (Design 1) cannot reliably demonstrate an effect on subsequent learning. Thus, we developed two designs (Design 2 and 3) in the following experiments to operate outcome predictability. The experiments described in this chapter had two goals: First, to investigate whether these two manipulations of the outcome's predictability in the initial training can exert an effect on subsequent learning in our paradigm and, secondly, to shed light on the possible mechanism.

For one group of Experiment 5 and Experiment 7, we reduced the predictability of an outcome (o2) by using a partial reinforcement procedure in the first training phase. In particular, o2 appeared only half of the time when its corresponding cue C was presented and therefore, it was only partly predictable. On the contrary, outcome o1 was consistently predictable by cue A (A→o1, C→o2, C→Ø). Since C was not able to reliably predict the occurrence of o2, o2 obtained lower predictability than o1. If the difference in outcome predictability could influence later learning, we would expect that learning about the o1's novel relationship would differ from learning about the o2 in Phase 2, when each outcome was fully predicted by novel cues.

For the other group of Experiment 5 and Experiment 6, outcome o2 was also only partly predictable in the initial training phase, since it was predicted by cue C half of the time and presented *without* any cue the other half of the time. In contrast, o1 was, again, consistently predictable by cue A (A→o1, C→o2, Ø→o2). If learning about o1 and o2 in the second phase were different from each other, when each of them was fully predicted by novel cues, it should be due to their different predictability learned from Phase 1. Moreover, since o2 was presented without signaling half of the time, we

expected that o2 would be more strongly associated with the contextual cues. In line with the US preexposure effect, the stronger context-o2 association formed in Phase 1 should retard novel cues to be associated with o2 in the subsequent phase. Thus, we particularly expected that the conduction of Design 3 would result in better learning about the cues associated with o1 than the cues associated with o2 in a subsequent phase.

Precise prediction of learning performance based on two designs was described in Experiment 5, since we executed computational simulations for both groups of Experiment 5. Furthermore, it is also notable that these two designs contained only two outcomes, so that the interference of the middle cave preference can be minimized.

3.1 Experiment 5

The present experiment consisted of two groups in which two different manipulations of outcome predictability were conducted respectively. For both groups, outcome o1 and o2 differed in their predictability during the initial training phase (see Table 3.1.1). Moreover, Cue B predicted the absence of any outcome to ensure that participants did not simply shift their attention to the caves at the onset of *any* discrete cue, without learning about the particular relationships between cues and outcomes. In the second phase, each outcome was consistently predicted by a novel cue. If we observed a difference in learning about the o1's and the o2's novel relationship in Phase 2, it should be due to the manipulation of outcome predictability applied in Phase 1. Furthermore, the Z- trial presented in Phase 2 had the same function as B- trial in the first Phase.

Table 3.1.1
Design of Experiment 5

	Phase 1	Phase 2
Group 1	A → o1, B → Ø,	X → o1, Y → o2
	C → o2, C → Ø	Z → Ø
Group 2	A → o1, A → o1, B → Ø,	X → o1, Y → o2
	B → Ø, C → o2, Ø → o2	Z → Ø

Note. Letters A-Z denote visual and auditory cues that were always followed by one of the two outcomes (i.e., the eyes of one of the animals in the experimental task): o1 was the fully predictable outcome, o2 was less predictable. Cues B and Z were followed by the absence of any outcome, denoted as Ø. For Group 2, o2 was presented *without* the presentation of cues on some trials, denoted as Ø.

Moreover, we made the predictions of two designs by using the simulation software ALTSim (Thorwart, Schultheis, König & Lachnit, 2009). The simulation was based on the Rescorla-Wagner Model (Rescorla & Wagner, 1972) which describes the change in associative strength between cues and *single* outcome as a result of conditioning. For the present experiment, we developed the calculation model since our designs obtained two outcomes. In addition, we introduced a contextual cue *Co* to determine to what degree the outcome would possibly be associated with the context. Since the context was consistently presented during the experiment, the responses during the presentation of a cue were actually activated by the cue-context compound. The inter-stimulus interval (ISI, interval between the offset of one cue to the onset of another) was considered the Co-Ø trial. Thus, the trials of the original design were transformed as shown in Table 3.1.2. The associability of the discrete cues (.6) was chosen to be higher than the contextual cue (.2) as they are more salient and relevant to the outcome than the context.

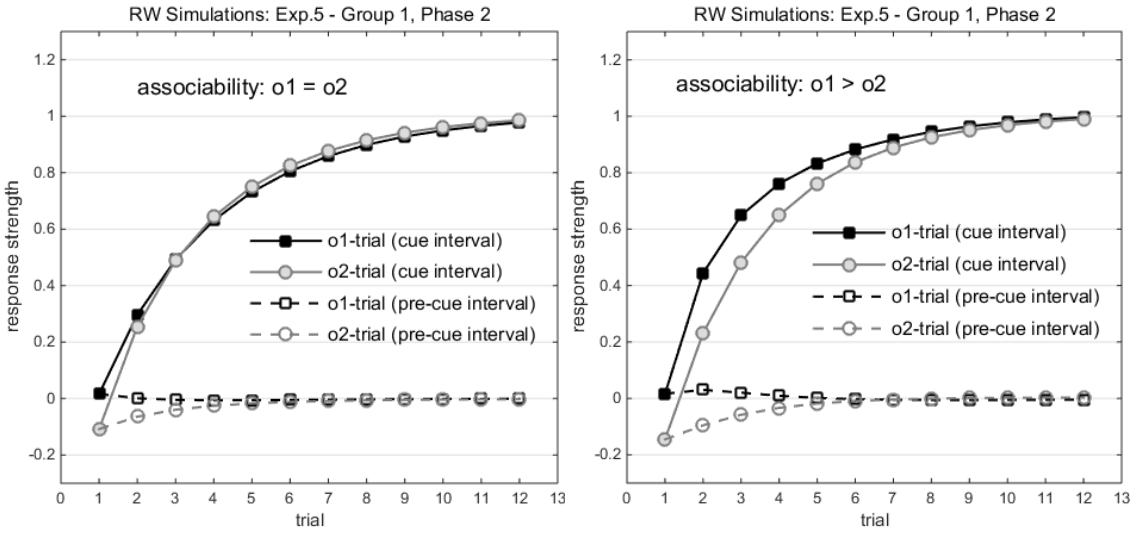
Table 3.1.2
Simulation for Experiment 5

	Phase 1	Phase 2
Group 1	A*Co* → o1, *Co* → Ø, B*Co* → Ø, *Co* → Ø	X*Co* → o1, *Co* → Ø
	C*Co*→ o2, *Co* → Ø, C*Co* → Ø, *Co* → Ø	Y*Co* → o2, *Co* → Ø
		Z*Co* → Ø, *Co* → Ø

Group 2	A*Co* → o1, *Co* → Ø, A*Co* → o1, *Co* → Ø	X*Co* → o1, *Co* → Ø
	B*Co* → Ø, *Co* → Ø, B*Co* → Ø, *Co* → Ø	Y*Co* → o2, *Co* → Ø
	C*Co*→ o2, *Co* → Ø, *Co* → o2, *Co* → Ø	Z*Co* → Ø, *Co* → Ø

Note. Letters A-Z denote cues and Co denotes the context. Cue-context compound was followed by one of the two outcomes (o1 and o2). The absence of stimuli is donated as Ø.

Firstly, we simulated the Phase 1 learning of two groups to determine the associative strength between every cue and outcome. The simulation was conducted with 24 blocks for Group 1 and 15 blocks for Group 2 as used in the experiment. It was consistent with our expectation that in both groups the associative strength between cue A and o1 was close to 1 at the end (.98 for Group 1 and .99 for Group 2) and greater than the associative strength between cue C and o2 (.56 for Group 1 and .81 for Group 2). Notably, the simulation predicted that the contextual cue would be barely associated with either of the two outcomes after Phase 1 learning for Group 1 (.01 for Co-o1, 0 for Co-o2). However, for Group 2, o2 would be relatively stronger associated with the contextual cue, while o1 would not (.01 for Co-o1 and .25 for Co-o2). This contextual association was then set to Phase 2 simulation since the context remained the same as in Phase 1.



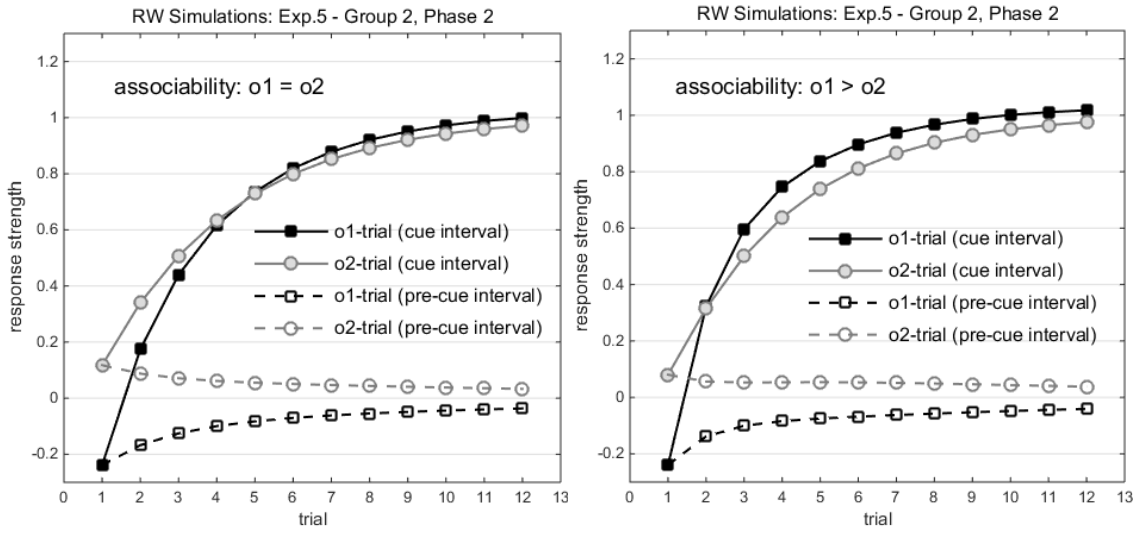


Figure 3.1.1. Simulations of Phase 2 learning based on Rescorla-Wagner Model for Group 1 (top figures) and Group 2 (bottom figures). The solid lines represent responding to the cue *during* the presence of cues in anticipation of two outcomes that differed in their predictability in Phase 1, while the dashed lines represent approach towards the outcome area *prior* to the presence of cues. The left two panels simulate Phase 2 learning, when two outcomes obtain the same associability in Phase 2, and the right two panels simulate Phase 2 learning when o1 obtains greater associability than o2 in Phase 2.

For the simulation of Phase 2 learning, we proposed two possibilities. First, the associability of the prior predictable outcome o1 increases and therefore is greater than o2. Second, the associability of o1 does not change and then equals the associability of o2. The upper panels of Figure 3.1.1 illustrate the responses of Group 1 during Phase 2 learning (left: $\beta_{o1} = \beta_{o2,}$ right: $\beta_{o1} > \beta_{o2}$), while the bottom panels predict Group 2 learning (left: $\beta_{o1} = \beta_{o2,}$ right: $\beta_{o1} > \beta_{o2}$). Because the RW-Model describes the change in associative strength with a single outcome, the associative strength between cues and each outcome was calculated separately. Afterwards, the prediction of one outcome on a given trial was calculated by using its associative strength with the cue (or cue compound) subtracting the association between this cue (or cue compound) and the other outcome on this trial. For instance, the prediction of o1 on an X-o1 trial was XCo-o1 association minus XCo-o2. In this way, Figure 3.1.1 represents the predicted responses to a given cue in anticipation of one certain outcome on every trial as the actual behavior data. The solid

line indicates the responses during the presentation of the cue (i.e. cue interval), whereas the dashed line suggests the behavior during the pre-cue interval when the cue is absent.

For Group 1, the simulation predicted a difference in anticipation of o1 and o2 during the cue interval only when the associability of o1 is greater than o2. Thus, if we observed a difference in Phase 2 learning for Group 1, it should be due to a change in the outcome's associability formed by Phase 1 learning.

For Group 2, if the associability of o1 is the same to o2, we might not observe a difference in responses between the two trial types during the cue interval in Phase 2, since responses during the cue interval were activated by the cue-context compound. However, o2 would be relatively stronger associated with the context during Phase 2 training, suggesting that participants might spend longer looking at the o2 area than o1 area during the pre-cue interval. In addition, if the associability of o1 is greater than o2, participants would still manifest a stronger preference for the o2 than o1 area during the pre-cue interval. Nevertheless, a stronger response in anticipation of o2 than o1 during the cue interval would only appear during the early trials of Phase 2. After a few trials, the responses to X would increase more rapidly than to Y.

Through comparison of the data between two groups, we are able to detect the possible mechanisms underlying the outcome predictability effect. In particular, if the effect is mediated by a change in the outcome's associability, rather than a blocking effect caused by context, we would expect more rapid learning about the prior predictable outcome than the prior less predictable outcome during Phase 2 training observed in Group 1. On the contrary, if the effect relies on an influence of context rather than a change in the outcome's associability, the effect should be only observed in Group 2, but not in Group 1.

3.1.1 Methods

Participants. Sixty-four undergraduate students from the Philipps-Universität Marburg, Germany (45 females, 19 males; M_{age}=22.84 years, age range 19-47 years; 32 participants in each group) participated in the experiment and received course credit or payment (EUR € 7). Data from seven additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used were similar to the previous experiments. Two outcomes as well as two caves were presented to participants during two training phases. The positions of two outcomes were counterbalanced. The cues within one learning phases were from the same modalities and the order of the two modalities (auditory vs. visual) were counterbalanced. Moreover, the sequence of outcomes' presentation during the first two trials in Phase 2 was counterbalanced (o1- and o2-trial or o2- and o1-trial).

Design and Procedure. The design of Experiment 5 was showed in Table 3.1.1. For Group 1, 96 trials were given in Phase 1, grouped into 24 blocks (A→o1, B→Ø, C→o2, C→Ø) and 36 trials in Phase 2 were grouped into 12 blocks (X→o1, Y→o2, Z→Ø). For Group 2, Phase 1 training contained 90 trials grouped into 15 blocks (A→o1, A→o1, B→ Ø, B→ Ø, C→o2, Ø→o2) and 36 trials were arranged into 12 blocks in Phase 2 (X→o1, Y→o2, Z→Ø). The trial order was randomized within every three blocks. Furthermore, we manipulated the presentation of the first two trials in Phase 2 training. A drift check was introduced to participants after each training phase.

3.1.2 Results

Gaze data*. Phase 1.* For Group 1, dwell time in responding to cue C was averaged across the two trials within each block (C→o2 and C→Ø), and referred to as o2-trial. For Group 2, trials were grouped according to their outcome, resulting in two trial types (o1-

trial, o2-trial). However, because participants were unable to predict o2 without signaling and perform an appropriate response, dwell time during the Ø→o2 trial was not entered into analyses. Further, dwell time in responding to cue A was averaged across the two trials within each block. Figure 3.1.2 and 3.1.3 (left panels) represent how long participants of two groups gazed at the goal area during the cue and the pre-cue interval in Phase 1 respectively. The black lines illustrate responses during o1-trials, while the gray lines were for o2-trials. Moreover, gaze time during the cue and the pre-cue interval was illustrated separately (solid vs. dashed line), since we considered that responses during the pre-cue interval might indicate the contextual associations. Notably, for the main analyses we still used the *dwell time*, as the time participants spent looking at the goal area during the cue interval minus the gaze time during the pre-cue interval, to indicate the association between the discrete cue and the outcome.

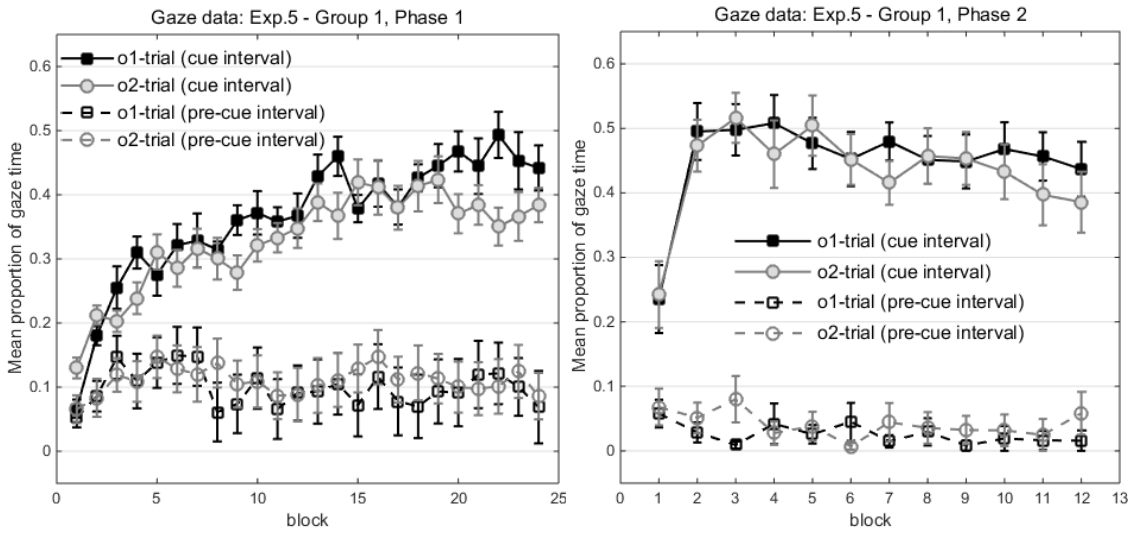


Figure 3.1.2. Gaze data of Group 1 in Experiment 5. The left panel shows mean proportion of time that participants gazed at the goal area during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks in Phase 1. The right panel shows mean proportion of gaze time during the cue and the pre-cue interval across 12 blocks in Phase 2.

