# The influence of contingency, cue elements and context salience on judgment of probabilistic binary relationships

Janie Rebecca Lober

Integrated Program in Neuroscience
McGill University, Montreal
August 2014

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Science.

## Acknowledgments

My gratitude goes to my supervisor Andy Baker, because without him none of this would have been possible. I was lucky to have a thesis supervisor who did what every graduate supervisor should do by teaching me to challenge what I know. Thank you for helping me become a better writer and for pushing me to do the best work you believed I was capable of doing. Many thanks go to Irina Baetu who was a wonderful teacher, able to clearly and patiently explain things to me all the way from Australia. I am also grateful to the members of my advisory committee, Karim Nader and Yogita Chudasama, for their positive feedback, input and encouragement. Additional thanks go to Alexandra Tighe for her exceptional work that was of such help to me and to James Baker for helping me test so many participants.

I had the fortune of being a part of a graduate program that has wonderful advisors and administrators. To Edith Hamel and the "three Joes" of the Integrated Program in Neuroscience: Joe Makkerh, Jo Nalbantoglu and Joe Rochford - thank you for all the ways you were able to help and guide me. The same goes for Bärbel Knäuper, Rhonda Amsel, Giovanna Locascio, Karine Gamache and Nina Pinzarrone within the Department of Psychology. Finishing grad school wouldn't have been possible without my family's unwavering support. Much thanks to my father, grandpa, Zack and Alice, and all my friends: thank you for believing in me. Finally, Mary B., Diane K., and Suzanne M. – thank you for all of the inspiration along the way.

# Abstract

Humans are fairly accurate at judging contingent relationships between cues/causes and outcomes/effects. For binary probabilistic relationships with multiple cues for a single outcome, a causal estimate of a single cue-outcome relationship is judged relative to that of the other cue(s). Contingency, cue elements and context salience were manipulated to better understand how cues are judged relative to each other. Judgments of a moderately positive target cue were reduced in the presence of a stronger positive cue and enhanced in the presence of a stronger negative cue. These decreased and increased ratings of the target cue support the Contrast Hypothesis over associative or normative and non-normative statistical theories of learning. All ratings were attenuated when the contextual cue was salient. The reduction was even stronger when cues shared multiple common elements. A single associative model of learning is used to interpret how cues are judged in contrast to each other and the effect of generalization on cue competition.

# Résumé

Les gens sont normalement assez précis à juger les perceptions de causalité. Pour les relations causales de probabilités binaires avec de multiples causes pour un seul effet, un estimé causal d'une seule relation de cause à effet est jugé relativement à une autre cause. La contingence, les éléments des causes et la proéminence des caractéristiques de l'environnement ont été manipulés pour mieux comprendre comment les causes sont jugées en comparaison l'une de l'autre. Les jugements d'une cause modérément positive étaient diminués en presence d'une cause fortement positive et augmentées en présence d'une cause fortement négative. Ces résultats soutiennent un mécanisme de contraste plutôt que des théories associatives traditionnelles ou déductives. Ceci suggère que l'attribution causale est le résultat d'un processus cognitif dans lequel une cause est jugée en contraste avec l'autre. De plus, tout les jugements étaient diminués en présence d'un environnement aux caractéristiques saillants et d'autant plus quand les causes partageaient deux éléments en commun. Un modèle d'apprentissage basé sur les théories associatives est utilisé pour mieux comprendre comment ces résultats peuvent expliquer la compétition entre plusieurs causes et l'effet de la généralisation sur cette compétition.

# Author Contributions

The three experiments presented in my thesis were designed by Andy Baker, Irina Baetu and I. Irina Baetu programmed the computerized task for each experiment. I supervised the running of the experiments with additional help from Alexandra Tighe and James Baker who assisted me in testing participants.

# Contents

# List of Figures

# Chapter 1

## Introduction

## 1.1 Introduction

The ability to understand causal relationships is fundamental to cognition and behavior. By understanding the correlations between events (e.g., conditioned and unconditioned stimuli, cause and effect, cue and outcome) animals can successfully learn relationships between events (Baker, Mercier, Vallée-Tourangeau, Frank & Pan, 1993; Baetu & Baker, Manuscript in preparation; Darredeau, Baetu, Baker & Murphy, 2009; Dickinson, Shanks & Evenden, 1984; Kamin, 1969; Wagner, Logan, Haberlandt & Price, 1968). In Pavlovian conditioning, a conditioned stimulus (CS, e.g., tone) is repeatedly paired with an unconditioned stimulus (US, e.g., shock). Over time the CS acquires the ability to elicit its own conditioned response, which can be used as a behavioral measure of what the animal has learned about the relationship between the CS and the US.