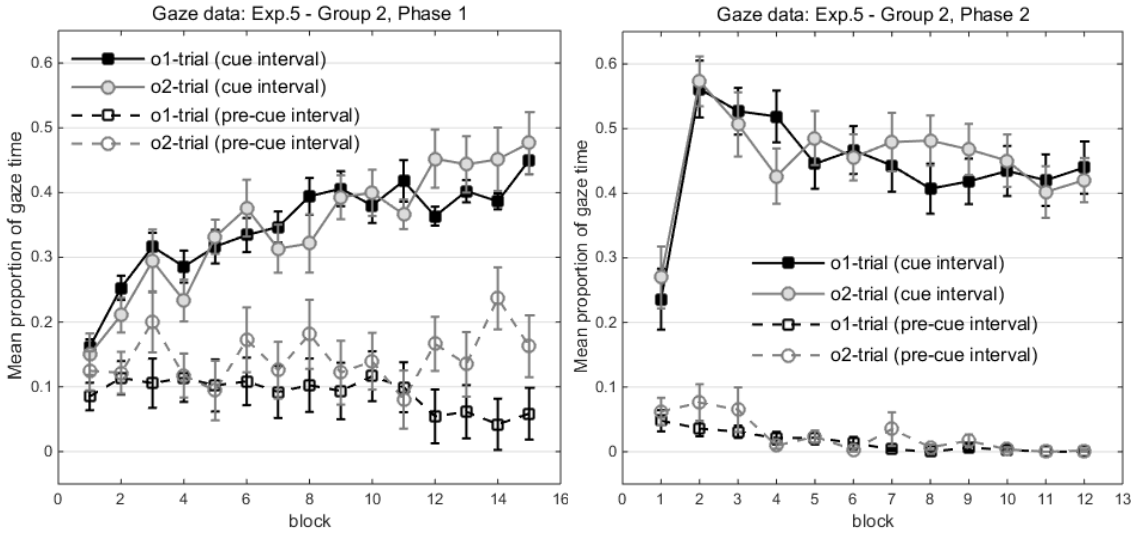


Figure 3.1.3. Gaze data of Group 2 in Experiment 5. The left panel shows mean proportion of time that participants gazed at the goal area during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 15 blocks in Phase 1. The right panel shows mean proportion of gaze time during the cue and the pre-cue interval across 12 blocks in Phase 2.

The left panel of Figure 3.1.2 illustrates the Phase 1 learning of Group 1. Participants spent more time looking at the o1 area *during* the presentation of cue A across blocks of Phase 1, compared to looking at the o2 area *during* C. Moreover, during the *pre-cue* interval, gaze time towards o1 and o2 area both maintained low and was not different from one another.

The data were entered into a 2 (predictability: predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) × 24 (block: 1-24) ANOVA in which predictability and block were within-subjects factors. The factor predictability showed a significant main effect, $F(1,30)=8.97$, $p<.01$, $\eta^2=.230$, indicating that participants gazed longer at the o1 cave than they did to the o2 cave during the corresponding cues. The test also revealed a significant main effect of block $F(23,690)=7.04$, $p<.001$, $\eta^2=.190$, showing that the accuracy of the anticipatory gaze increased across blocks. However, the predictability × block interaction did not reach the significance, $F(23,690)=1.32$, $p=.217$.

None of the other main effects and interactions were significant (largest F=1.09, corresponding p=.370).

In addition, we analyzed gaze time during the cue and the pre-cue interval separately by using the analog ANOVA test for each interval. For responses during the *cue interval*, the factor predictability showed a trend that participants spent more time looking at the o1 area than o2 area, $F(1,30)=4.03$, $p=.054$. Moreover, the predictability × block interaction also revealed a trend that this difference in gaze time towards the predictable and the less predictable outcome increased across blocks, $F(23,690)=1.62$, $p=.096$. The main effect of block was, again, significant, $F(23,690)=9.43$, $p<.001$, $\eta^2=.239$. Additionally, we also noted an impact of cave condition which significantly interacted with predictability, $F(1,30)=4.41$, $p<.05$, $\eta^2=.128$. No further main effect nor interaction reached the significance (largest F=.84, corresponding p=.367).

For the responses during the *pre-cue interval*, neither the main effect of predictability, $F(1,30)=1.17$, $p=.288$, nor its interaction with block, $F(23,690)<1$, reached significance. We only observed a significant predictability × cave condition interaction, $F(1,30)=15.48$, $p<.001$, $\eta^2=340$, indicating that participants favored the upper cave than the bottom cave. None of the other main effects and interactions were significant (largest F=2.15, corresponding p=.153).

The left panel of Figure 3.1.3 represents Phase 1 learning of Group 2. During the cue interval, the increment of gaze time in anticipation of the predictable outcome o1 is similar to the less predictable outcome o2. On the contrary, participants generally gazed longer at the cave of o2 than o1 across blocks, when the cue was *not* presented (i.e. pre-cue interval).

The data was analyzed by using a 2 (predictability: predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) × 15 (block: 1-15) ANOVA in which

predictability and block were within-subjects factors. A significant main effect of predictability showed longer dwell time in anticipation of o1 than o2 in general, $F(1,30)=11.00$, $p<.01$, $\eta^2=.268$. However, its interaction with block was not significant, $F(14,420)=1.14$, $p=.321$. Furthermore, the factor block revealed a significant main effect, $F(14,420)=8.49$, $p<.001$, $\eta^2=.220$. In addition, the counterbalancing factor cave condition also showed an impact on participants' performance: The predictability × cave condition × block interaction was significant, $F(14,420)=1.80$, $p<.05$, $\eta^2=.057$. No further main effects nor interactions were significant (largest $F=1.31$, corresponding $p=.261$).

In following we examined the gaze behavior during the cue and the pre-cue interval separately by using the analog ANOVA tests. For the cue interval, neither the main effect of predictability, $F(1,30)<1$, nor its interaction with block, $F(14,420)=1.66$, $p=.061$, reached significance. The main effect of block was significant, $F(14,420)=11.98$, $p<.001$, $\eta^2=.285$. In addition, the significant predictability × cave condition interaction indicated a preference for the upper cave over the bottom one, $F(1,30)=10.04$, $p<.01$, $\eta^2=.251$. None of the other main effects and interactions were significant (largest $F=1.13$, corresponding $p=.332$).

For the pre-cue interval, predictability revealed a significant main effect, $F(1,30)=16.69$, $p<.001$, $\eta^2=.358$, and significantly interacted with block, $F(14,420)=2.37$, $p<.05$, $\eta^2=.073$, suggesting that participants gazed longer at the area of o2 than o1 when the cue was *not* presented, and this difference increased across blocks during Phase 1 learning. In addition, the predictability × cave condition interaction was also significant, $F(1,30)=9.07$, $p<.01$, $\eta^2=.232$. None of the other main effects and interactions were significant (largest $F=1.40$, corresponding $p=.201$).

Phase 2. The right panels of Figure 3.1.2 and 3.1.3 illustrate the Phase 2 learning for Group 1 and Group 2, in which the prior predictable outcome o1 and the prior less

predictable outcome o2 were consistently predicted by novel cues. For the first group, gaze time towards the o1 and the o2 area rapidly inreased within the first three blocks and then slightly declined during the remaining blocks, *when* the corresponding cue was presented (i.e. cue interval). Notably, there was no difference in gaze time between o1- and o2-trials during the cue interval. In contrast, gaze time towards the cave of o2 was a little bit longer than looking at the cave of o1 during the most blocks of Phase 2, *before* the corresponding cue was presented (i.e. pre-cue interval). For the second group, gaze time towards the o1 and the o2 area immediately increased from Block 1 to Block 2 and then declined across the rest blocks *during* the presentation of cues. However, *before* the presentation of cues, participants gazed slightly longer at the cave of o2 than o1, especially during the first three blocks.

The data of two groups were compared by using a 2 (outcome predictability: previously predictable or less predictable) × 2 (Group 1 or 2) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on predictability and block. The factor outcome predictability revealed a non-significant trend that participants spent more time looking at the o1's area than o2 across two groups, $F(1,60)=3.21$, $p=.078$. However, neither the outcome predictability × group interaction, $F(1,60)=2.65$, $p=.109$, nor the outcome predictability × group × block interaction, $F(11,660)<1$, reached significance. This suggests that learning about the novel relationships of the outcomes in Group 1 did not differ from Group 2 based on the previous predictability of the outcomes. Only the main effect of block was significant, $F(11,660) =16.01$, $p<.001$, $\eta^2=.211$. None of the other main effects and interactions reached significance (largest $F=3.80$, corresponding $p=.056$). In addition, in the analog Bayesian repeated measures ANOVA, a BF of 5 substantially supported the model containing main effects of all factors over the model including an additional group ×

predictability interaction. Furthermore, a BF of 591.89 provided decisive evidence for the model with all main effects and all two-way interactions within factor group, oucome predictability and block over the model including an additional group × outcome predictability × block interaction.

Since outcome predictability yielded a non-significant trend in the last analysis, we further examined the Phase 2 learning of each group separately. A 2 (outcome predictability: previously predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on predictability and block was conducted to analyze two groups' data respectively.

For Group 1, the factor outcome predictability revealed a significant main effect, $F(1,30)=6.66$, $p<.05$, $\eta^2=.182$, suggesting that participants gazed longer at the o1 cave than o2 cave during Phase 2 learning. However, the outcome predictability × block interaction was not significant, $F(11,330)<1$. The main effect of block was, again, significant, $F(11,330)=7.88$, $p<.001$, $\eta^2=.208$. None of the other main effects and interactions reached significance (largest $F=3.53$, corresponding $p=.070$).

Furthermore, gaze time of Group 1 during the cue interval and the pre-cue interval was examined separately, by using the analog ANOVA test with repeated measures on outcome predictability and block. For the cue interval, neither the main effect of predictability, $F(1,30)=6.66$, $p=.162$, nor its interaction with block, $F(11,330)<1$, was significant. This indicated that responses during o1- and o2-trials did not differ from one another, *when* the cue was presented. We only observed a significant main effect of block, $F(11,330)=7.53$, $p<.001$, $\eta^2=.201$, and a significant cave condition × outcome predictability interaction, $F(1,30)=9.03$, $p<.01$, $\eta^2=.231$. No further main effects or interactions was significant (largest $F=1.56$, corresponding $p=.174$). A Bayes factor of 5.75 provided substantial evidence for the model containing the main effect of cave

condition and block over the model with all three main effects. Moreover, a BF of 406.74 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval, we observed a significant main effect of outcome predictability, $F(1,30)=4.85$, $p<.05$, $\eta^2=.139$, showing that participants gazed longer at the o2 cave than o1 cave when the cue was *not* presented. None of the other main effects and interactions reached significance (largest $F=3.55$, corresponding $p=.069$).

For Group 2, the main analysis did not show a significant main effect of outcome predictability, $F(1,30)<1$, nor a significant outcome predictability × block interaction, $F(11,330)<1$. So learning about the prior predictable outcome o1 and the prior less predictable outcome o2 was not different from one another. Only block revealed a significant main effect, $F(11,330)=8.53$, $p<.001$, $\eta^2=.221$. None of the other main effects and interactions reached the significance (largest $F=.96$, corresponding $p=.458$). A BF of 12.67 strongly supported the model containing the main effect of cave condition and block over the model with all three main effects, while a BF of 223.85 provided decisive evidence for the main effects model over the model including an additional outcome predictability × block interaction.

Moreover, we also analyzed the performances of Group 2 during the cue and the pre-cue interval separately by using the analog ANOVA test. For the cue interval, neither the main effect of predictability, $F(1,30)<1$, nor the outcome predictability × block interaction, $F(11,330)<1$, was significant. We only observed a significant main effect of block, $F(11,330)=8.81$, $p<.001$, $\eta^2=.227$. None of the other main effects and interactions was significant (largest $F=1.43$, corresponding $p=.204$). A Bayes factor of 10.33 provided strong evidence for the model containing the main effect of cave condition and block over the model with all three main effects. In addition, a BF of 144.23 decisively supported

the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval in Phase 2 training, outcome predictability showed a non-significant trend that participants spent longer time looking at the o2 cave than o1, when the cue was *not* presented, $F(1,30)=4.00$, $p=.055$. Moreover, the main effect of block became significant, $F(11,330)=4.81$, $p<.01$, $\eta^2=.138$. No further main effects or interactions reached the significance (largest $F=1.39$, corresponding $p=.246$).

Mouse data. In addition, we captured the locations of the cursor during the tasks to determine the hand movements in the preparation of the outcome's appearance, which can also indicate learning. Figure 3.1.4 and 3.1.5 illustrate the mean proportion of time that participants of the two groups placed the cursor within the goal area *during* the presentation of the corresponding cues (i.e. solid lines for the cue interval) and shortly *before* the presentation of the corresponding cues (i.e. dashed lines for the pre-cue interval) in two phases, respectively.

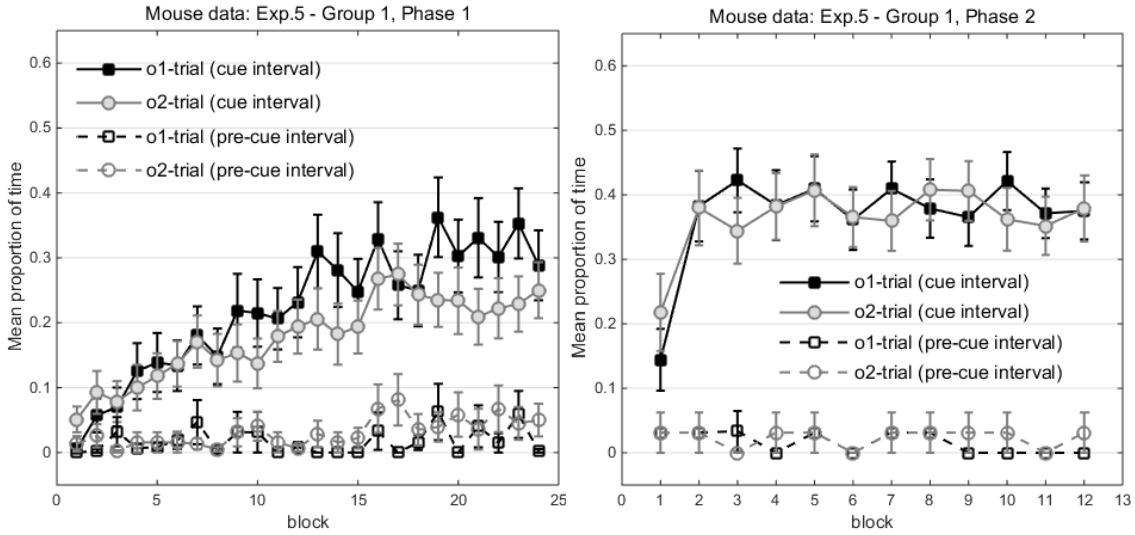


Figure 3.1.4. Mouse data of Group 1 in Experiment 5. The left panel shows mean proportion of time that participants placed the cursor at the goal area during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks in Phase 1. The right panel shows mean proportion of mouse time during the cue and the pre-cue interval across 12 blocks in Phase 2.

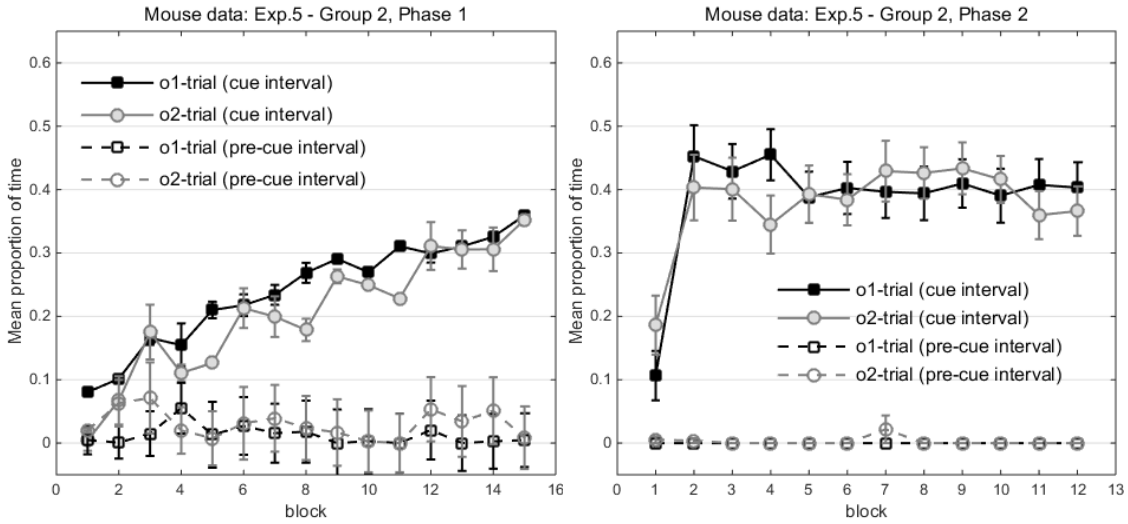


Figure 3.1.5. Mouse data of Group 2 in Experiment 5. The left panel shows mean proportion of time that participants placed the cursor at the goal area during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 15 blocks in Phase 1. The right panel shows mean proportion of mouse time during the cue and the pre-cue interval across 12 blocks in Phase 2.

Phase 1. The left panels of Figure 3.1.4 and 3.1.5 display the Phase 1 learning of two groups, in which the black lines represent responses in preparation of o1 and the gray lines for o2. In both groups, responses during the *cue interval* increased across the blocks, while responses during the *pre-cue interval* generally remained low. For Group 1, responses to cue C was averaged across the two trials within each block (C→o2 and C→Ø) and referred to as o2-trial. For Group 2, responses during the Ø→o2 trial was not entered into analyses. Moreover, responses to cue A was averaged across the two trials within each block.