Human causal reasoning experiments are analogous to conditioning in animals. In these experiments participants are asked to judge the degree to which they believe an action (analogous to Operant Conditioning) or observed event (analogous to Pavlovian Conditioning) predicts an outcome. Compared to animal conditioning, one advantage is that participants can report what they believe to be the relationship between variables and how they reached that conclusion.

Outside of the laboratory, accurate reasoning about uncertain relationships has important implications. It can be adaptive for survival, as this can guide behavior to allow animals to approach or avoid desired or undesired outcomes (Baker et al., 1993; Baker, Murphy, Mehta & Baetu, 2005; Eysenck & Martin, 1987; Msetfi, Wade & Murphy, 2012). The ability to understand relationships is complicated by the fact that most real life causal relationships are probabilistic rather than deterministic, with effects that are graded rather than binary (Baker, Murphy & Vallée-Tourangeau, 1996). As such, causal attribution typically involves understanding a relationship in which there is much ambiguous information (Baetu, 2010). Although real world probabilistic relationships are ubiquitous, the nature of these relationships varies according to specific properties of the events. For example, a cause may be generative (excitatory) and increase the likelihood of the effect, or preventive (inhibitory) and decrease the probability of the effect.

## 1.2 Contingency

In binary causal relationships, there are four possible relationships between events. In the 2x2 contingency table shown in Figure 1, Cell A events represent the frequency of trials in which the cue and the outcome co-occur. Frequencies in Cell B are those in which the cue occurs but the outcome does not. Cell C indicates the frequency of the outcome in the absence of the cue. Finally, Cell D indicates the frequency of trials in which both cue and outcome are absent. As such, Cell A and Cell D events are examples of a generative (excitatory) relationship between cue and outcome, whereas Cells B and C provide evidence of preventive (inhibitory) causal relationship (Baker, Msetfi, Hanley & Murphy, 2011). The normative statistic for the one-way contingency between a cause and effect, Delta P ($\Delta P$), is calculated using these four cell frequencies (Allan, 1980). $\Delta P$ is a statistic for unconditional probability that is derived from the difference between two conditional probabilities: the probability of the outcome in the absence of the cue, P(Outcome|No Cue: $P(O|\sim C)$ and the probability of the outcome in the presence of the cue, P(Outcome|Cue: $P(O|C)$. This is represented by the formula:

$$[\Delta P = P(O|C) - P(O|\sim C) = A/(A+B) - C/(C+D)]$$

An important characteristic of ΔP is that as long as the difference between the two conditional probabilities remains the same, ΔP remains the same. Therefore, there can be equal ΔPs with different combinations of trial type frequencies (Baker, Msetfi, Hanley & Murphy, 2011). An example of this is shown in Figure 2. Similar to a correlation coefficient, the value of ΔP ranges from -1.0 to 1.0, reflecting the directionality and the strength of the contingency (Msetfi, Wade & Murphy, 2012). Positive values represent generative probabilistic relationships in which the cue increases the likelihood of the outcome. ΔPs with negative values represent preventive probabilistic relationships where the cue predicts a decrease in the likelihood of the outcome. A ΔP of either -1.0 or 1.0 reflects deterministic relationships in which the presence of the cause fully predicts the absence (ΔP = -1.0) or the presence (ΔP = 1.0) of the outcome. In non-contingent relationships (ΔP = 0), there is an equal probability of the occurrence of the outcome in the presence and absence of the cue.

## 1.3 Learning Theories

One of the aims of cognitive psychology is to better understand the process by which humans and other species make causal inferences. This understanding should account for both accurate and inaccurate inferences.

### 1.3.1 Rescorla-Wagner model

Theories of associative learning, such as the Rescorla and Wagner (1972) model assume that learning causal relationships develops over time, through the formation associations between events/actions and subsequent outcomes (Baker, Murphy & Vallée-Tourangeau, 1996). Associative theories posit that prior experience either strengthens or weakens one’s internal representations of the connections between these events. When a CS and a US (or cue and outcome) are perceived to have a strong connection, a causal relationship is assumed. The strength of these connections can be altered, and the change in one's internal representation of the relationship occurs unconsciously and effortlessly (De Houwer, 2009; Mitchell, De Houwer & Lovibond, 2009).

As for how the strength of these connections is increased, research has shown that the frequency of CS-US pairings and close spatial or temporal contiguity are not sufficient to produce learning (Kamin, 1969; Wagner, 1968). This has led to a number of associative theories to consider the role of surprise (unexpectedness of the US/outcome) in the formation of associations (McLaren and Mackintosh, 2000, 2002; Pearce, 1987; Rescorla and Wagner, 1972). The associative strength between events (e.g., CS and US, cause and effect, cue and outcome) is altered only if the outcome is surprising (unexpected). Specifically, Rescorla and Wagner's (1972) model uses the delta rule: On each trial, the amount of change in the associative strength in the relationship between events depends on the difference between the expected versus the actual outcome. This difference represents the amount of surprise of the outcome (Baetu, 2010; Baetu, Baker, Darredeau & Murphy, 2005). The change in associative strength between the events can be calculated with the following formula:

$$\Delta V = \alpha \beta (\lambda - \Sigma V)$$

Delta V ($\Delta V$, change in predictive value) represents the change in associative strength between the target CS and the US (also, cause-effect and cue-outcome). $\alpha$ and $\beta$ are learning rate parameters for the salience of the CS and US, respectively. A critical feature of the Rescorla-Wagner model is the linear operator ($\lambda - \Sigma V$), which is adapted from Bush and Mosteller (1951). Here, the summed associative strength between all cues present ($\Sigma V$), not just the target cue or single CS, is subtracted from the asymptote of associative strength - the maximum amount of conditioning/learning that can occur (λ). The Rescorla-Wagner (1972) model defines λ to equal zero in the absence of the US/outcome: if there is no outcome, there is no ability for association to develop between the cue and the outcome. Because all cues' associative strengths are aggregated in the calculation of ΣV, all cues interact with each other and influence learning about the relationship between the target cue and the outcome (Rescorla and Wagner, 1972). Furthermore, all cues compete with each other for a limited amount of associative strength. That means on any given trial the overall change in associative strength (ΔV) between a single cue and the outcome is a function of the sum of the associative strength of all cues. Using an example with three cues (X, A, Context), this can be represented by the following equation:

$$(\lambda - \Sigma V) = \lambda - (V_{\text{Cue X}} + V_{\text{Cue A}} + V_{\text{Context}})$$

The linear operator (λ-ΣV) can be thought of as a mathematical formalization of surprise and represents prediction error (Haselgrove & Evans, 2010). Prediction error is the discrepancy between the expectation of the outcome and what actually occurs. With the Rescorla-Wagner (1972) model prediction error is referred to as "selective": a change in associative strength for a cue-outcome relationship is influenced by the associative strength of the other concurrent causal relationships (associations) (Haselgrove & Evans, 2010).

Prediction error is necessary for the formation and strengthening of associations between events (Corlett et al., 2007; Haselgrove & Evans, 2010). When there are multiple cues presented concurrently, as is the case in the environment outside of the laboratory, an organism needs to allocate attention to certain cues. In this case, prediction error will effect what the organism learns about each cue's relationship with the outcome (Corlett et al., 2007). Prediction error will be positive (e.g., $\Sigma V < \lambda$) when or if an unpredicted outcome occurs, or negative (e.g., $\Sigma V > \lambda$) if an expected outcome does not occur (Corlett et al., 2007; den Ouden, Friston, Daw, McIntosh &

Stephan, 2009; Morris et al., 2011; Schultz, 1998). Neurobiological research provides evidence for the role of prediction error in learning associations between events (Corlett et al., 2007; den Ouden et al., 2009; Morris et al., 2011; Schultz, 1998). Specifically, dopaminergic projections to the striatum and frontal cortex are involved in mediating the effects of reward on learning (Schultz, 1998). Dopaminergic neurons can be thought of as neurological correlates of a signal that provides information about upcoming outcomes (Schultz, 1998).

A large body of data supports the theory that learning occurs over time via the formation of associations between events (Baker et al.,1993; Baker, Murphy & Vallée-Tourangeau, 1996; Msetfi, Wade & Murphy, 2012; Shanks, Medin & Holyoak, 1996). As well, an advantage of associative theories such as the Rescorla-Wagner (1972) model is their parsimony and computational simplicity.

### 1.3.2 Probabilistic Contrast

However, other researchers provide alternate explanations of causal reasoning (Cheng & Novick, 1990, 1992; Goedert & Spellman, 2005; Peterson & Beach, 1967; Spellman, 1996; Yarlas, Cheng, & Holyoak, 1995). These theories propose that humans can judge causal relationships by isolating confounding alternative causes (Goedert & Spellman, 2005, 2007) For instance, Cheng and Novick's (1990, 1992, 1997) Probabilistic Contrast model proposes that individuals calculate "causal power" in their computation of covariations between events. According to this model, humans act as intuitive statisticians by mentally computing tests of conditional probabilities (Cheng & Novick, 1990, 1992, 1997; Spellman, 1996). That is, individuals do not only compute a test for the unconditional probability between events (or $\Delta P$), but they are able to contrast each specific *conditional probability* (or conditional contingency). These tests of conditional contingencies are equivalent to the tests for the main effects, interactions, and post-hoc comparisons used in statistical analyses of variance (Baker, Murphy & Vallée-Tourangeau, 1996). With this process of reasoning an individual is therefore able to eliminate confounding factors or causes (Cheng & Novick 1992; Spellman, 1996). Like a scientist who studies one variable (Cause 1) by holding the other (Cause 2) constant, the reasoner who is interested in the relationship between Cause 1 and the effect will try to hold Cause 2 constant. That is, they will calculate a contrast (conditional $\Delta P$) for Cause 1 in the absence and another in the presence of Cause 2. Statistically, this shows the effect of Cause 1 independent of Cause 2 (a main effect) and whether Cause 1 has different effects at different levels of Cause 2 (an interaction). Probabilistic Contrast theory (Cheng & Novick, 1992) may account for how individuals judge causal relationships in situations where human judgments of causal relationships do not approximate the unconditional $\Delta P$ (Allan, 1993; Shanks, 1993; Spellman, 1996).