For the first group, participants put the cursor longer around the cave of o1 than o2 across the blocks, *when* the cue was presented (i.e. cue interval). However, this difference was not showed during the pre-cue interval: The time participants placed the cursor around the o1's and the o2's area both remained low *before* the presentation of the cues. In the second group, participants placed the cursor longer around the o1 cave than the o2 cave during the *cue interval* across the first 12 blocks. On the contrary, when the

cue was *not* presented (i.e. pre-cue interval), participants showed a preference for the less predictable outcome o2 over the predictable outcome o1 at the beginning (from Block 2 to 3) as well as the end of Phase 1 (from Block 12 to 14).

We analyzed the data of two groups (cue interval minus pre-cue interval) by using an ANOVA with the factor predictability (predictable vs. less predictable), cave condition (o1 in top vs. bottom cave) and block (for Group 1: 1-24; for Group 2: 1-15), in which predictability and block were within-subjects factors. Moreover, we also used this ANOVA test to examine responses during the cue and the pre-cue interval separately.

For Group 1, the main analyses revealed a significant main effect of predictability, $F(1,30)=16.65$, $p<.001$, $\eta^2=.357$, and a significant predictability × block interaction, $F(23,690)=2.50$, $p<.01$, $\eta^2=.077$, suggesting that participants showed stronger responses in anticipation of the predictable outcome o1 than the less predictable outcome o2, and this difference increased across blocks. Furthermore, we also noted a significant main effect of block, $F(23,690)=5.66$, $p<.001$, $\eta^2=.159$. None of the other main effects and interactions were significant (largest $F=1.24$, corresponding $p=.274$).

Moreover, the additional analyses of the responses during the cue and the pre-cue interval confirmed the descriptive analyses. For the cue-interval, the main effect of predictability became significant, $F(1,30)=5.99$, $p<.05$, $\eta^2=.166$, indicating that the participants placed the cursor longer around the o1 cave than the o2 cave *during* the presentation of the corresponding cues. However, the predictability × block interaction was not significant, $F(23,690)=1.59$, $p=.124$. The factor block also revealed a significant main effect, $F(23,690)=6.59$, $p<.001$, $\eta^2=.180$. No further main effects or interactions were observed (largest $F=1.63$, corresponding $p=.212$). For the pre-cue interval, we did not observe any significant main effect or interaction, neither the main effect of

predictability, $F(1,30)=2.60$, $p=.117$, nor the predictability × block interaction, $F(23,690)=1.31$, $p=.271$.

For Group 2, the main analyses yielded a significant main effect of predictability, $F(1,30)=9.40$, $p<.01$, $\eta^2=239$, and a significant main effect of block, $F(14,420)=12.71$, $p<.001$, $\eta^2=.298$. However, the predictability × block interaction did not reach significance, $F(14,420)<1$. None of the other main effects and interactions were observed (largest $F=1.23$, corresponding $p=.288$).

Additionally, the mouse movements during the cue and the pre-cue interval were also examined. For the cue interval, the main effects of predictability, $F(1,30)=4.97$, $p<.05$, $\eta^2=142$, and block, $F(14,420)=11.67$, $p<.001$, $\eta^2=.280$, appeared significant. However, we did not observe a significant predictability × block interaction, $F(14,420)<1$. No further main effects or interactions became significant (largest $F=1.60$, corresponding $p=.215$). For the pre-cue interval, we only found a non-significant trend that participants placed the cursor longer around the o2 cave than o1 cave, $F(1,30)=3.93$, $p=.057$. None of the other main effects and interactions reached the significance (largest $F=2.80$, corresponding $p=.107$).

Phase 2. The right panels of Figure 3.1.4 and 3.1.5 illustrate the performances of the participants in two groups during the cue and pre-cue interval, when the two outcomes were predicted by the novel cues in Phase 2. For Group 1, we did not observe any difference in mouse movement between the two trial types (X-o1 vs. Y-o2), neither during the cue interval nor the pre-cue interval. For Group 2, the time that participants spent placing their cursor around the o1 area *during* X (i.e. cue interval) rapidly increased across the first four blocks and then declined, while the time that cursor was put around the o2 area *during* Y increased across the first ten blocks. On the contrary, participants did not move the cursor towards the outcome area during the pre-cue interval.

We firstly compared the two groups by using a 2 (outcome predictability: previously predictable or less predictable) × 2 (Group 1 or 2) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on outcome predictability and block. We did not observe any difference in learning between two groups: Neither the outcome predictability × group interaction, $F(1,60)<1$, nor the three-way interaction between outcome predictability, group and block, $F(11,660)<1$, became significant. Moreover, outcome predictability did not reveal a significant effect, $F(1,30)=1.20$, $p=.277$. Only the main effect of block appeared significant, $F(11,660)=11.46$, $p<.001$, $\eta^2=.160$. No further main effects or interactions was observed (largest $F=1.60$, corresponding $p=.154$). A BF of 12.42 strongly supported the model containing main effects of all factors over the model including an additional group × predictability interaction. A BF of 354.51 decisively favored the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including an additional group × outcome predictability × block interaction. Furthermore, we also stated the evidence for the effect of outcome predictability and its interaction with block across two groups. A BF of 8.75 provided substantial evidence for the model containing the main effect of group, cave condition and block over the model with all four main effects. In addition, a BF of 203.03 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

Secondly, the analog ANOVA test was used to analyze the data during cue and pre-cue interval separately, to further determine if any effect would be observed during the particular interval.

For the cue interval, neither the main effect of outcome predictability, $F(1,30)<1$, nor its interaction with block, $F(11,660)=1.22$, $p=.293$, was significant. Furthermore, the

data also suggested that there was no difference in learning between groups: Neither the outcome predictability × group interaction, $F(1,60)<1$, nor the outcome predictability × group × block interaction, $F(11,660)<1$, appeared significant. We only observed a significant main effect of block, $F(11,660) =10.72$, $p<.001$, $\eta^2=.152$. None of other main effects or interactions was significant (largest $F=1.78$, corresponding $p=.108$). A BF of 10.04 provided strong evidence for the model containing main effects of all factors over the model including an additional group × outcome predictability interaction. And a BF of 338.21 decisively supported the model with all main effects and all two-way interactions within factor group, predictability and block over the model including an additional group × outcome predictability × block interaction. Moreover, the test also strongly supported the invariance of outcome predictability with a BF of 18, showing preference for the model containing the main effect of group, cave condition and block over the model with all four main effects. In addition, a BF of 311.77 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval, the analyses confirmed that none of the groups manifested the preference for one outcome over the other: Neither the main effect of outcome predictability, $F(1,30)<1$, nor the outcome predictability × block interaction, $F(11,660)<1$, nor the group × outcome predictability interaction, $F(1,30)<1$, nor the group × outcome predictability × block interaction, $F(11,660)<1$, reached significance. The test did not reveal any main effects or interactions (largest $F=1.15$, corresponding $p=.308$.). A BF of 8.66 substantially supported model containing main effects of all factors over the model including an additional group × outcome predictability interaction. Furthermore, the BF of 140.04 decisively favored the model with all main effects and all two-way interactions within factor group, predictability and block over the model

including an additional group × outcome predictability × block interaction. Notably, the test provided substantial evidence for the model containing the main effect of group, cave condition and block over the model with all four main effects (BF=6.74). And a BF of 1581.47 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

3.1.3 Discussion

The present experiment approached two manipulations of the outcome's predictability in the initial training. For Group 1, both the gaze and the mouse data confirmed the expectation of Phase 1 training that responses to the cue associated with the predictable outcome was stronger than to the cue associated with the less predictable outcome. This indicates that participants successfully discriminated the difference in the predictability of two outcomes. Moreover, both data confirmed that such a difference in responses between two trial types was observed only during the cue interval, but not the pre-cue interval. Given the fact that the context was consistently presented even when the cue was absent, approaches towards the outcome area during the pre-cue interval can be interpreted as the responses activated by the context. Thus, these results confirmed the expectation that o1 and o2 were both barely associated with the context. Since cue A perfectly predicted the occurrence of o1, it was a much stronger predictor of o1 than the context and, consequently, the association between the context and o1 should be relatively weak. Meanwhile, although cue C was less predictive than cue A, it is still more informative than the contextual cue to predict o2 and, thus, can effectively inhibit the contextual cue to be associated with o2.

In Phase 2 training, we observed a difference in dwell time between two trial types (X-o1 vs. Y-o2), when each outcome was fully predictable by a novel cue. Moreover, this difference was due to a longer gaze time at the o2 area than o1 area during the *pre-cue*

interval, and responses to X did not differ from Y during the *cue interval*. These results are not consistent with our expectation, since the simulation predicted a difference in responses between the two trial types only during the cue interval due to a higher associability of o1 than o2 formed by Phase 1 training. Thus, our data disconfirmed the hypothesis that a higher predictability of an outcome increases the associability of this outcome and then results in more rapid learning about its novel relationship in the subsequent learning phase.

The data of Phase 2 learning proposed two possibilities. First, since participants experienced that o2 was less likely to be predicted in the previous phase, they might attempt to more frequently detect its appearance in a novel situation (Phase 2) which led to a longer gazing time at the o2 area when the cue was absent. However, if it were the case, we should also observe the same bias during the pre-cue interval in the initial training, and this preference should benefit learning about its novel relationship with Y in Phase 2. On the contrary, neither a bias towards the o2's over the o1's area during the pre-cue interval in Phase 1 nor a longer gaze time in anticipation of o2 than o1 during the cue interval in Phase 2 was observed. The second possibility is that the longer gaze time towards the o2 area during the pre-cue interval indicates a stronger association between the context and o2, and this association did then retard forming the association between o2 and the novel cue Y. However, participants did not show a difference in gaze time between the o1- and the o2-trial during the pre-cue interval of Phase 1 and the two outcomes were both fully predictable in Phase 2. Thus, it is still discussable why o2 was suddenly more strongly associated with the context than o1 during the Phase 2 training.

In contrast to the gaze data for Phase 2 learning, we noted that mouse data did not show any preference for one outcome over the other in Phase 2 learning. This proposed a possibility that differences in learning about the previous predictable and the previous

less predictable outcome might only appear on a certain behavior level. On the other hand, the inconsistent performance between eye fixation and motor reaction also raises the question if the finding of gaze data is reliable or not. Thus, the data of Group 1 still requires further replications.

For Group 2, the main analyses of both the gaze and the mouse data yielded a difference in responding between the A-o1 and C-o2 trial, in line with our expectation. Moreover, through the additional analyses we noted a longer gaze time towards the o2 area than o1 area during the pre-cue interval, but not during the cue interval. Because both the cue A and C were fully predictive, participants were able to perform the appropriate responses to cue C as well as to cue A. On the contrary, the preference for the o2 over the o1 area during the pre-cue interval can be interpreted as the stronger context-o2 association which confirmed our expectation. Thus, the actual A-o1 association was greater than C-o2 since responses during the cue interval was considered to be activated by the cue-context compound. However, the additional analyses of the mouse data revealed different results as the gaze data. We observed a significant difference in responding between the two trial types during the cue interval, but not the pre-cue interval (only a non-significant trend). Thus, we noted the difference in anticipatory eye gaze and motor reaction as learning indicator with the present design in our paradigm. In particular, gazing at the outcome area during the pre-cue interval did not mean participant would move the cursor towards this area. Moreover, they might shift the eye fixation towards the o2 area as soon as cue C was presented, but move the cursor hesitantly.

For the second phase of training, the main analyses did not show a difference in dwell time between the X-o1 and Y-o2 trial, so that the manipulation of outcome predictability for Group 2 did not actually bias subsequent learning about this outcome. Notably, we only observed a trend that participants spent a longer time looking at the o2

area than o1 area during the pre-cue interval in Phase 2. Considering the great difference in gaze time towards the o1 and the o2 area during the pre-cue interval at the end of Phase 1, this result was surprising. According to these results, we proposed two possibilities. First, the simulation suggested that the context-o2 association would decline during the learning process of Phase 2. However, our data showed that learning about X-o1 and Y-o2 was completed almost within the first two blocks. Thus, such a quick acquisition in Phase 2 may result in that less strong response towards the o2 area during the pre-cue interval in Phase 2 than in Phase 1. The second possibility is that the context-o2 association formed in Phase 1 was not successfully transferred to the Phase 2 training. It is possible that the transfer of the acquired associative strength in our paradigm can be easily influenced or harmed. Thus, we were highly motivated to improve the manipulations in the next experiment to ensure that the Phase 1 learning can be successfully transferred to Phase 2.

It is notable that a similar problem was already discussed in the human conditioning literatures. For instance, Hinchy, Livibond and Ter-Horst (1995) claimed in their human blocking studies that one factor of many failures in obtaining a blocking effect with human subject was the boundaries between phases. Thus, they intermixed the trials of two phases (i.e. pre-training and compound training trials) masking the transition to the test phase to reduce the phase barriers. Following those ideas, we planned to remove the interruption between phases in the subsequent experiment.

Moreover, the mouse data did not show any difference between the X-o1 and Y-o2 trial during the Phase 2 training, neither during the cue nor the pre-cue interval. These results also indicate that participants might manifest different responding during learning on the different behavior levels.

3.2 Experiment 6

This experiment extended the design and the manipulation conducted in the second group of Experiment 5 to demonstrate an effect of manipulating outcome predictability on subsequent learning and further detect if the effect is based on a blocking effect caused by context. The outcome's predictability was manipulated in the first training phase in the same way as in Group 2 of the previous experiment. Outcome o1 was consistently predicted by cue A and therefore fully predictable, while o2 was only partly predictable since it was preceded by cue C half of the time and presented *without* any cue the other half of the time (A→o1, A→o1, C→o2, Ø→o2). With this design, it was expected that a stronger context-o2 association than context-o1 would be formed after completing learning.

Table 3.2
Design of Experiment 6

Phase 1	Transit	Phase 2
A → o1, A → o1, B → Ø	A → o1, Ø → o2	R → o1, S → o2, T → Ø
B → Ø, C → o2, Ø → o2		X → o1, Y → o2, Z → Ø

Note. Letters A-Z denote visual and auditory cues that were always followed by one of the two outcomes (i.e., the eyes of one of the animals in the experimental task): o1 was the fully predictable outcome, o2 was less predictable. Cues B and Z were followed by the absence of any outcome, denoted as Ø. For Group 2, o2 was presented *without* the presentation of cues on some trials, denoted as Ø.

Moreover, the present experiment aimed to encourage a successful transfer of this contextual association from Phase 1 to Phase 2. For this purpose, there was no interruption between phases in the present experiment and a break was performed once within Phase 1. Furthermore, we introduced an additional transit block between two phases which contained one A-o1 and one Ø-o2 trial (see Table 3.2), in order to remind participants of the different predictability between o1 and o2 as well as the contextual association with o2. The order of the two trials was counterbalanced, so that two outcomes were equally

frequently presented shortly before the Phase 2 learning. In the second phase, every outcome was fully predicted by two novel cues (X→o1, Y→o2, R→o1, S→o2). We introduced three additional cues in the present experiment, as compared to Experiment 5, to decelerate the learning rate during Phase 2 training. If learning about o1 and o2 in Phase 2 were different from each other, it should be due to their different predictability learned from Phase 1. If a stronger contextual association with o2 than o1 was formed in Phase 1 and successfully transferred to Phase 2, we expected that this association would retard learning about the novel relationships with o2 in Phase 2.

3.2.1 Methods

Participants. Thirty-two undergraduate students from the University of Sydney (25 females, 7 males; M_{age}=18.23 years, age range 17-22 years) participated in this experiment and received course credit. Data from five additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used were the same as in Experiment 5 with only two exceptions: First, the auditory cues were presented in Phase 1 and the visual cues in Phase 2. Second, the X-o1 trial was introduced on the first trial of Phase 2 for half of the participants while the Y-o2 trial for the other half.

Design and Procedure. The present experiment consisted of 146 trials. Phase 1 training contained 84 trials grouped into 14 blocks (A→o1, A→o1, B→ Ø, B→Ø, C→o2, Ø →o2) and two additional trials as Block 15 (A→o1, Ø→o2). In Phase 2, 60 trials were arranged into 10 blocks (X→o1, Y→o2, Z→Ø, R→o1, S→o2, T→Ø). The trial order was randomized within every two blocks. The order of two trials in Block 15 was counterbalanced. We also manipulated the trial type on the first trial of Phase 2, so that o1 and o2 were equally frequently presented at the beginning. A short break was

introduced after the first ten blocks in Phase 1 and a drift check was performed after Phase 2 training.

3.2.2 Results

Gaze data. *Phase 1.* The left panel of Figure 3.2.1 illustrates how long participants spent looking at the goal area *during* the presentation of a given cue and *shortly before* the presentation of the cue in Phase 1 (solid line for cue interval and dashed line for pre-cue interval). Notably, responses during the Ø→o2 trial was not entered into analyses since participants were unable to predict o2 without signaling. Moreover, dwell time in responding to cue A was averaged across the two trials within each block.

As shown in the figure, gaze time towards the o1 area during the presentation of cue A (black solid line) did not differ from gaze time at the o2 area during C (gray solid line), and both of them increased across blocks in Phase 1. On the contrary, participants gazed longer towards the o1 cave (black dashed line) than o2 cave (gray dashed line) across blocks during the pre-cue interval, particularly on the last three blocks. In the main analyses, we examined the acquisition of A-o1 and C-o2 association with dwell time (i.e. gaze time towards the goal area during the cue interval minus the time during the pre-cue interval).