## 1.4 Factors that influence accuracy of judgment

Along with these two theoretical perspectives on causal learning, consider the fact that in the absence of confounding variables such as individual characteristics (mood personality, motivation) and experimental characteristics (outcome density, context as a causal cue, and the presence of multiple cues) humans are fairly accurate at judging causal relationships (Barberia, Baetu, Msetfi & Baker, 2011; Blanco, Matute & Vadillo, 2009; Msetfi, Murphy, Simpson & Kornbrot. 2005; Msetfi, Wade & Murphy, 2012). One of the reasons animals are accurate at reasoning about uncertain events is that they use certain cues to better understand these relationships. Early research by Wasserman, Elek, Chatlosh and Baker (1993) demonstrated that contingency is a crucial cue used to understand causal relationships. Despite varied outcome densities (e.g., high, moderate, low) per condition, participants accurately judged the causal relationship. In fact, judgments were almost perfectly correlated ($r = 0.97$) with the actual contingency ($\Delta P$) (Wasserman et al., 1993).

However, the ability for humans to accurately judge causal relationships does not depend solely on contingency (Baker et al., 1993; Shanks, Pearson & Dickinson, 1989). In an active/instrumental causal reasoning task, Shanks, Pearson & Dickinson (1989) found that, despite a strong contingent relationship, an increase in the temporal delay between events weakened participants' judgments of contingency.

### 1.4.1 Evidence from animal conditioning

Rescorla (1969) demonstrated that animals are sensitive to manipulations of contingent relationships between a CS and a US.  Rats were either exposed to 1) CS-US pairings with no USs (outcomes) during the lapse in time between trials (inter-trial interval: ITI), or 2) CS-US pairings with USs (outcomes) presented during the ITI. Rats in the former group showed greater conditioning than rats exposed to outcomes (USs) presented during the ITI. This provides evidence that in order to be able to reason accurately about CS-US (or cue-outcome) relationships, animals consider not only what happens in the presence of the CS, but also what outcomes occur or do not occur in the absence of the US. Of further note, each group was exposed to the same number of total CS-US pairings; therefore, Rescorla's (1969) experiment provides evidence that frequency of CS-US pairings are not sufficient to produce learning.

### 1.4.2 Context

In conditioning and causal reasoning, the context may be thought of as a cue that is always present – it consists of environmental characteristics and stimuli. For example, an animal develops a conditioned response within the context of the testing chamber. The context (in this case, the testing chamber) provides its own set of cues that might develop their own relationship with the outcome as well as with the target cue (e.g., the CS) and competing cues. The association between the context and other cues means that the context can influence the behavioural response. For example, a change in context can recover a conditioned fear response that was previously extinguished in another context (Bouton and Swartzentruber, 1986; Bouton, 1993a, 2004).

Baker's (1977) between-days animal conditioning signaling experiments were the first to investigate the influence of context on how animals learn relationships between events. Rats were exposed to either uncorrelated, non-contingent relationships between a CS and a US (noises and shocks) (e.g., $\Delta P = 0$), or negatively correlated, inhibitory relationships between noises and shocks (analogous to $\Delta P = -1.0$). First (Experiment 1A), on even days animals were exposed to trials where a US occurred in the absence of a discrete CS (no Tone) (Context→Shock). So, on even days there was an excitatory association between the context and the shock. These days were followed by the odd-numbered days in which they were exposed to the opposite: A target CS (Tone), this time in the absence of a US (Tone+Context→No Shock). Because the CS (tone) became negatively correlated with the US (shock) the tone became a conditioned inhibitor. As the tone came to signal the absence of the shock, the animals showed a decrease in freezing in response to the tone. In other words, rats exposed to the negative correlation (or $\Delta P = -1.0$) between events were less suppressed in lever pressing than the rats in the uncorrelated (or $\Delta P = 0$) group. In other words, the former group of rats learned that the tone predicted no shock, so there was a reduction in freezing (less of a conditioned emotional response) therefore increasing lever pressing.

Subsequently (Experiment 1B) the rats were divided into three groups: negatively correlated, positively correlated, and uncorrelated (control group).  On even days the animals were exposed to a second CS (Light) in the presence of context followed by the US (Light+Context→Shock). The paradigm for the odd days was repeated: animals were given trials with the conditioned inhibitor (Tone) and the context in the absence of the US (Tone+Context→No Shock).

Compared to the control group, the result was a decrease in conditioned inhibition to the Tone, as a result of an increase in associative strength between the other cues and the outcome. Inhibition *only* occurred when the inhibitory cue (tone) was paired with a background cue that had an excitatory relationship with the outcome. Removing this background cue removed conditioned inhibition. Therefore, Baker (1977) concluded that conditioned inhibition is mediated by the effect of another cue. The initially negative correlation between the tones and shocks was affected by what the animals learned about the Context. There would not have been a decrease in conditioned inhibition when introducing a second CS (light). Put another way, compared to the animals who showed conditioned inhibition in Experiment 1A, rats in Experiment 1B learned that the light came to signal the shock, thereby reducing excitation between the context and the shock.

#### 1.4.2.1 Associative explanation

Associative theories can account for how the context affects contingency learning. Compare the situations in which a CS and the context occur in the absence of a US, versus when a CS and a US occur in the presence of the context. This can be illustrated by following example. Initially, a CS (e.g., Tone) is presented in the absence of a US (e.g., Shock), however, on these trials the context is another cue that is present. Following which are trials where the US is presented in the absence of the CS. According to the Rescorla-Wagner (1972) model, on the initial context with Tone trials the associative strength of the tone is zero ($V_{Tone} = 0$) because there is no Shock. Then, after trials on which the context is paired with the Shock, the associative strength increases ($V_{Tone+Context}$ = positive). Thus, if $V_{Tone} = 0$ and $V_{Tone+Context}$ = positive, the change in associative strength of the Tone ($\Delta V_{Tone}$ ) will decrease as the tone loses associative strength with the shock. According to the calculation with the linear operator, $\Delta V_{Tone} = \lambda - \Sigma V = 0 - V_{Tone+Context}$, the loss of associative strength of the tone, from zero to negative means that The tone is now perceived as an inhibitory cue. That is, the context forces the tone to lose associative strength and become inhibitory. Blocking learning about the Context→Shock relationship should block conditioned inhibition, i.e., prevent learning that the Tone is inhibitory. For instance, if Context→Shock trials are followed by Context+Light→Shock trials, the Light will gain associative strength and reduce (block) learning about the association between the Context and the Shock.

For human causal reasoning, all four types of relationships in the binary contingency table occur within the context. In certain situations, judgments of contingencies are especially susceptible to be influenced by the manipulation of the context. When the context occurs by itself, that is, in the absence of both the target cue and the outcome (Cell D, Figure 1), associative theories posit that the association between the context and the outcome will extinguish (Baker, Murphy & Vallée-Tourangeau, 1996).

In fact, research has shown that in the absence of both a target cue and the outcome (Cell D, Figure 1), the time between trial presentations can be mistaken to be part of the inter-trial interval (ITI) (Msetfi et al., 2005; Msetfi, Murphy, Simpson & Kornbot, 2007). Participants exposed to longer ITIs were less accurate in their judgments of causality. Higher frequencies of

Cell D events will decrease the overall ΔP and participants tend to perceive a weaker relationship between events (Msetfi, Murphy, Simpson & Kornbot, 2007; Msetfi, Wade & Murphy, 2012).

### 1.4.3 Outcome density

Another experimental factor that can affect participants' accuracy in judgments about probabilistic events is the outcome density. Outcome density is the overall proportion of times the outcome occurs on all trials, independent of whether or not it is paired with the cue. It can be calculated using the following formula considering frequencies from the binary contingency table (Figure 1) (Baker, Msetfi, Hanley & Murphy, 2011):

$$(A+C)/(A+B+C+D)$$

Research has shown that humans will often judge event information in a biased manner (Anderson & Sheu, 1995; Kao and Wasserman, 1993; Wasserman, 1990). For instance, in situations of high outcome density, participants often overestimate the ability of the cause to predict the effect, especially for non-contingent relationships ($\Delta P = 0$) (Baker, Murphy & Vallée-Tourangeau, 1996). This phenomenon is consistent with the report that when judging binary contingent relationships, participants attribute different degrees of importance to the different cells of the contingency table. Specifically, logical causal reasoning is often skewed when individuals attribute greater weight or perceived sense of importance for pairings in which both the cue and the outcome co-occur (Cell A, Figure 1) (Anderson & Sheu, 1995; Kao & Wasserman, 1993; Wasserman, 1990).

## 1.5 Cue competition

The concurrent presentation of multiple cues also affects the accuracy of judgments.