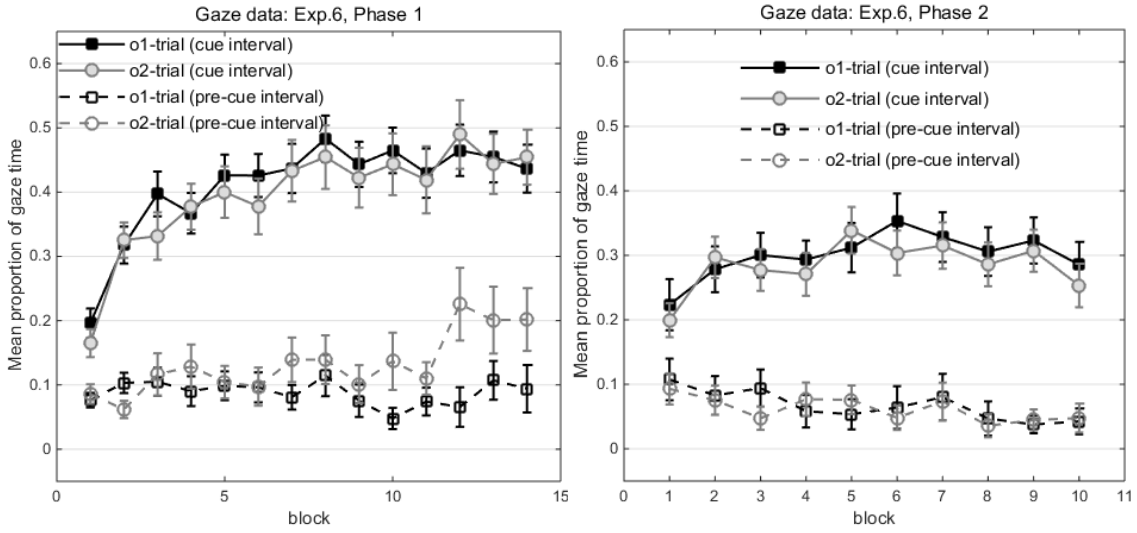


Figure 3.2.1. Gaze data Experiment 6. The left panel shows mean proportion of time that participants gazed at the correct outcome's cave during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 14 blocks in Phase 1. The right panel shows mean proportion of gaze time during the cue and the pre-cue interval across 10 blocks in Phase 2.

The data was entered into a 2 (predictability: predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) × 14 (block: 1-14) ANOVA in which predictability and block were within-subjects factors. The factor predictability revealed a significant main effect, $F(1,29)=9.37$, $p<.01$, $\eta^2=.244$, suggesting participants showed longer dwell time in anticipation of o1 than o2. However, its interaction with block was not significant, $F(13,377)<1$. The main effect of block appeared significant, $F(13,377)=6.20$, $p<.001$, $\eta^2=.176$. In addition, the counterbalancing factor cave condition significantly interacted with block, $F(13,377)=2.77$, $p<.01$, $\eta^2=.087$. No further main effects nor interactions were significant (largest $F=2.73$, corresponding $p=.109$).

In addition, the gaze behavior during the cue and the pre-cue interval was analyzed respectively by using the analog ANOVA test. For the cue interval, neither the main effect of predictability, $F(1,29)<1$, nor its interaction with block, $F(13,377)<1$, reached significance. We only observed a significant main effect of block, $F(13,377)=9.97$, $p<.001$, $\eta^2=.256$. None of the other main effects and interactions were significant (largest $F=3.56$, corresponding $p=.069$).

For the pre-cue interval, predictability yielded a significant main effect, $F(1,29)=17.65$, $p<.001$, $\eta^2=.378$, as well as a significant interaction with block, $F(13,377)=2.62$, $p<.05$, $\eta^2=.0083$, showing that participants gazed longer at the area of o2 than o1 when the cue was *not* presented, and this difference increased across blocks of Phase 1. No further main effects or interactions reached the significance (largest $F=1.60$, corresponding $p=.216$).

Phase 2. The right panel of Figure 3.2.1 displayed Phase 2 learning in which the prior predictable outcome o1 and the prior less predictable outcome o2 were fully predicted by novel cues. Dwell time was averaged within block based on the outcome (black line for o1 trial vs. gray line for o2 trial). During the cue interval, the time that participants spent looking at the goal area, increased gradually for both trial types across the first half phase and then slightly declined. During the pre-cue interval, gazing time towards the area of o1 and o2 both decreased across blocks. Notably, neither during the cue nor the pre-cue interval appeared a difference between two trial types.

A 2 (outcome predictability: previously predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) ×10 (block: 1-10) ANOVA with repeated measures on predictability and block was conducted to determine the Phase 2 learning. The test did not show an effect of outcome predictability, $F(1,30)<1$, nor an interaction between outcome predictability and block, $F(9,270)<1$, indicating learning about o1 and o2 was not different from one another in Phase 2. The main effect of block appeared significant, $F(9,270)=5.71$, $p<.001$, $\eta^2=.160$. In addition, we observed the influence of the counterbalancing factor on dwell time: The three-way interaction between cave condition, outcome predictability and block was significant, $F(9,270)=2.61$, $p<.05$, $\eta^2=.80$. None of the other main effects and interactions reached the significance (largest $F=3.27$, corresponding $p=.081$). A BF of 8.54 substantially favored the model containing the main effect of cave condition and block over the model with all three main effects. And a BF of 246.99 decisively supported the main effects model over the model including an additional predictability × block interaction.

Furthermore, gaze behavior during the cue and the pre-cue interval was analyzed respectively by using the analog ANOVA. For the cue interval, neither the main effect of outcome predictability, $F(1,30)<1$, nor the outcome predictability × block interaction,

$F(9,270)<1$, reached significance. The main effect of block was significant, $F(9,270) = 4.23$, $p<.01$, $\eta^2=.124$. Additionally, we noted the influence of the counterbalancing factor cave condition on the performances: The two-way interaction between cave condition and outcome predictability, $F(1,30) = 7.69$, $p<.01$, $\eta^2=.204$, and the three-way interaction between cave condition, outcome predictability and block, $F(9,270) = 2.37$, $p<.05$, $\eta^2=.073$, were significant. None of the other main effects and interactions was observed (largest $F=1.35$, corresponding $p=.251$). A Bayes factor of 4.80 provided substantial evidence in favor of the model with the main effect of cave condition and block over the model with all three main effects. In addition, a BF of 271.63 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval in Phase 2, we only observed a significant interaction between cave condition and outcome predictability, $F(1,30)=7.69$, $p<.01$, $\eta^2=.204$, indicating the preference for the upper cave over the bottom one. None of other main effects and interactions was significant (largest $F=2.02$, corresponding $p=.083$). A Bayes factor of 8.5 substantially supported the model with the main effect of cave condition and block over the model with all three main effects. And a BF of 183.15 provided decisive evidence for the main effects model over the model including an additional outcome predictability × block interaction.

Mouse data. We also measured the mouse data which describes how long participants placed the cursor around the goal area in the preparation of the outcome's appearance. Figure 3.2.2 illustrates the performances during Phase 1 (left panel) and Phase 2 (right panel) for the two trial types (o1- and o2- trial) during the cue and the pre-cue interval respectively.

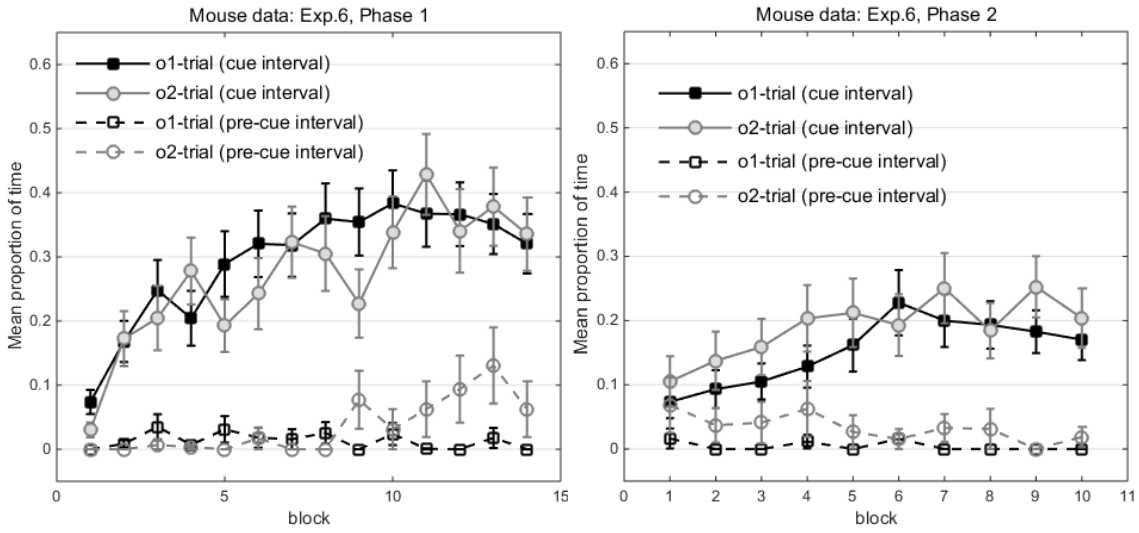


Figure 3.2.2. Mouse data of Experiment 6. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 14 blocks in Phase 1. The right panel shows mean proportion of mouse time during the cue and the pre-cue interval across 10 blocks in Phase 2.

Phase 1. Responses during the Ø→o2 trial was not entered into analyses and responses to cue A was averaged across the two trials within each block. As shown in the figure, during the cue interval, responses to the corresponding cues increased across blocks for both the o1 and the o2 trial, but there was no difference between the two trial types. On the contrary, during the pre-cue interval, participants did show a preference for the o2 cave over the o1 cave across blocks, especially on the last four blocks.

We analyzed the Phase 1 data with a 2 (predictability: predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) × 14 (block: 1-14) ANOVA in which predictability and block were within-subjects factors. Predictability revealed a significant main effect, $F(1,30)=4.86$, $p<.05$, $\eta^2=.139$, and a significant interaction with block, $F(13,390)=2.30$, $p<.05$, $\eta^2=071$, indicating that responses to cue A was stronger than to C, and this difference increased across blocks. Moreover, block also yielded a significant main effect, $F(13,390)=8.07$, $p<.001$, $\eta^2=.212$. In addition, the counterbalancing factor showed the influence on the performance: Cave condition

demonstrated a significant main effect, $F(1,30)=7.11$, $p<.05$, $\eta^2=.192$, and significantly interacted with block, $F(13,390)=4.89$, $p<.001$, $\eta^2=.140$. None of other main effects and interactions was significant (largest $F=2.02$, corresponding $p=.083$).

Further, the mouse data for the cue and the pre-cue interval were analyzed with the analog ANOVA test respectively. For the cue interval, neither the main effects of predictability, $F(1,30)=1.41$, $p=.294$, nor its interaction with block, $F(13,390)=1.63$, $p=.129$, appeared significant, showing that reactions during A and C did not differ from each other. The main effect block was significant, $F(13,390)=9.95$, $p<.001$, $\eta^2=.249$. Additionally, the counterbalancing factor cave condition revealed a significant main effect, $F(1,30)=7.76$, $p<.01$, $\eta^2=.205$, and a significant interaction with block, $F(13,390)=4.11$, $p<.01$, $\eta^2=.120$. None of other main effects and interactions reached significance (largest $F=3.61$, corresponding $p=.067$).

For the pre-cue interval, the main effect of predictability was not significant, $F(1,30)=2.30$, $p=.140$. But the predictability × block interaction appeared significant, $F(13,390)=2.57$, $p<.05$, $\eta^2=.079$, indicating a stronger preference for o2 area over o1 area during the absence of cues was shown across blocks. No further main effects or interactions was observed (largest $F=2.30$, corresponding $p=.140$).

Phase 2. The right panel of Figure 3.2.2 demonstrates the mouse data in Phase 2 training. Responses was averaged within block based on the outcome (black line for o1 trial vs. gray line for o2 trial). During the presentation of the corresponding cues, participants paced the cursor longer around the o2 cave than o1 cave across the first five blocks, and the difference disappeared across the rest blocks. During the pre-cue interval, it is similar to the cue interval, participants showed a preference for the o2 over the o1 area from block 1 to 5 and then the difference declined.

The mouse data of Phase 2 training were analyzed by using a 2 (outcome predictability: previously predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) ×10 (block: 1-10) ANOVA with repeated measures on predictability and block was conducted to determine the Phase 2 learning. We did not observe an main effect of outcome predictability, $F(1,30)<1$, nor its interaction with block, $F(9,270)<1$, suggesting learning about o1 and o2 was not different from one another in Phase 2. Block revealed a significant main effect, $F(9,270)=7.87$, $p<.001$, $\eta^2=.208$. None of the other main effects and interactions reached the significance (largest $F=1.37$, corresponding $p=.246$). A BF of 6.35 provided substantial evidence in favor of the model containing the main effect of cave condition and block over the model with all three main effects. A BF of 168.42 decisively favored the main effects model over the model including an additional outcome predictability × block interaction.

Moreover, we examined the mouse movements for the cue and the pre-cue interval separately by using the analog ANOVA. For the cue interval, it was contrary to the descriptive analyses, neither the main effect of outcome predictability, $F(1,30)<1$, nor its interaction with block appeared significant, $F(9,270)=1.15$, $p=.337$, suggesting responses for o2 trial did not differ from o1 trial during the presentation of cues. Only block revealed a significant main effect, $F(9,270)=5.86$, $p<.01$, $\eta^2=.163$. None of the other main effects and interactions was observed (largest $F=1.15$, corresponding $p=.337$). With the analog Bayesian repeated measures ANOVA, a BF of 0.37 provided anecdotal evidence for the main effects model including all factors (outcome predictability, cave condition and block) over the model with the effects of cave condition and block. On the contrary, a BF of 211 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval in Phase 2, it was also inconsistent with the descriptive analyses, as the test did not reveal any significant main effect or interaction (largest F=1.79, corresponding p=.170). In particular, neither the main effect of outcome predictability, $F(1,30)=1.44$, p=.239, nor the outcome predictability × block interaction, $F(9,270)<1$, reached significance. Nevertheless, the analog Bayesian repeated measures ANOVA demonstrated an opposite result: A BF of 0.01 provided very strong evidence supporting the main effects model including all three factors (outcome predictability, cave condition and block) over the model with the effects of cave condition and block. On the other hand, a BF of 205.93 decisively favored the main effects model over the model including an additional outcome predictability × block interaction.

3.2.3 Discussion

The present experiment extended the design and the manipulation of the second group in Experiment 5 to investigate whether a strong contextual association with the less predictable outcome formed in Phase 1 would impair novel cues to be associated with this outcome in Phase 2. Moreover, we aimed to encourage a successful transfer of the contextual association by removing the interruptions between two phases in the present experiment.

For the first phase, in line with our expectation, both the gaze and the mouse data revealed a stronger response for o1 trials as compared to o2 trials. This indicates that participants successfully discriminated the difference in predictability between two outcomes. Further, the different responses appeared only during the pre-cue interval, suggesting a stronger context-o2 association as compared to context-o1, which also confirms our expectation.

However, the data of the second phase training was inconsistent with our expectation. First, both the gaze and the mouse data showed that forming associations

between o2 and the novel cues proceeded in the same way as o1 and its cues. Second, participants did not show any preference for the o2 area over o1 during the pre-cue interval. This result was surprising since we did find a stronger context-o2 association at the end of Phase 1 and learning proceeded smoothly without any interruption from Phase 1 to Phase 2. Based on the data, one possibility is that the contextual association with our design was not strong enough to be transferred between phases. However, it is also possible that participants might immediately realize the new patterns would be present, once a novel cue appeared, and are therefore less likely to be influenced by the previous experience with the contextual association.

Considering the data of the present experiment and the second group of Experiment 5, it appears that presenting the outcome alone without any cue half of the time indeed decreases its predictability and forms a stronger contextual association with it. However, this contextual association cannot impact the subsequent learning, when the outcome is paired with novel cues. Overall, the data of the two experiments suggest that the manipulation of outcome predictability with the present design cannot bias future learning about the outcome in our paradigm.

Further, based on our conclusion that context cannot mediate an effect of the manipulation of outcome predictability on subsequent learning in our paradigm, it raises a question of how to interpret the results of the first group in Experiment 5. For this group, we reduced the predictability of outcome o2 by using a partial reinforcement procedure in the initial training phase and observed that the prior less predictable outcome o2 was less readily associated with the novel cue than the prior fully predictable outcome o1 in Phase 2. According to the simulations, such a difference in Phase 2 learning between the two trial types should be due to a change in the associability of the outcomes formed in Phase 1, rather than an effect of context blocking. However, through the additional

analyses of Phase 2 learning, we found a difference in gaze time between the two trial types during the pre-cue interval, but not during the cue interval. If such a result suggests a stronger contextual-o2 association retard learning about novel cues associated with o2, it is inconsistent with our conclusion based on the data of the second group in Experiment 5 and the present experiment. Hence, it is essential to replicate the results of Group 1 in Experiment 5. The next experiment aimed to reproduce the effect observed in Experiment 5 by using the same design as Group 1.