When there are multiple competing cues for a given outcome, the presence of a stronger cue can alter the perception of the other cue's relationship to the outcome (Dickinson, Shanks & Evenden, 1984; Kamin, 1969; Shanks, 1985; Van Hamme and Wasserman, 1994; Wagner, Logan, Haberlandt & Price, 1968).

### 1.5.1 Relative Validity

The fact that stimuli are judged relative to each other was demonstrated in Wagner's (1968) experiment where two groups of rats were presented with two audiovisual compound stimuli, each consisting of one of two Tones ($T_1$, $T_2$) with different frequencies and one Light (L) (Wagner, Logan, Haberlandt & Price, 1968). All rats were trained to lever press for food in response to the compound CSs. For animals in the true discrimination (TD) group, the $T_1L$ compound was always followed by the outcome, whereas the outcome never occurred after the presentation of $T_2L$.

Therefore, relative to the Light, the Tones provided relatively more information about the outcome (e.g., $T_1$ fully predicts the outcome, $T_2$ fully predicts no outcome). For the partial discrimination group (PD) the outcome followed half of the presentations of $T_1L$ as well as half of the presentations of $T_2L$. That is, for the PD group, the Tones were not better predictors of the outcome than the Light.

Despite the fact that the Light was followed by the outcome on 50% of its presentations in both treatments (TD and PD), when conditioning to the Light was tested alone (L), the animals in the PD group showed stronger conditioning than the animals in the TD group. Wagner's (1968) experiment thus provided evidence that a cue that is highly correlated with the outcome (e.g., Tone) can weaken judgments about a cue that provides relatively less information about the outcome (e.g., Light). Wagner (1968) concluded that the critical feature for the formation of associations between events is not a cue's absolute information about an outcome, but the information it provides about the outcome *relative to other cues*.

### 1.5.2 Blocking

Blocking (Kamin, 1969) is another example of what happens when the presence of one cue influences the perception of the other cue (Note: the term blocking refers to both the experimental paradigm and the observed effect/phenomenon) (Baker et al., 1993). Blocking has been demonstrated frequently in humans (Dickinson, Shanks, & Evenden, 1984; Matute, Arcediano & Miller, 1996; Shanks, 1985) and in other animals (Dickinson, Nicholas & Mackintosh, 1983). In a typical Kamin (1969) blocking procedure, animals are initially exposed to trials on which a single cue (e.g., a white Noise, N) is followed by an outcome (e.g., Shock) (N+). Following this are trials in which the Noise is paired in compound with the target cue (a Light) and this compound is paired with the outcome (NL+). The result is that when behavior is measured in response to the Noise alone, the conditioned emotional response (freezing) is suppressed. Prior learning that the Noise predicts the shock therefore "blocks" or prevents learning of the relationship between the Light and the Shock - regardless of the fact that the Light is regularly paired with the shock.

Blocking and relative validity illustrate three features about conditioning and causal reasoning. It is important to consider these features in both experimental and daily situations outside of the laboratory where individuals are exposed concurrently presented cues. First, contiguity between events is not sufficient to produce learning of the relationship between these events. A cue must provide unique, non-redundant, information about the outcome's occurrence. Furthermore, surprise about the outcome is required to produce learning. Finally, multiple cue-outcome relationships are judged relative to each other and therefore a stronger cue can reduce learning about a weaker cue (Baker et al., 1993; Baetu & Baker, Manuscript in preparation; Darredeau et al., 2009).

### 1.5.3 Cue competition in causal reasoning

To study how the concurrent presentation of multiple cues can affect judgments, Baker et al. (1993) used an instrumental computerized causal reasoning task that was based on Dickinson, Shanks and Evenden's (1984) paradigm. Baker and colleagues (1993) gave participants the task to judge the likelihood of a tank successfully crossing a minefield. The outcome was the successful crossing of the field and two cues were used as potential causes for this outcome. The target cue that participants controlled, was the color of the camouflage of the tank (Cue X). The competing cue that participants could not control was the presence or absence of a plane flying overhead (Cue A). The target cue was a moderate predictor of outcome ($\Delta P_X = 0.5$) whereas the competing cue was either perfectly generative/excitatory ($\Delta P_A = 1.0$) or preventive/inhibitory ($\Delta P_A = -1.0$).

Compared to the control condition which had a non-contingent relationship between the competing cue and the outcome ($\Delta P_X/\Delta P_A = 0.5/0$), participants underestimated the ability of the tank to cross the field when the tank and plane were both generative causes ($\Delta P_X/\Delta P_A = 0.5/1.0$) as well as when the plane was a perfect predictor of the tank *not* being able to cross the field ($\Delta P_X/\Delta P_A = 0.5/-1.0$) (Baker et al., 1993). Thus, blocking was found in both the 0.5/1.0 and the 0.5/-1.0 conditions, supporting both Rescorla and Wagner's (1972) and Cheng and Novick's (1990; 1992) explanations about cue competition.