Further, some studies about the learned predictiveness effect for cues suggested that manipulating participants' beliefs about the predictiveness of cues via explicit instructions can influence the demonstration of the effect. In particular, when participants were informed that the cues that were previously predictive in the initial training phase were *unlikely* to be predictive in the following phase, the learned predictiveness effect was abolished (e.g., Don & Livesey, 2015; Shone, Harris, & Livesey, 2013) or reversed as participants learned more about the previously nonpredictive cues than the previously predictive cues (Mitchell et al., 2012). Those data indicate that a level of cognitive control can bias the attentional preference towards cues to some degree and therefore influence the demonstration of the learned predictiveness effect. Notably, informing participants of a control group in those experiments that the previously predictive cues were also *likely* to be predictive in the following phase can consistently produce the learned predictiveness effect. These results suggest that this kind of instruction can facilitate the demonstration of the effect, regardless of the fact if an automatic attentional allocation based on the predictiveness of cues or/and a controlled cognitive process are responsible for the learned predictiveness effect. Moreover, the study by Griffiths et al. (2015) which demonstrated an effect of outcome predictability on subsequent learning indicated a possibility that the effect might be based on inferential reasoning to some degree. Thus,

we executed an instructional manipulation in the next experiment with which participants would be explicitly informed about the outcome's predictability prior to the second training phase. If the outcome predictability effect does exist in the present paradigm, participants should reliably demonstrate the effect in Phase 2 when the instruction is consistent with the actual manipulation of the outcome's predictability.

3.3 Experiment 7

The present experiment applied the design of the first group in Experiment 5 to examine whether its manipulation of outcome predictability can reliably exert an effect on subsequent learning about this outcome. It was the same as with the original design insofar as that one outcome appeared half of the time when cue C was presented and therefore was partly predictable, while another outcome was consistently predictable by cue A. In the second training phase, each outcome was fully predicted by a novel cue. Moreover, we added the instructions prior to the second training phase. Participants in one group were informed that the outcome, which was fully predictable in the previous phase, was most likely to be predictable in the following phase. This instruction was consistent with the actual manipulation of the outcome's manipulation in the present experiment. In contrast, participants from the other group were told that the outcome, which was fully predictable in the previous phase, was less likely to be predictable in the following phase. Thus, this kind of instruction reversed the actual manipulation. If the outcome's predictability learned in the past does bias subsequent learning, we expected the observation of the effect in the first group. Moreover, if the effect can be altered by cognitive control, we should observe a difference in Phase 2 learning between two groups, since the instruction for the second group was the opposite to the actual design.

3.3.1 Methods

Participants. Twenty-four undergraduate students from Philipps-Universität Marburg, Germany participated in this experiment (41 females, 23 males, M_{age}=24.92 years, age range 19-39 years) in exchange for course credit or payment (EUR € 8). Data from three additional participants were excluded from analysis due to missing or invalid data for more than 10% of the total measurements.

Apparatus and Stimuli. The stimuli used in the present experiment were exactly the same as Group 1 of Experiment 5. Two outcomes as well as two caves were presented to participants during two training phases. The positions of two outcomes were counterbalanced. The cues within one learning phases were from the same modality and the order of the two modalities (auditory vs. visual) were counterbalanced. Moreover, the sequence of outcomes' presentation during the first two trials in Phase 2 was counterbalanced (o1- and o2-trial or o2- and o1-trial).

Design and Procedure. The instructions were the same as the previous experiment with one exception: Participants read the following additional instructions (in German) before the second phase.

For Group 1:

Im Folgenden werden Sie weiterhin Fische fangen und gleichzeitig Tiere füttern, wenn diese aufwachen.

Dabei ist sehr wahrscheinlich, dass das Aufwachen jener Tiere, die bis jetzt gut vorhersagbar war, auch im Folgenden gut vorhersagbar ist.

For Group 2:

Im Folgenden werden Sie weiterhin Fische fangen und gleichzeitig Tiere füttern, wenn diese aufwachen.

Dabei ist sehr unwahrscheinlich, dass das Aufwachen jener Tiere, die bis jetzt gut vorhersagbar war, auch im Folgenden gut vorhersagbar ist.

Phase 1 consisted of 96 trials, grouped into 24 blocks (A→o1, B→Ø, C→o2, C→Ø) and Phase 2 contained 36 trials grouped into nine blocks (W→o1, X→o2, Y→o3, Z→Ø). The trial order was randomized within every three blocks. Furthermore, we manipulated the presentation of the first two trials in Phase 2 training. A drift check was introduced to participants after each training phase.

3.3.2 Results

Gaze data*. Phase 1.* The left panels of Figure 3.3.1 and 3.3.2 demonstrate how long participants of two groups spent looking at the goal area during the cue and the pre-cue interval (solid vs. dashed line) in Phase 1 training. The black lines represent the gaze behavior for A-o1 trial, while the gray lines were the averaged gaze time across the C-o2 and the C-Ø trial within every block. The main analyses in following used dwell time (i.e. gazing time during the cue interval minus the time during the pre-cue interval.) to indicate anticipatory responses.

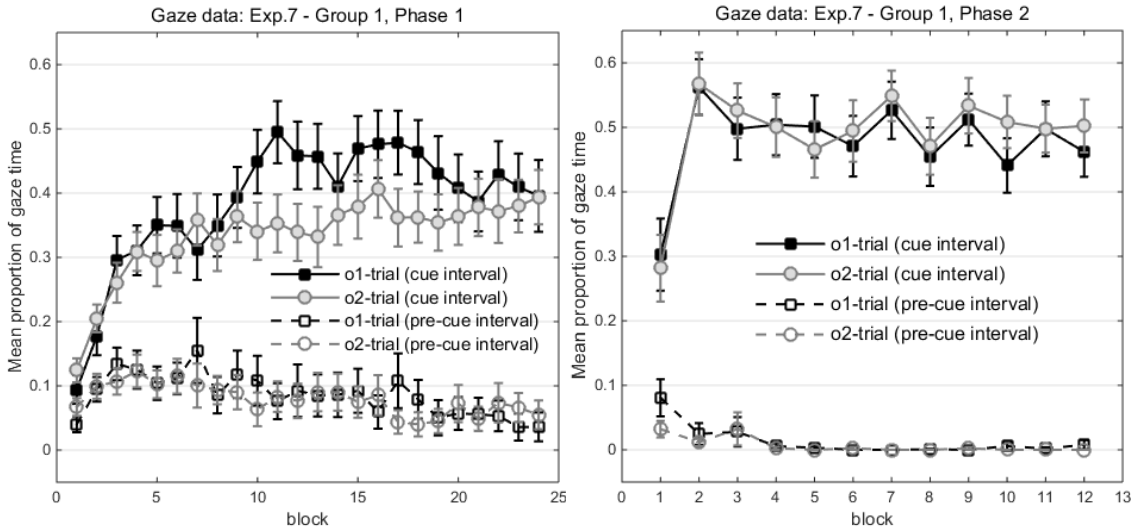


Figure 3.3.1. Gaze data of Group 1 in Experiment 7. The left panel shows mean proportion of time that participants gazed at the correct outcome's cave during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks

in Phase 1. The right panel shows mean proportion of gaze time during the cue and the pre-cue interval across 12 blocks in Phase 2.

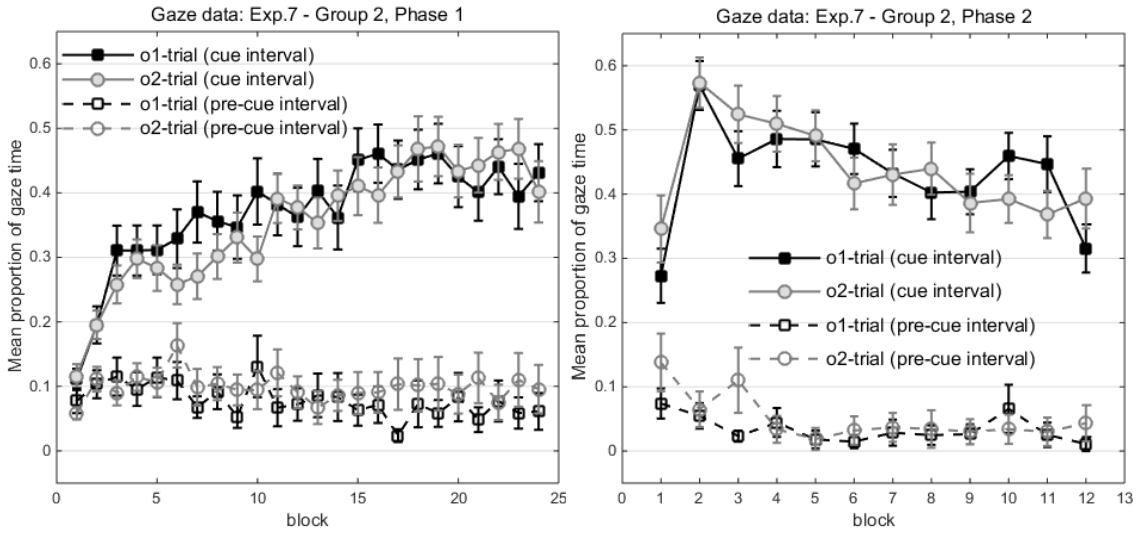


Figure 3.3.2. Gaze data of Group 2 in Experiment 7. The left panel shows mean proportion of time that participants gazed at the correct outcome's cave during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks in Phase 1. The right panel shows mean proportion of gaze time during the cue and the pre-cue interval across 12 blocks in Phase 2.

The left panel of Figure 3.3.1 illustrates the Phase 1 learning of Group 1. Generally, the gaze time towards the goal area during the cue interval increased across blocks, while the time during the pre-cue interval remained relatively low. Moreover, a difference in gaze time between the two trial types appeared only for the cue interval, but not for the pre-cue interval. The left panel of Figure 3.3.2 represents Phase 1 learning of Group 2. We also found an increment in gaze time during the cue interval across blocks, while gaze time generally maintained low during the pre-cue interval. Moreover, there was no difference between two trial types for both intervals.

The data of each group were entered into a 2 (predictability: predictable or less predictable) ×2 (cave condition: o1 in top or bottom cave) × 24 (block: 1-24) ANOVA in which predictability and block were within-subjects factors. Predictability revealed a significant main effect, $F(1,29)=5.39$, $p<.05$, $\eta^2=.357$, and a significant interaction with block, $F(23,667)=1.94$, $p<.05$, $\eta^2=.063$. We also noted a significant main effect of block

$F(23,667)=9.24$, $p<.001$, $\eta^2=.242$. None of the other main effects and interactions were significant (largest $F=2.62$, corresponding $p=.116$).

In addition, we examined gaze time during the cue and the pre-cue interval separately by using the analog ANOVA. For the cue interval, the test revealed a significant main effect of predictability, $F(1,30)=6.72$, $p<.05$, $\eta^2=.183$, and a significant predictability × block interaction, $F(23,690)=1.97$, $p<.05$, $\eta^2=.061$. We also noted a significant main effect of block $F(23,690)=10.34$, $p<.001$, $\eta^2=.256$. Additionally, the counterbalancing factor cave condition significantly interacted with predictability, $F(1,30)=9.42$, $p<.01$, $\eta^2=.239$. None of the other main effects and interactions was significant (largest $F=1.09$, corresponding $p=.372$).

For the pre-cue interval, neither the main effect of predictability, $F(1,30)<1$, nor its interaction with block, $F(23,667)<1$, reached significance. We observed a significant main effect of block, $F(23,667)=2.06$, $p<.05$, $\eta^2=.066$, and a significant predictability × cave condition interaction, $F(1,30)=5.07$, $p<.05$, $\eta^2=149$. None of the other main effects and interactions was significant (largest $F=2.02$, corresponding $p=.166$).

For Group 2, it is inconsistent with our expectation that neither the main effect of predictability, $F(1,30)=2.84$, $p< =.102$, nor its interaction with block, $F(23,690)=1.20$, $p=.286$, reached significance. We only observed a significant main effect of block, $F(23,690)=10.36$, $p<.001$, $\eta^2=.257$. No further main effects nor interactions were significant.

In addition, the gaze behavior during the cue and the pre-cue interval was further analyzed separately by using the analog ANOVA. For the cue interval, neither the main effect of predictability, $F(1,30)<1$, nor its interaction with block, $F(14,420)=1.66$, $p=.061$, reached significance. The main effect of block was significant, $F(14,420)=11.98$, $p<.001$, $\eta^2=.285$. Moreover, the significant predictability × cave condition interaction indicated a

preference for the upper cave over the bottom one, $F(1,30)=10.04$, $p<.01$, $\eta^2=.251$. None of the other main effects and interactions were significant (largest $F=1.13$, corresponding $p=.332$).

For the pre-cue interval, predictability revealed a non-significant trend that participants showed a preference for o2 cave than o1 before the presentation of cues, $F(1,30)=3.02$, $p=.093$. The test only yielded a significant interaction between the counterbalancing factor cave condition and predictability, $F(1,30)=6.99$, $p<.05$, $\eta^2=.189$. None of the other main effects and interactions reached significance.

Phase 2. The right panels of Figure 3.3.1 and 3.3.2 illustrate the Phase 2 learning for Group 1 and Group 2, in which the prior predictable outcome o1 and the prior less predictable outcome o2 were consistently predicted by novel cues. For the first group, gaze time towards the o1 and o2 area during the cue interval reached the peak within the first two blocks and then slightly declined across the rest blocks. Moreover, we did not observe a difference between two trial types. During the pre-cue interval, we noted a difference in gaze time between the o1 and the o2 trial on Block 1. For the second group, gaze time during the cue interval reached the peak within the first two blocks for both trial types, and responses in anticipation of o1 and o2 did not differ from one another. During the pre-cue interval, participants gazed longer towards the o2 area than o1 on the first three blocks.

The data of two groups were compared by using a 2 (outcome predictability: previously predictable or less predictable) × 2 (Group 1 or 2) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on outcome predictability and block. The test demonstrated a significant main effect of block, $F(11,660)=19.24$, $p<.001$, $\eta^2=.243$, and a significant group × block interaction, $F(11,660)=2.11$, $p<.05$, $\eta^2=.034$. Additionally, we noted an impact of counterbalancing factor, the

group × cave condition interaction was significant, $F(1,60) = 8.35$, $p < .01$, $\eta^2 = .122$. None of the other main effects and interactions reached the significance (largest $F = 3.80$, corresponding $p = .056$). Notably, we did not observe any difference in learning about the prior predictable and the prior less predictable outcome (main effect of outcome predictability: $F(1,60) < 1$, outcome predictability × block interaction: $F(11,660) < 1$). Moreover, two groups did not differ from each other in Phase 2 learning with respect to the previous predictability of the outcomes (outcome predictability × group interaction: $F(1,60) < 1$, outcome predictability × group × block interaction: $F(11,660) < 1$). In an analog Bayesian repeated measures ANOVA, a BF of 15 provided strong evidence for the model including the main effect of group, cave condition and block over the main effects model with all four main effects, and a BF of 3852.58 decisively supported the main effects model over the model including an additional outcome predictability × block interaction. Furthermore, a BF of 4.62 substantially favored the main effects model over the model including an additional group × outcome predictability interaction. And a BF of 411.35 provided decisive evidence for the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including an additional group × outcome predictability × block interaction.

In addition, the analog ANOVA test was conducted to determine the performances during the cue and the pre-cue interval separately. For the cue interval, the main effect of block, $F(11,660) = 16.12$, $p < .001$, $\eta^2 = .212$, and the group × block interaction, $F(11,660) = 2.81$, $p < .01$, $\eta^2 = .0045$, appeared significant. In addition, we noted the influence of counterbalancing factor, as the group × cave condition interaction became significant, $F(1,60) = 4.46$, $p < .05$, $\eta^2 = .069$. None of the other main effects and interactions reached significance (largest $F = 1.59$, corresponding $p = .212$). In the analog Bayesian repeated measures ANOVA, a BF of 10.5 strongly supported the model including the main effect

of group, cave condition and block over the main effects model with all four main effects, and a BF of 1598.72 decisively supported the main effects model over the model including an additional outcome predictability × block interaction. Moreover, a BF of 12.33 provided strong evidence for the main effects model over the model including an additional group × outcome predictability interaction, and a BF of 81.11 decisively favored the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including an additional group × outcome predictability × block interaction.

For the pre-cue interval, the test revealed a significant group × outcome predictability interaction, $F(1,60) = 4.25$, $p < .05$, $\eta^2 = .066$, indicating two groups differed in gaze time based on the outcome's previous predictability, when the cue was absent. Moreover, block also yielded a significant main effect, $F(11,660) = 9.82$, $p < .001$, $\eta^2 = .141$. None of other main effects and interactions appeared significant (largest $F = 3.69$, corresponding $p = .059$).

Furthermore, because of the significant group × predictability interaction the pre-cue interval, gaze data of two groups during this interval were further analyzed respectively. Since the X-o1 as well as the Y-o2 association were acquired within the first two blocks of Phase 2 in both groups, data of each group was analyzed with a 2 (outcome predictability: previously predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) ×2 (block: 1-2) ANOVA with repeated measures on outcome predictability and block. For Group 1, outcome predictability demonstrated a trend that participants gazed longer towards the o1 area than o2 during the absence of the cue across block 1 and 2, $F(1,30) = 2.92$, $p = .098$. The main effect of block was significant, $F(1,30) = 9.33$, $p < .01$, $\eta^2 = .237$. For Group 2, outcome predictability also revealed a non-significant trend, in the opposite direction as in Group 1, that participants spent a longer time looking towards the

o2 area than o1 in block 1 and 2, when the cue was absent, $F(1,30) = 3.43$, $p = .074$. In addition, the main effect of cave condition appeared significant, $F(1,30) = 5.76$, $p < .05$, $\eta^2 = .161$.

Mouse data. The time that participants spent placing the cursor towards the goal area during the different trial types was shown in Figure 3.3.3 and 3.3.4.

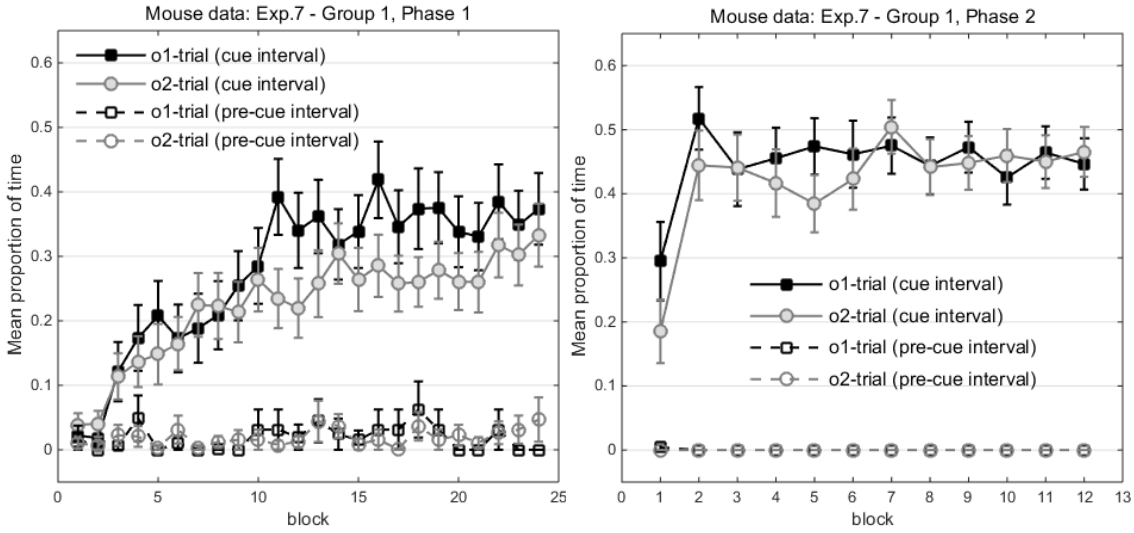


Figure 3.3.3. Mouse data of Group 1 in Experiment 7. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave during the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks in Phase 1. The right panel shows mean proportion of mouse time during the cue and the pre-cue interval across 12 blocks in Phase 2.

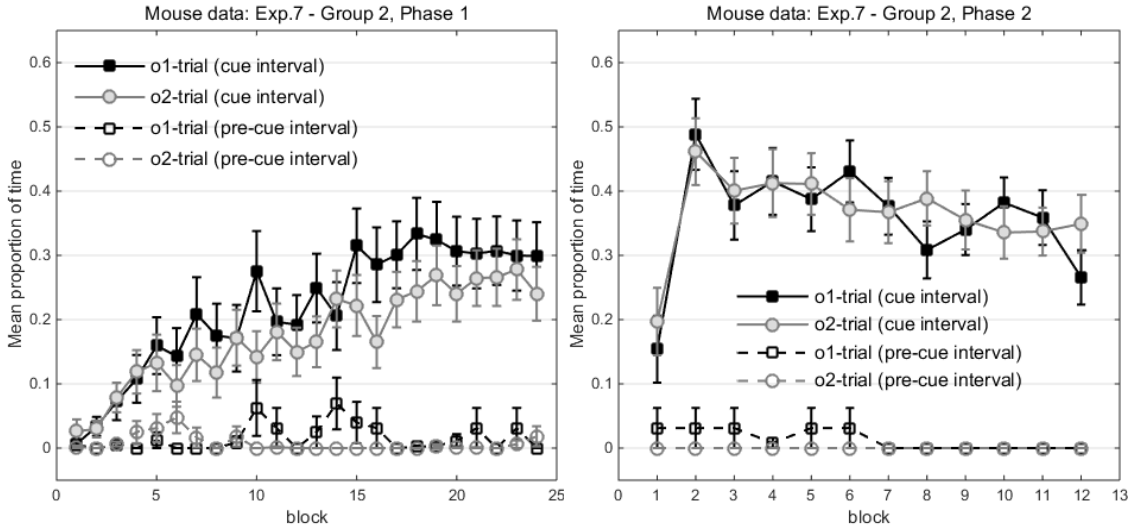


Figure 3.3.4. Mouse results of Group 2 in Experiment 7. The left panel shows mean proportion of time that participants placed the cursor at the correct outcome's cave during

the cue interval (solid lines) and the pre-cue interval (dashed lines) per block across the 24 blocks in Phase 1. The right panel shows mean proportion of mouse time during the cue and the pre-cue interval across 12 blocks in Phase 2.

Phase 1. The left panels of Figure 3.3.3 and 3.3.4 represent mouse movements during the cue and the pre-cue interval (solid vs. dashed line) for two groups. The black lines demonstrate the responses for A-o1 trial. Mouse data across the C-o2 and the C-Ø trial were averaged within every block and presented by gray lines. Responses during the *cue interval* increased in both groups across blocks, while the reactions during the *pre-cue interval* generally maintained low. Moreover, the difference between two trial types appeared only for the cue interval, but not for the pre-cue interval.

We analyzed the data of two groups (cue interval minus pre-cue interval) by using an ANOVA with the factor predictability (predictable vs. less predictable), cave condition (o1 in top vs. bottom cave) and the block (1: 1-24), in which predictability and block were within-subjects factors.

For Group 1, predictability revealed a significant main effect, $F(1,30)=12.49$, $p<.01$, $\eta^2=.294$, and but its interaction with block did not reach significance, $F(23,690)=1.58$, $p=.116$. The main effect of block was, again, significant, $F(23,690)=11.04$, $p<.001$, $\eta^2=.269$. None of the other main effects and interactions was significant (largest $F=1.39$, corresponding $p=.188$).

In addition, mouse movements during the cue and the pre-cue were examined by using the analog ANOVA test. For the cue-interval, the test demonstrated a significant main effect of predictability, $F(1,30)=13.44$, $p<.01$, $\eta^2=.309$, and a significant main effect of block, $F(23,690)=11.60$, $p<.001$, $\eta^2=.279$. No further main effects or interactions was observed (largest $F=1.57$, corresponding $p=.117$). For the pre-cue interval, we did not observe any significant main effect or interaction (largest $F=1.11$, corresponding $p=.358$),

neither the main effect of predictability, $F(1,30)<1$, nor the predictability × block interaction, $F(23,690)<1$.

For Group 2, the main analyses yielded a significant main effect of predictability, $F(1,30)=5.67$, $p<.01$, $\eta^2=.159$, as well as its interaction with block, $F(23,690)=1.99$, $p<.05$, $\eta^2=.062$. Furthermore, the main effect of block appeared significant, $F(23,690)=8.87$, $p<.001$, $\eta^2=.228$. None of the other main effects and interactions was observed (largest $F=1.28$, corresponding $p=.26$).

In the analog ANOVA test, performances of Group 2 participants during the cue and the pre-cue interval were analyzed separately. For the cue interval, we observed a significant main effects of predictability, $F(1,30)=5.12$, $p<.05$, $\eta^2=.146$, and a significant main effect of block, $F(23,690)=8.53$, $p<.001$, $\eta^2=.221$. None of other main effects and interactions was significant (largest $F=1.57$, corresponding $p=.220$). For the pre-cue interval, the test did not reveal any significant main effect or interaction (largest $F=1.80$, corresponding $p=.167$).

Phase 2. The right panel of Figure 3.3.3 illustrates the performances of Group 1 during Phase 2 training. The time participants spent placing the cursor towards the goal area during the cue interval increased rapidly from block 1 to 2 for both trial types. Moreover, the responses in anticipation of o1 is relatively stronger than o2 across the first half phase. During the pre-cue interval, participants did not move the cursor towards the outcome area at all. The right panel of Figure 3.3.4 represents Group 2 performances in Phase 2. Responses during the cue interval immediately rose and reached the peak across the first two blocks for both trial types. We did not observe a difference in responses between two trial types during the cue interval. Moreover, responses during the pre-cue interval remained low during the whole phase. Participants placed the cursor relatively longer towards the o1 cave than the o2 cave during the first six blocks.

Data of two groups were compared by using a 2 (outcome predictability: previously predictable or less predictable) × 2 (Group 1 or 2) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on predictability and block. We noted an effect of group, $F(1,60)=4.00$, $p=.05$, $\eta^2=.062$, and a significant group × block interaction, $F(11,660)=13.28$, $p<.001$, $\eta^2=.181$, showing that participants of Group 1 generally demonstrated stronger responses than Group 2 across blocks. The main effect of block was also significant, $F(11,660)=5.42$, $p<.001$, $\eta^2=.083$. Notably, we observed a significant group × outcome predictability × block interaction, $F(11,660)=2.05$, $p<.05$, $\eta^2=.033$, indicating that two groups differed in anticipatory mouse movements from each other based on the outcome's previous predictability across blocks. In addition, the counterbalancing factor cave condition significantly interacted with group, $F(1,60)=8.83$, $p<.01$, $\eta^2=.128$. None of other main effects and interactions was significant (largest $F=1.75$, corresponding $p=.192$).

Since learning about the prior predictable and the prior less predictable outcome differed between two groups across blocks, we further examined the data of Group 1 and 2 separately with a 2 (outcome predictability: previously predictable or less predictable) × 2 (cave condition: o1 in top or bottom cave) ×12 (block: 1-12) ANOVA with repeated measures on outcome predictability and block. For Group 1, we only found a significant main effect of block, $F(11,330)=7.86$, $p<.001$, $\eta^2=.208$. Neither the main effect of outcome predictability, $F(1,30)<1$, nor its interaction with block, $F(11,330)=1.03$, $p=.4$, reached significance. No further main effects or interactions was significant (largest $F=2.22$, corresponding $p=.147$). A Bayes Factor of 2.78 provided anecdotal evidence in favor of the model containing the main effect of cave condition and block over the model with all three main effects. In addition, a BF of 110.37 decisively favored the main effects model over the model including an additional outcome predictability × block interaction.

For Group 2, the test revealed a significant main effect of block, $F(11,330) = 7.80$, $p < .001$, $\eta^2 = .206$, and a significant effect of cave condition, $F(1,30) = 7.71$, $p < .01$, $\eta^2 = .205$. No further main effects or interactions was significant. Outcome predictability did not demonstrate any effect (the main effect: $F(1,30) = 1.36$, $p = .252$, the outcome predictability × block interaction: $F(11,330) = 1$, $p = .424$). A BF of 3.86 substantially supported the model containing the main effect of cave condition and block over the model with all three main effects, and a BF of 160 provided decisive evidence for the main effects model over the model including an additional outcome predictability × block interaction.

In the additional analyses we compared mouse data during the cue and the pre-cue interval between Group 1 and 2, respectively. For the cue interval, outcome predictability did not reveal any effect (main effect: $F(1,60) < 1$, the outcome predictability × block interaction: $F(11,660) = 1.02$, $p = .414$, the outcome predictability × group interaction: $F(1,60) < 1$, the outcome predictability × group × block interaction: $F(11,660) = 1.04$, $p = .397$). We only observed a significant main effect of block, $F(11,660) = 14.81$, $p < .001$, $\eta^2 = .198$, and a significant cave condition × group interaction, $F(1,60) = 9.33$, $p < .01$, $\eta^2 = .135$. None of other main effects and interactions was significant. A Bayes factor of 4 substantially supported the model containing main effects of all factors over the model including an additional group × outcome predictability interaction, and a BF of 81.87 provided very strong evidence for the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including an additional group × outcome predictability × block interaction. Notably, a BF of 10.25 provided strong evidence for the model containing the main effect of group, cave condition and block over the model with all four main effects, and a BF of 741.98 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

For the pre-cue interval, we did not observe any main effects or interactions (largest F=1.05, corresponding p=.017.). A BF of 0.52 provided anecdotal evidence in favor of the model including the main effects of all factors and an additional group × outcome predictability interaction over the main effect model containing. A BF of 147.03 decisively favored the model with all main effects and all two-way interactions within factor group, outcome predictability and block over the model including an additional group × outcome predictability × block interaction. Notably, a BF of 0.49 provided anecdotal evidence for the main effect model over the model containing the main effect of group, cave condition and block. A BF of 924.84 decisively supported the main effects model over the model including an additional outcome predictability × block interaction.

3.3.3 Discussion

The present experiment applied the partial reinforcement procedure to reduce the predictability of the outcome o2 in Phase 1 and detected if this manipulation can decrease the rate of learning about this outcome in subsequent learning. Furthermore, we also executed an instructional manipulation to determine if the cognitive control plays a role in producing the outcome predictability effect.

According to both the gaze and the mouse data, participants of the first group successfully discriminated the difference in the outcomes' predictability in Phase 1 and manifested stronger responses to the cue associated to the predictable outcome, as compared to the cue associated to the less predictable outcome. In the second phase, each outcome was fully predicted by a novel cue. However, participants did not demonstrate a difference in learning about the prior predictable and the prior less predictable outcome, even when we explicitly informed them that the previous predictable outcome would be predictable as well in the second phase. Thus, the present experiment did not replicate the key finding from Group 1 of Experiment 5. Notably, we did observe that participants

showed a trend to a longer gazing time at the area of the prior predictable outcome than the prior less predictable outcome during the pre-cue interval. This is inconsistent with the results shown by the first group in Experiment 5 as it demonstrated preference for the area of the prior less predictable outcome during the pre-cue interval in Phase 2. It is possible that this preference observed in the present experiment is caused by the instruction. However, such an influence only shortly appeared and did not actually affect forming the association between the outcome and the novel cue.

For the second group, according to the gaze data, we did not find a difference in learning about the predictable and the less predictable outcome in Phase 1. On the contrary, the mouse data confirmed that responses in anticipation of the predictable and the less predictable outcome differed from each other. Through the additional analyses, we found that they tended to place the cursor longer around the o2 cave during the absence of the cue which might indicate a stronger association between the context and o2 than context and o1. Considering the inconsistent results between the gaze and the mouse data, it is arguable if participants of Group 2 successfully learned the difference in the predictability between o1 and o2. In Phase 2, there was no difference in learning about the prior predictable and the prior less predictable outcome. Moreover, participants demonstrated a trend to gazing longer towards the o2 cave than o1 during the pre-cue interval, which is in the opposite direction as Group 1. It is possible that this preference has been transferred from Phase 1 since it already appeared in the first phase. However, it is also possible that the instruction might encourage them to detect the appearance of o2 since the introduction discounted the contingencies of o1.

Because both the gaze and the mouse data demonstrated a difference in Phase 2 learning between two groups, it suggests that the instructional manipulation might show some influences on the participants' performance. However, such an influence cannot

actually affect forming the association between the novel cues and the outcomes. It is noteworthy that Group 1 with the explicit instruction about the outcome's predictability did not demonstrate an effect of the outcome's previous predictability on subsequent learning. Thus, it seems that the reduction of the outcome's predictability with the partial reinforcement procedure cannot actually impair later learning about this outcome.

Chapter 4: General Discussion

Seven experiments were conducted by using a goal-tracking task with human subjects to investigate if and how the learned predictability of an outcome influences subsequent learning about this outcome. In the first four experiments (Study I), the predictability of outcome o2 and o3 was reduced in the first training phase: Each of them was preceded by cue C half of the time and by cue D on the other half. On the contrary, outcome o1 was consistently preceded by a discrete cue and fully predictable. In a subsequent training phase, each outcome was paired with novel cues and became fully predictable. If learning about o1 differed from o2 and o3 in Phase 2, it should be attributed to the different predictability learned in the first phase.

According to both the gaze and the mouse data, all four experiments showed that participants successfully discriminated the difference in the outcomes' predictability in Phase 1. For the second phase training, the gaze data of Experiment 1 demonstrated that the prior predictable outcome o1 was more readily associated with the novel cue as compared to the prior less predictable outcomes o2 and o3. Such a difference in Phase 2 learning suggested that a higher predictability of the outcome can accelerate subsequent learning about this outcome. However, the mouse data of Experiment 1 only showed a non-significant trend that participants placed the cursor longer towards the o1 area than the o2 and the o3 area in Phase 2, that is not completely consistent with gaze behavior. Considering the arguments of some literatures that the mechanism responsible for the selection of motor responses is not necessary for control over the focus of visual attention (Foulsham, Walker, & Kingstone, 2011; Pashler, 1991), one possible explanation is that gaze allocation and the mouse movements in the present paradigm might rely on different cognitive processes. Thus, the effect of outcome predictability on subsequent learning might only manifest in gaze allocation but not the motor responses. Further, an alternative

interpretation of the inconsistency between the gaze and the mouse data is that the effect of outcome predictability shown in the gaze data might not be reliable enough to be observed on the other behavior level.

Nevertheless, such an effect of outcome predictability on later learning observed in Experiment 1 was not reproduced by the next three experiments (i.e. Group 1 of Experiment 2 and 3, and Experiment 4). Neither the gaze data nor the mouse data demonstrated more rapid learning about the prior predictable outcome than the prior less predictable outcomes in Phase 2, even when we carefully improved the counterbalancing manipulations to reduce its interference with actual learning performances. Further, because participants showed a general bias towards the outcome presented in the middle cave, an additional manipulation was employed for one group of Experiment 3 to reduce the middle cave advantage. We presented the less predictable outcome o3 in the middle cave for all participants of this group and then removed it as well as the middle cave in the second training phase. As a result, this group did not demonstrate a difference in learning about the prior predictable and the prior less predictable outcome in Phase 2. Thus, in all four experiments with the same manipulation of the predictability, we only observed once that the prior predictable outcome was more rapidly associated with the novel cue than the prior less predictable outcome. It appears that the current manipulation of predictability might not be able to reliably demonstrate an effect. Before coming to a conclusion as to whether or not the effect exists, we further approached two other manipulations of outcome predictability in Experiment 5 to 7 (Study II).

In addition, having observed the outcome predictability effect in Experiment 1, we aimed to detect whether the effect relies on a change in the outcome's associability due to the manipulation of outcome predictability or a blocking effect caused by context. Thus, we conducted the context shift between two training phases for a group in both

Experiment 2 and 3. Furthermore, for another group in these two experiments, we executed the context shift with the outcome removal to reduce the middle cave advantage. According to both the gaze the mouse data, none of those groups showed a difference in learning about the prior predictable and the prior less predictable outcomes in Phase 2. However, without the replication of the outcome predictability effect in the control group of these experiments, it is implausible to determine whether the results of these treatment groups were due to the manipulation of the context shift or the inexistence of the effect.