However, other findings are inconsistent with these predictions and results. First, blocking of a weaker cue can occur past zero. That is, the target cue with a moderately positive contingency (e.g., $\Delta P_X = 0.5$) is judged to be an *inhibitory/preventive* cause that decreases the likelihood of the outcome (e.g., $\Delta P_X = -0.4$) (Baetu & Baker, Manuscript in preparation; Darredeau et al., 2009). In contrast, the associative and normative rule-based theories predict that the target cue will be blocked because the cue is perceived as less informative, and therefore judgments should approach zero, *not* develop an inhibitory relationship with the outcome.

Second, blocking of a weaker cue by a stronger cue is not the only evidence of cue competition. In cross-polarity competition treatments a positive cue is paired with a stronger negative cue (e.g., $\Delta P_X/\Delta P_A = 0.5/-1.0$). In this condition judgments of the weaker cue can be *increased* (enhanced) (Baker et al., 1993, Experiment 5; Vallée-Tourangeau, Murphy & Baker, 1998; Darredeau et al., 2009; Baetu & Baker, Manuscript in preparation). Enhanced ratings of the target cue (e.g., actual $\Delta P_X = 0.5$ perceived as $\Delta P_X = 0.8$) are inconsistent with the assumption (e.g., by the Rescorla-Wagner model) that blocking of a target cue should occur regardless of whether the stronger cue is excitatory or inhibitory.

## 1.6 Cue competition: Explanations and predictions

Both associative and normative rule-based theories predict how learning occurs when there are multiple cues for a given outcome, and both theories provide explanations of cue competition. Overall, the difference is that cue competition is proposed to occur either because the associative strength of the moderate cue is weakened by the presence of a stronger cue (Rescorla & Wagner, 1972), or because individuals are able to act as “intuitive statisticians” or scientists (Peterson & Beach, 1967; Spellman, 1996), for example by mentally computing conditional contrasts for relationships between events (Cheng & Novick, 1990; 1992).

## 1.6.1 Associative theories

According to associative models, a cue that is a stronger predictor of the outcome will acquire most of the associative strength, thereby reducing the associative strength between a moderate cue and the outcome. Therefore, the weaker moderate cue is blocked. In other words, the blocking cue develops a stronger association with the outcome and therefore the blocked cue is perceived as providing redundant information about the likelihood of the outcome (Kamin, 1969; Rescorla & Wagner, 1972).

Associative theories posit that there is less learning about cues that are redundant, regardless of whether the cues predict the presence or the absence of the outcome (Baetu, 2010; Baker, Murphy & Vallée-Tourangeau, 1996; Rescorla & Wagner, 1972). When competing cues (e.g., X and A) are excitatory/generative (predict an increase in the probability of the outcome) and have positive contingent relationships with the outcome ($\Delta P_X/\Delta P_A = 0.5/1.0$) or if one cue is inhibitory/preventive ($\Delta P_X/\Delta P_A = 0.5/-1.0$) associative theories predict that the weaker cue (in this case X) will be blocked. Associative theories provide two explanations for how blocking occurs as a result of change in associative strength. First, when both the target and the stronger competing cue are the same polarity and both excitatory cues (e.g., $\Delta P_X = 0.5/\Delta P_A = 1.0$) the stronger cue (A) acquires most of the associative strength and therefore the target cue (X) has less associative strength with the outcome. Secondly, when the stronger cue fully predicts the absence of the outcome ($\Delta P_A = -1.0$) it is the *context* that becomes an excitatory/generative cue that blocks the weaker cue (Baker, Murphy & Vallée-Tourangeau, 1996).

## 1.6.2 Normative rule-based theories

Cheng and Novick’s (1992) Probabilistic Contrast model also predicts that a stronger cue will reduce judgments of a moderate cue, whether or not both cues have contingencies of the same or opposing polarities. Humans can are “intuitive scientists” (Spellman, 1996) able to compute a conditional contrast between cues. In addition to difference between the probability of the outcome in the presence and absence of the (overall $\Delta P$), two conditional probabilities are calculated: the probability of the outcome conditional on the presence of both cues at the same time, and the probability of the outcome conditional on the presence of one cue without the other.

For example, consider the target cue/cause X with a confounding cue that always predicts the outcome $\Delta P_A = 1.0$. Because the confounding cause is fully generative, the outcome will occur regardless of whether or not X occurs. The probability of the outcome in the presence of A is subtracted from the probability of the outcome with XA. This means that the conditional contingency for X is zero due to the contrast between conditional contingencies. The conditional contingency for X is calculated with the formula:

(i) $\Delta P\ (O \mid XA) - \Delta P\ (O \mid A) = 1.0 - 1.0 = 0$

Therefore, the model predicts that when $\Delta P_A = 1.0$ judgments of X trend towards zero, but will not go beyond zero. The same thing occurs when the confounding stronger cause is fully preventive ($\Delta P_A = -1.0$):

(ii) $\Delta P\ (O \mid XA) - \Delta P\ (O \mid A) = -1.0 - -1.0 = 0$

In summary, Cheng and Novick’s (1990, 1992) model 1) does not predict enhancement and 2) does not predict blocking past zero. However, prediction of blocking in 0.5/1.0 and 0.5/-1.0 fits with empirical evidence that has found blocking with cues of opposite polarity (Baker et al., 1993, Experiment 4; Baker et al., 2000, Experiment 1; Vallée-Tourangeau et al., 1998).