Considering that the manipulation of outcome predictability used in the first four experiments might not be able to exert an effect on subsequent learning, we examined two other designs (Design 2 and 3) to reduce the predictability of o2 in the first training phase for the remaining three experiments (Study II). For Design 2, cue C was followed by o2 on half the trials, so o2 was partly predictable. For Design 3, o2 was preceded by cue C half of the time and presented *without* signaling the other half of the time. Although both manipulations obtained the reduction of o2's predictability, they differed in managing the predictiveness of cue C. With Design 2, not only o2 was less predictable, but cue C was also less predictive, since participants were not able to predict the appearance of o2 when C was presented. On the contrary, cue C with Design 3 was fully predictive since it was consistently followed by o2, even though o2 was also less predictable.

According to the computational simulations based on the Rascorla-Wagner model, we expected that a relatively stronger context-o2 association during Phase 1 training would be formed with Design 3, but not with Design 2. Further, during the second phase training, o1 and o2 were each paired with novel cues and fully predictable with both Design 2 and 3. According to the simulation, if we observed a difference in learning about the novel association with o1 and o2 in Phase 2 with Design 2, it should be due to a change

in the outcome's associability caused by the manipulation of predictability in Phase 1. With Design 3, we expected that the stronger context-o2 association formed in Phase 1 would retard forming the association between the novel cue and o2 in Phase 2, despite a change in the outcome's associability.

Experiment 5 examined two designs with two groups. For the first group, both the gaze data and the mouse data confirmed our expectation of Phase 1 learning. The predictable outcome o1 was stronger associated with cue A than the less predictable outcome o2 with cue C, and neither o1 nor o2 were strongly associated with the context since participants did not tend to the o1 or the o2 area during the pre-cue interval across training. This indicates that Design 2 succeeded in distinguishing the predictability between o1 and o2 in Phase 1. Because o1 was consistently predicted by A in Phase 1, the cue is a much stronger predictor of o1 and the association between the context and o1 should therefore be relatively weak. On the other side, although cue C was less predictive than cue A, it is still more informative than the contextual cue to predict o2 and, thus, can effectively inhibit the contextual cue to be associated with o2.

In spite of the successful manipulation of the outcome's predictability in Phase 1, the observation of Phase 2 learning with Design 2 is not fully consistent with our expectations. For Group 1, the gaze data did demonstrate better learning about the prior predictable than the prior less predictable outcome. But this difference is based on a longer gazing time towards the o2 area in preference to o1 during the pre-cue interval. If this preference during the pre-cue interval reflexes an attentional bias for o2 in a general manner, since participants experienced that o2 was less likely to be predicted in Phase 1 and might allocate more attention to detect its appearance in Phase 2, it should provide an advantage to learning about the o2's novel relationship and we should also observe a higher prediction of o2 during the cue interval. However, the gaze behavior during the

cue interval did not differ between the two trial types. Further, another possibility is that the preference towards the o2 over the o1 area during the pre-cue interval might indicate the stronger contextual association with o2 than o1 across Phase 2 training. In this case, the gaze behavior indeed opposes our expectation that a difference in learning about o1 and o2 in Phase 2 should be due to the change in the outcome's associability caused by the different predictability learned in Phase 1. Moreover, given that o2 did not demonstrate a stronger association with context than o1 in Phase 1 and both the cues and the outcomes in Phase 2 obtained the same predictiveness/predictability, it is unclear why o2 suddenly performed a stronger association with the context in Phase 2. In fact, if these results are the consequence of the predictability manipulation used in Phase 1 and not incidental, we should reliably observe the same results with the same design.

In contrast, the mouse data of the same participants for Phase 2 training are not in agreement with the gaze data, as participants did not prefer to place the cursor towards one outcome over another, neither for the cue nor for the pre-cue interval. It is always arguable whether mouse movements are equivalent to gaze allocation in outcome prediction. However, given the fact that mouse movements and gaze behavior denoted a high consistency throughout Phase 1 training, their discrepancy shown in Phase 2 casts doubt on the reliability of the results with the gaze data in Phase 2.

As a matter of fact, Experiment 7 with the same manipulation of outcome predictability did not demonstrate the same results. For the first group of Experiment 7, both the gaze data and the mouse data, again, approved our expectation for Phase 1 learning that the predictable outcome o1 was more strongly associated with cue A, as compared to o2 with cue C, and both outcomes were barely associated with context. But for the second phase training, we did not observe rapid learning about the novel relationship with o1 than o2, even though we explicitly informed participants in Group 1

that the previous predictable outcome would be predictable as well in the second phase. This challenges the finding observed in Experiment 5. If the results of Group 1 in Experiment 5 indicate that the manipulation of outcome predictability can systematically bias subsequent learning, it is unreasonable that Group 1 of Experiment 7 failed to replicate the effect. Hence, it seems that the results of Experiment 5 are incidental.

The second group of Experiment 7 contained the same predictability manipulation but a different instruction from Group 1, as the participants were told that the predictable outcome from Phase 1 is less likely to be predictable in Phase 2. For the Phase 1 training, it is notable that we for the first time noted a difference in learning performances between gaze behavior and mouse movements. On the one hand, the gaze data did not demonstrate that o1 was more strongly associated with A than o2 with C and participants performed a non-significant trend of longer gazing towards the o2 than the o1 area during the pre-cue interval; on the other hand, the mouse data showed stronger responses in anticipation of o1 than o2, in particular during the cue interval. One possibility is that participants tended to look at the o2 area more frequently regardless of the cue due to the uncertainty of o2, but the actual movements favored the predictable outcome when the cue appeared. However, because of the inconsistency between the gaze and the mouse data, it is difficult to conclude if participants successfully discriminated the predictability between o1 and o2 or just invented an effective gaming strategy (i.e. looking at the o2 cave but moving the mouse to the o1 cave). For the second phase, we did not observe a difference in learning about o1 and o2. Nonetheless, because of the lack of the evidence of the successful discrimination in Phase 1, it is unclear if the results of Phase 2 should be due to the manipulation of instruction or a failed acquisition of the different predictability in Phase 1. Meanwhile, we noted a difference in Phase 2 performances between two groups. In particular, Group 1 tended to gaze longer towards the o1 area, while Group 2 tended

to the o2 area, when the cue was absent. Considering that Group 1 did not report an outcome predictability effect, this might be attributed to the different emphasis of instruction despite an influence of the predictability's manipulation in Phase 1. Hence, the data suggest that the instruction can bias the attentional preference to some degree, but it cannot alter the acquisition of the associative relationships between cues and outcomes throughout the whole training phase.

Design 3 was investigated with the second group of Experiment 5 and Experiment 6. The manipulation of outcome predictability was approved by both the gaze and the mouse data of Phase 1 training in two experiments. It is consistent with our expectations that o1 was more strongly associated with A than o2 with C, and participants particularly demonstrated a preference for the o2 over the o1 cave during the pre-cue interval. However, none of two experiments reported a difference in learning about the prior predictable and the prior less predictable outcome in Phase 2, even though we removed the break between phases in Experiment 6 to enhance the transfer of the contextual associations from Phase 1 to Phase 2 learning. This suggests that the manipulation of outcome predictability with Design 3 cannot demonstrate an effect on subsequent learning in our paradigm.

In consideration of the US preexposure effect, the Phase 1 pairings in our design can be regarded as a mixture of preexposure (Ø-o2) and the conditioning phase (C-o2), that were separated in the classical procedure for the outcome preexposure effect. Our observation of Phase 1 is consistent with the previous findings (e.g., Baker & Mackintosh, 1979; Baker et al., 1981; Kamin, 1961; Maier & Seligman, 1976; Randich & LoLordo, 1979; Taylor, 1956) that the associative strength between C and o2 was lower than A and o1, and o2 was stronger associated with the context than o1. However, such a stronger context-o2 association was unable to retard forming a novel association with o2 when o2

was paired with novel cues in Phase 2. One interpretation is that the relatively higher salience of the cue, as compared to the neutral background layout as context, protected the competition between them. Another possibility is that human subjects in our paradigm might be sensitive to the change in patterns between phases and might perceive the different phases as independent experiments (Arcediano, Matute and Miller, 1997), so the contextual associations cannot exert an effect on learning in the subsequent training phase.

In summary, we approached three designs to manipulate outcome predictability. Although the experimental data confirmed all manipulations in the initial training phase, none of them can reliably produce an effect of subsequent learning. The single observations of an influence of outcome predictability with Design 1 and 2 cannot be reproduced in the other experiments. Hence, our data suggest that manipulating the predictability of an outcome in our paradigm cannot impact subsequent learning about this outcome.

4.1 Cue Processing vs. Outcome Processing

Initially, the present study is inspired by the learned predictiveness effect, which describes that a cue previously experienced to be a better predictor of the outcome than all other cues present will be learnt more rapidly about in future. (see Le Pelley, 2004; Mitchell & Le Pelley 2010, for a review). Thus, we investigated if manipulating the predictability of an outcome can bias subsequent learning about the novel association with this outcome. As a result, our data did not confirm that outcome predictability could exert a similar effect as the cue's predictiveness. Regarding this matter, we consider that outcome processing may differ from cue processing, at least on the basis of the function of stimuli's predictiveness/predictability. In the following, we will view the mechanisms responsible for the learned predictiveness effect and, accordingly, discuss possible reasons for the fact that outcome predictability cannot exert the similar effect.

According to Mackintosh (1975), the learned predictiveness effect is based on competition between cues in terms of associability. When multiple cues predict one outcome, they compete with each other in prediction of the outcome and the cue, which is experienced to be a better predictor of the outcome than all other cues present, gains more processing power and maintains greater associability. In line with the Mackintosh model for cues, when outcomes differed from one another in how well they can be predicted by other cues in the past, it is possible that the associability of the outcomes (β) varies due to its associative history that will shape the rate of which the outcome will enter into a novel association.

In line with the assumptions of the Mackintosh theory, the most studies about the learned predictiveness effect paired outcome with multiple simultaneously presented cues to encourage the competition between cues (e.g. Le Pelley & McLaren, 2013). Further, some studies with animal subjects reported that presenting a single cue to signal the occurrence of the outcome with manipulation of the cue's predictiveness, which was operated by varying the probability of the outcome's occurrence followed by cues, could not demonstrate an effect proposed by the Mackintosh theory (e.g., Hall & Pearce, 1982; Kaye & Pearce, 1984; Wilson et al.,1992). Thus, it was considered that the learned predictiveness effect requires within-compound discriminations. On the contrary, the present experiments paired cues with a single outcome. This manipulation might produce less strong competition between outcomes than outcome compound present on every trial.

However, other researches contradict the proposal that the learned predictiveness effect requires within-compound discriminations. For instance, Le Pelley et al. (2010) and Kattner (2014) successfully observed the learned predictiveness effect by using the single-cue training paradigm to human subjects. Thus, they argued that the presentation of a single cue, without the direct comparison of cues on every trial based on a

simultaneous presentation of cues, can still successfully establish the learned predictiveness effect with human subjects. According to these arguments, if the outcome predictability effect were similar to the learned predictiveness effect for cues, presenting single outcome on every trial should not prohibit the demonstration of the effect with human subjects.

Since the single presentation of outcome is less likely to explain why outcome predictability cannot exert an effect on subsequent learning in the present paradigm, another implication of our data is that processing of outcomes differs from cues. In the following, we look back upon the differences between cue and outcome and then discuss, if their different features result in the different processing of them.

In principle, cue and outcome are different in two dimensions. First, cues usually precede outcomes in the vast majority of conditioning experiments, since cues in this manner govern the responses based on learning and the anticipatory behaviors are measured to indicate associative learning. Second, outcomes are initially assumed to inherently maintain high biological significance, such as more salient affective or motivational significance, which has the potential to elicit stronger and more numerous responses from subjects without learning. In contrast, cues, prior to be involved into an association with an outcome, are ordinarily neutral stimuli which elicit little or no responding (i.e. low biological significance). Thus, only when cues are paired with outcomes, they can acquire higher biological significance due to the association with the outcome. In this manner, it is discussable whether the difference in temporal order and/or biological significance between cues and outcomes can result in the differential processing of them.

Gunther, Miller and Matute (1997) approached this issue by examining the different effects of extinction of contextual associations on the cue- and outcome-

preexposure effects. The cue- and outcome-preexposure effect describe that preexposure to a stimulus can retard subsequent conditioning involving this stimulus, regardless of whether it serves as cue to precede an outcome (i.e. cue preexposure effect, also called latent inhibition), or as an outcome to follow a cue (i.e. outcome preexposure effect, also called US-preexposure effect). Further, it has been observed that an extinction of association between the context and the preexposed stimulus, following preexposure and prior to the conditioning phase, can attenuate the US-preexposure effect (Randich, 1981), but not the cue-preexposure effect (Hall & Minor, 1984). Through manipulating the biological significance of stimulus (i.e. intensity), Gunther and his colleagues (1997) demonstrated that the difference in processing of cues and outcomes is on the basis of their different biological significance, not the temporal order.

Further, several researchers reported that stimuli of greater biological significance are more likely to be protected against cue competition, like blocking or overshadowing (e.g., Miller & Matute, 1996; Oberling, Bristol, Matute, & Miller, 2000). In particular, Miller and Matute demonstrated backwards blocking (i.e., poor responding to cue X as a result of A-outcome trials that follow AX-outcome trials) which has been previously observed in causal judgment by humans but not in Pavlovian conditioning with nonhuman subjects. They considered that the outcome used in the animal studies has always been of high biological significance to subjects (e.g., food, water, footshock) and the intended blocked cue (X) had acquired biological significance during the first phase of training (AX-outcome trials), prior to the blocking treatment (A-outcome trials). Thus, they argued that the failed observation of backwards blocking in the previous animal studies was due to the acquired biological significance of the to-be-blocked cue X. This hypothesis was confirmed by their data, since they successfully demonstrated backwards conditioning by using a sensory preconditioning procedure to protect cue X from gaining

biological significance during Phase 1. Additionally, the third experiment of their study has shown that forward blocking appears more readily with cues of moderate intensity (i.e. low biological significance) than cues of high intensity (i.e. high biological significance). Given that blocking is representative of associative cue competition effects in general, their finding provided evidence that cues of high biological significance are protected from cue competition. Furthermore, the study conducted by Oberling and colleagues (2000) demonstrated that intense auditory stimuli as cues (i.e., high biological significance) were protected from overshadowing, which was another example of cue competition.

Relating to the present research, since we asked if β varies due to a competition between the predictable and the less predictable outcome, one possibility is that the feature of outcome might be relatively resistant to the competition without additional manipulation of the outcome's biological significance. However, we also noted that the outcomes used in the present experiment, namely the eye symbols of animals, are not inherent of high physical intensity or motivational importance, but rather acquired the control of behavior during the experiment, as they leaned clicking on them would gain game credit. However, since it has been demonstrated that the two sources of biological significance have a similar effect on behavior control (Denniston, Miller, & Matue, 1996; Gunther, Miller, & Matute, 1997), it is reasonable to predict that our outcomes still possess higher biological significance to a certain degree. Hence, from a theoretical standpoint, a manipulation of the outcome's predictability does not necessarily elicit the competition between outcomes.

4.2 Outcome Predictability Effect and a Change in β

Recently, some investigators reported that they observed the outcomes of higher predictability to be more readily learned about in a subsequent learning phase, as compared to the outcomes of lower predictability (Griffiths et al., 2015; Griffiths, Erlinger, Beesley & Le Pelley, 2017; Quigley, Eatherington & Haselgrove, 2017; Thorwart, et al., 2017). However, by discovering the details of their paradigms, it is arguable whether their findings rely on some particular manipulations and whether their effect is mediated by a change in β due to the competition between outcomes.

Griffiths et al. (2015) firstly demonstrated that the manipulation of outcome predictability can influence performances in subsequent learning, by using a human causal learning "allergist" task. During the first training phase, two outcomes were fully predictable via their particular cues (p1, p2), and the other two outcomes (u1, u2) were rendered unpredictable by having been paired with the same cue (e.g., A→p1, X→u1, X→u2, AX→p1u1, AX→p1u2). During the second phase, one previously predictable and one previously unpredictable outcome were presented simultaneously and preceded by a novel predictive cue with an additional unpredictive cue (e.g., EY→p1u2, GY→p1u1). The primary dependent variable was the likelihood ratings in the subsequent test phase. In all experiments, the prior unpredictable outcomes (u1, u2) were less readily associated with novel cues, when these cues were fully predictive of the outcomes in the second phase (e.g., cue E consistently predicted outcome p1 and u2 in Phase 2). The authors interpreted their data as evidence that the prior predictability of an outcome can be encoded as a specific feature of the outcome and transferred to subsequent learning, thus shaping that outcome's associability.

For the findings of Griffiths et al. (2015), we firstly noted the different paradigms applied to the present experiments and their studies, as we used the paradigm with the

conditioning magazine approach, while Griffiths and his colleagues employed the human causal judgment task. Miller and Matute (1996) pointed out that animal conditioning and human causal judgment experiments differ in strength of biological significance of stimuli. They claimed that introducing an allergic reaction in a fictitious patient is less important to the well-being of the subjects than food, water or electric shock which are directly delivered to the subjects in the typical Pavlovian conditioning in animals. If the outcomes used in our paradigm contain a higher biological significance than outcomes used in the studies by Griffiths et al. (2015), it is possible that an effect of outcome competition is less likely to be observed in the present experiments. However, given the fact that our participants are introduced to simply play a computer game, and the biological significance of our outcomes is not inherently high, we cannot conclude that the biological significance of our outcomes must be significantly higher than the outcomes used in the studies of Griffiths et al.

Second, we also noted that outcomes were presented in a different way between our and their experiments, as we trained the association with a single cue, while they presented outcomes with a different predictability in compound. if the outcome predictability effect requires competition between the predictable and the less predictable outcome, such a simultaneous presentation of outcomes can encourage the competition between outcomes for processing power, so that participants might experience greater subjective discrepancy in the predictability of outcomes. Consequently, their participants might demonstrate a stronger effect of the learned predictability on subsequent learning than would be the case with the single outcome presentation used in the present studies. Although this is a possibility, the evidence that this subjective discrepancy is important even for changes in cue associability is not strong. Several studies have found that relative differences in predictiveness among discrete cues presented on the same trial are not

necessary for the learned predictiveness effect, and may indeed play no role in determining its strength (Kattner, 2015; Le Pelley et al., 2010; Livesey et al., 2011). Moreover, regarding the studies by Le Pelley et al. (2010) that successfully established the learned predictiveness effect by using the single-cue training, if the effect is, similar to the learned predictiveness effect for cues, governed by a change in outcome associability, the single outcome presentation should still be able to demonstrate the outcome predictability effect.

It is notable that Griffiths et al. selected participants as a high-performer group because their average prediction accuracy of the predictable outcome was higher than the other participants across Phase 1. In fact, only the higher-performer group, not the lower-performer group, showed higher ratings of the cues associated with the prior predictable outcome than of the cues associated with the prior unpredictable outcome in the test phase. The authors interpreted that the manifestation of the outcome predictability effect requires a full acquisition of Phase 1 learning. However, since they only regarded the higher prediction accuracy of the predictable outcome in Phase 1, it is possible that they selected participants who generally favored the predictable outcome. Thus, the higher ratings of the cues associated with the prior predictable outcomes might be due to the individual differences.

Another notable difference between present and Griffiths' studies is that we analyzed data from accurate responses during learning, while Griffiths et al. mainly discussed data from the subsequent test phase in which participants reported about Phase 2 learning via a likelihood rating. Interestingly, when looking at learning during Phase 2, Griffiths et al. did not reliably observe that the prediction accuracy was greater for the previously predictable outcome than for the previously unpredictable outcome. Therefore,

the effect of learned predictability might be consistently observed in the test phase, but not during learning.

This observation is, however, problematic for an account of the outcome predictability effect that it is similar to Mackintosh's (1975) model. We should observe the opposite pattern if learned predictability directly influences the associability of the outcome (β). A larger difference in the association between previously predictable and less predictable outcomes should have been demonstrated during the initial Phase 2 trials, but not necessarily after completing Phase 2 training. During the first trial in Phase 2, the associability of novel cues (α) and their associations with the outcomes were equal. If the β of the previously predictable outcome is greater than the β of the previously less predictable outcome, this then leads to a rapid increment of its associations. In this fashion, the response to the cue associated with the previously predictable outcome will be greater than to the cue associated with the previously less predictable outcomes at the beginning of Phase 2. After Phase 2 training, the associations with all outcomes should be approaching asymptote, so that the difference in response is no longer necessarily evident. Crucially, the eye gaze measurements, which indicated overt attention allocated to the outcomes in Phase 2, did not report any difference between the prior predictable and the prior less predictable outcome during Phase 2 training. On the other hand, a longer gaze time at the predictive cues (E-H) than at the nonpredictive cue Y in Phase 2 was observed that accords well with the attentional perspective for the learned predictiveness effect. Such ambiguous observations raised the question whether the different performances in respect of the previous predictability of outcomes observed in their studies can really reflect the outcome predictability effect based on a change in β.

Further, we noted a specific manipulation with Griffiths et al.'s design that they presented an additional nonpredictive cue Y on every trial in the second phase.

Considering that all outcome values (p1, p2, no p, u1, u2, no u) were presented on the same screen during the test phase in Griffiths et al.'s study and they observed higher ratings for the unpredictable outcomes, over predictable outcomes, for the nonpredictive cue Y, it is possible that their effect on test ratings is based to some degree on inferential processes. Indeed, Griffiths et al. discussed several possible inferential sources of their "certainty matching" effects. So possibly, participants establish a model which contains the information about the degree of cues' predictiveness and outcomes' predictability (a view of causal model seen Waldmann, 1996; De Houwer, 2009), and preferentially link the cues and the outcomes which match in this manner (i.e. linking the previous predictable outcome to the predictive cues and the previous unpredictable outcome to the nonpredictive cue). In such circumstances, different ratings for the prior predictable and prior unpredictable outcomes do not necessarily require a difference in rate of forming associations with those outcomes during learning in an associative account.

Interestingly, another study by Griffiths et al. (2017) with a visual search task provided similar results. Participants were asked to respond as soon as possible based on the orientation of a presented arrow which could occur in one of eight locations. Further, they manipulated the locations of the array present in Phase 1 to indicate whether it can be perfectly predicted by a given cue. For instance, some cues fully predicted the location of the arrow in the upcoming search array (i.e. predictable locations), while some other cues predicted the arrow appearing in either of two different locations (i.e. unpredictable locations). In Phase 2, the novel cues were all fully predictive of the locations of the arrow. Crucially, when they added an additional cue which was invalid to predict the location of arrow to the learning phase, they, again, observed faster responses for prior unpredictable locations than the prior predictable locations following the invalid cue, whereas responses were faster for prior predictable locations than prior unpredictable locations following a

valid cue. Such results recall our speculations about "the certainty matching effect" on the performance discussed above.

In contrast to those studies, our experiments did not provide an additional nonpredictive cue to be associated with the prior less predictable outcome, so the participants in the present experiments are unable to distinguish the outcomes in Phase 2 based on such "certainty matching". If the effect observed by Griffiths and colleagues (2015, 2017) is an influence of inferential reasoning, it seems to be reasonable that we cannot demonstrate the effect of outcome predictability with our designs. Moreover, although we also investigated if inferential reasoning plays a role in the demonstration of the outcome predictability effect (Experiment 7), it seems that the instructional manipulation (i.e. informing participants that the prior predictable outcome would be also predictable in the following phase) cannot establish the effect. One possible reason is our participants have rapidly acquired the Phase 2 associations (i.e., within two blocks), since Phase 2 training in Experiment 7 obtained only three different parings (X-o1, Y-o2, Z-Ø). Thus, an influence of higher cognitive control could not be observed throughout the whole phase. However, the alternative explanation is that a simple instructional manipulation is insufficient to establish the outcome predictability effect. Instead, the effect may require more complex cognitive processing, such as linking cues to outcomes on the basis of the (learned) predictiveness/predictability of all stimuli.

Notably, a study by Thorwart, et al. (2017) supports the considerations that the effect of predictability manipulation observed in Griffiths et al. (2015) did not really illustrate a learned-predictiveness-like effect. The experiment with the same paradigm as Griffiths et al. (2015) demonstrated the same results: Higher ratings for the previous predictable outcomes than the previous unpredictable outcomes were observed in the test phase, but not during learning. Additionally, another experiment reported in the paper

manipulated predictiveness of cues with a modification of the original design of Griffiths et al. (2015) and reproduced the learned predictive effect. Notably, eye gaze behavior was measured in both experiments to capture overt attention allocated for the cues and the outcomes present during learning. The gaze data provided important evidence to seek some understanding of the "outcome predictability effect" observed in such paradigms with respect of the learned predictiveness effect. On the one hand, in the experiment about the learned predictiveness effect, they constantly found longer gaze times for the prior predictive cue than the prior unpredictive cue for both the choice (i.e. between the onset of a trial and the onset of the feedback about the prediction accuracy) and the feedback interval (i.e. between the onset of the feedback and the offset of the trial) during Phase 2 learning, confirming a general attentional preference for the prior predictive cue over the prior unpredictive cue. On the other hand, the gaze data for the experiment carrying the predictability manipulation are quite surprising. In particular, a greater attention paid to the unpredictable outcome than to the predictable outcome for the feedback interval in Phase 1 was observed, suggesting that participants still put effort into learning about the unpredictable outcome despite of its unpredictability. Further, for Phase 2 learning, neither during the choice nor the feedback interval did they observe the attentional discrepancy between the prior predictable and the prior unpredictable outcome. Those data address two points. First, participants did not ignore the unpredictable outcomes during Phase 1 learning due to its unpredictability, whereas they did ignore the unpredictive cues in the experiment demonstrating the learned predictiveness effect. Second, there is no attentional preference during Phase 2 learning based on the previous predictability of the outcomes, whereas more attention was devoted to the prior predictive cue than the prior unpredictive cue. In this manner, it can be determined that the impact of predictability manipulation on performances in a subsequent learning observed with

the paradigm of Griffiths et al. (2015) does not rely on a bias in attentional allocation, as it has been shown for the learned predictiveness effect.

Furthermore, considering that the gaze data is not completely representative of the stimuli's associability, Thorwart, et al. extended the manipulation in the next two experiments to determine if the learned predictiveness effect and the observed outcome predictability effect rely on the same mechanisms, in particular, the change of stimuli's associability. For this reason, predictability of the outcomes was manipulated during Phase 1 in one experiment and those outcomes were delivered as cues in a second phase to consistently predict novel outcomes. Likewise, in the other experiment, Phase 1 cues which differed in the predictiveness, served as outcomes to be fully predicted by novel cues. Thus, if two effects are based on a general processing of stimuli's associability, both the learned predictiveness effect and the outcome predictability effect should be observed despite such functional shift. However, the results rejected the possibility that two effects are based on the same mechanism, because none of two experiments demonstrated a difference in Phase 2 learning on the basis of the previous predictiveness/predictability of stimuli. Hence, it seems that an influence of the predictability manipulation observed in Griffithes et al.'s paradigm should be regarded as a result of some other mechanisms rather than an associative account. In summary, according to the different results observed with Griffiths' paradigm and ours, it seems that the demonstration of an outcome predictability effect is dependent on the applied paradigm. Possibly, providing a nonpredictive cue to be associated with the prior unpredictable outcome in a subsequent phase is essential for a demonstration of the outcome predictability effect.

The last study which reported an observation of the outcome predictability effect was conducted by Quigley, et al. (2017). They applied a serial letter-prediction task and required participants to learn about the relationships between letters, and correspondingly

press one of two target buttons "X" and "Z" as rapidly as possible. In a modified design for the second experiment, the predictable outcome X is consistently predicted by cue P (P-**X**), while the other three cues (F, G and W) predict the unpredictable outcome Z. Additionally, these three cues are paired with each other, so that during the presentation of one cue it is impossible to predict either the outcome Z or one of the other two unpredictive cues will occur (e.g., F-**Z**, F-G, F-W). Moreover, the two letters "S" and "H" are paired with each other in Phase 1 (*H-S, S-H*), and serve as cue to predict outcome X and Z in Phase 2. For the second phase, all Phase 1 pairings are presented again, but H and S are not paired with each other. Instead, H fully predicts X, while S consistently predicts Z (H-**X**, S-**Z**). A test phase, following Phase 2, required participants to rate how predictive each stimulus was of the target stimuli (X and Z). As a result, participants responded more rapidly to the cue associated with the predictable X than to the cue associated with the unpredictable Z in Phase 1. Notably, during Phase 2 training, they responded more quickly to cue H in prediction of the prior predictable outcome X than to cue S to predict the occurrence of the prior less predictable outcome Z. Moreover, predictive ratings of X based on cue H were higher than of Z for cue S. The authors viewed those results as a hint that the associative history of an outcome can regulate the associability of this outcome and, consequently, impact the readiness with which the outcome will be associated with novel cues.

For their experimental, we noted a specific manipulation that the Phase 1 pairings were also presented in Phase 2, except H-S and S-H. We considered that such a manipulation might establish some consequences on Phase 2 learning. First, if the context can be more strongly associated with the less predictable outcome (Z) than with the predictable outcome X due to the less predictive power of the cues (F/G/W) related to Z, such a context-Z association might be very strong in Phase 2 and block learning about the

novel relationship between S and Z. Second, although Z is fully predictable related to S, it is still less predictable than X in a general manner, since it is unpredictable relative to F, G and W (F/G/W-Z) in Phase 2. Possibly, participants also perceived Z as an unpredictable outcome in Phase 2 and performed a difference in learning about H-X and S-Z. Third, given that H and S were consistently paired with each other in Phase 1, it also invites the alternative explanation based on "the certainty matching effect". Because participants had experienced that H and S were both fully predictive and predictable in Phase 1, they might encode such predictive features to them. Considering the unpredictive feature of Z relative to all cues present in Phase 2, it might be less readily to link S and Z since they did not match each other in the predictive feature.

In contrast to their design, outcomes present in the second phase in our experiments were fully predictable throughout Phase 2, and the novel cues paired with outcomes in Phase 2 did not gain any predictive value prior to Phase 2 training. Thus, our design does not invite the processing of the inferential reasoning for Phase 2 training.

In summary, all the studies which have demonstrated the outcome predictability effect, obtained the specific manipulations, as compared to our experiments. It suggests a possibility that the outcome predictability effect observed in those studies is paradigm-specific. Moreover, it seems less likely that the outcome predictability effect is mediated by a change in associability of outcomes which is comparable to the Mackintosh theory for cues (Mackintosh, 1975).

Chapter 5: Conclusion

A series of experiments were conducted by taking a goal-tracking magazine approach in humans to investigate if the manipulation of the outcome predictability can impact subsequent learning about the outcome. For all experiments, outcomes differed in their predictability in the initial training phase and then became fully predictable by novel cues in the second training phase. Considering the learned predictiveness effect for cues that a higher predictiveness of a cue accelerates subsequent learning about its novel relationship with novel outcomes, we expected that our experiments would demonstrate more rapid learning about the prior predictable than the prior less predictable outcome in the second phase, namely *the outcome predictability effect*. Moreover, we approached three different designs to operate the outcome's predictability in the initial training. However, none of them could reliably demonstrate the outcome predictability effect, indicating that manipulating the predictability of an outcome in the present paradigm cannot bias the readiness with which the outcome will enter into a novel association. Additionally, we also found that a relatively strong association between context and the less predictable outcome formed in the past cannot retard learning about novel cues associated with this outcome.

Considering that the learned predictiveness effect relies on a change in the associability of cues due to cue competition (Mackintosh, 1975), we discussed the possible reason why outcome predictability cannot exert a similar effect. It has been proposed that the difference in processing of cues and outcomes is based on their different biological significance (Gunther et al., 1997), since outcomes are inherently of higher biological significance than cues. Moreover, it has been shown that stimuli with greater biological significance are more likely to be protected against cue competition (e.g. Miller & Matute, 1996; Oberling et al. 2000). Hence, we speculate that outcomes presented in

the present experiments obtained relatively high biological significance and might be protect against a competition between the predictable and the less predictable outcome. If it were the case, the associability of outcomes would not vary based on its previous predictability. Consequently, subsequent learning would not be affected by outcome predictability experienced in the past.

Moreover, we reviewed all experiments that currently reported the observation of the outcome predictability effect (Griffiths et al., 2015; Griffiths, et al., 2017; Quigley, et al., 2017; Thorwart, et al., 2017) and discussed if their findings represent an effect of outcome predictability on β. Nonetheless, it seems that the effect observed in their experiments is more likely to be paradigm-specific, rather than a result of a change in β. Further, we particularly noted two special manipulations in those experiments that might moderate or mediate the outcome predictability effect. First, the novel cues associated with the prior predictable and the prior unpredictable outcomes differed in their predictivness in the current training phase (Griffiths, et al., 2015, 2017) or in the past (Quigley et al., 2017). So possibly, participants preferentially linked the prior predictable outcome to the (prior) predictive cues and the prior unpredictable outcomes to the (prior) nonpredictive cues, that resulted in different learning about the prior predictable and the prior unpredictable outcomes. Second, when an outcome is fully predictable by a certain cue but unpredictable by other distract cues at the same time (see the study by Quigley et al., 2017), learning about the cue, which is perfectly predictive of this outcome, can be retarded.

Overall the present experiments provided evidence that the manipulation of outcome predictability cannot exert an effect on subsequent learning in our goal-tracking paradigm with human subjects, and the learned predictability of an outcome cannot regulate its associability. However, it requires further investigations to determine if these

results are based on an influence of the stimuli's biological significance on outcome competition, and what mechanism is responsible for the outcome predictability effect observed in the other paradigms.

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Appendix A: Summary of effect sizes in seven experiments

Table A

Summary of effect sizes in seven experiments

Experiment		Cohen's *d*	
		Gaze data	Mouse data
Exp. 1		0.42	0.38
Exp. 2	Group 1	0.07	0.15
	Group 2	0.11	0.02
	Group 3	0.05	0.13
Exp. 3	Group 1	0.07	0.02
	Group 2	0.24	0.24
	Group 3	0.03	0.36
	Group 4	0.20	0.04
Exp. 4		0.18	0.25
Exp. 5	Group 1	0.45	0.16
	Group 2	0.02	0.12
Exp. 6		0.08	0.07
Exp. 7	Group 1	0.18	0.15
	Group 2	0.08	0.22

Note. Effect size was estimated based on a procedure suggested by Morris and DeShon (2008) for repeated measures designs.

Erklärung

Ich versichere, dass ich meine Dissertation

„Outcome Predictability: Does associative history of outcomes bias subsequent learning in a human goal-tracking paradigm?“

selbständig ohne unerlaubte Hilfe angefertigt und mich dabei keiner anderen als der von mir ausdrücklich bezeichneten Quellen und Hilfen bedient habe.

Die Dissertation wurde in der jetzigen oder einer ähnlichen Form noch bei keiner anderen Hochschule eingereicht und hat noch keinen sonstigen Prüfungszwecken gedient.

Marburg an der Lahn, 16.05.2018

Wei Liu

Curriculum Vitae

Curriculum Vitae is not a part of the publication.