### 1.6.3 The Contrast Hypothesis

The observation of both reduced (blocked) and increased (enhanced) ratings of a moderate or zero contingency target cue questions how relative validity between competing cues can affect causal judgments (Baetu, Baker, Darredeau & Murphy, 2005; Darredeau et al., 2009). Associative rule based models predict that according to the relative validity effect, blocking will occur if a stronger competing cue discounts judgments of a weaker cue. This happens regardless of whether the contingencies of the competing cues are of the same or opposite polarity. However, participants' enhanced judgments of the relationship between the moderate cue and the outcome when the competing cue is fully preventive ($\Delta P_X/\Delta P_A = 0.5/-1.0$) is not in accordance with that prediction. To account for this discrepancy, Darredeau et al. (2009) proposed the "Contrast Hypothesis" to explain a mechanism for cue competition that can be used to predict when blocking and enhancement will occur.

According to the Contrast Hypothesis, a generative or preventive strong causal factor will push estimates of the weaker cue in the opposite direction. This can explain why participants overestimated the target cue's likelihood to predict the outcome when ($\Delta P_X/\Delta P_A$) 0.5/-1.0. Because A is strongly negative, X is perceived to have a more generative relationship with the outcome than it actually does. In other words, enhancement occurs as a result of *the contrast* between cues. Blocking also occurs because of contrast between cues. When competing cues have contingencies of the same polarity ($\Delta P_X/\Delta P_A$) 0.5/1.0 the stronger cue (A) also pushes judgments of the target cue (X) in the opposite direction. Judgments of the contingency between X and the outcome are made in contrast to $\Delta P_A = 1.0$, and therefore X is perceived as having a weaker and even inhibitory relationship with the outcome than its actual moderate contingency (e.g., objective $\Delta P_X = 0.5$ judged as $\Delta P_X = -0.30$).

Darredeau et al.'s (2009) Contrast Hypothesis makes three predictions about cue competition that differ from predictions made by the Rescorla-Wagner (1972) model or Cheng and Novick's (1990, 1992) Probabilistic Contrast model. Figure 3 compares how these theories predict cue competition. In the control condition where the target cue (X) is a more informative than the competing cue (A) ($\Delta P_X = 0.5/\Delta P_A = 0$), all three theories predict that participants' judgments of A will be reduced due to blocking by X (Figure 3). According to the traditional associative and statistical/inferential theories of learning, in the same-polar condition ($\Delta P_X = 0.5/\Delta P_A = 1.0$) judgments of the target will be reduced toward *but not past* zero. However, Darredeau et al.'s (2009) Contrast Hypothesis assumes that due to the mechanism by which cues are contrasted to one another, a moderate target cue can indeed be perceived to decrease the likelihood of the outcome.

Via a mechanism of either reduced associative strength or one of contrast between conditional probabilities, the associative and normative rule-based theories respectively predict blocking of cue X in the opposite polarity case when the stronger cue is inhibitory. Indeed, participants have underrated the target cue in this condition ($\Delta P_X = 0.5/\Delta P_A = -1.0$) (Baker et al., 1993; Baker, Berbrier & Vallée-Tourangeau, 1989; Wasserman, Chatlosh & Neunaber, 1983; Wasserman, Elek, Chatlosh & Baker, 1993). Conversely, Darredeau et al. (2009) predict that due to contrast between cues, ratings of the target cue will be enhanced when the competing cue fully predicts the absence of the outcome ($\Delta P_X = 0.5/\Delta P_A = -1.0$). Some results support this prediction (Baetu & Baker, Manuscript in preparation; Darredeau et al., 2009).

Considering the context as another cue, if a salient context is excitatory ($\Delta P_C = 1.0$), it should push the target toward zero; it is simply that the mechanism of contrast is with the context and that is what reduces judgments of X. Similarly, if the competing cue is fully inhibitory

($\Delta P_x/\Delta P_A = 0.5/-1.0$) the context's relationship with the outcome will be perceived as strongly excitatory. This strong generative relationship between the context and the outcome could potentially push judgments of the target cue away from being enhanced. Therefore, due to the context, when $\Delta P_A = -1.0$, enhancement of X could be reversed into blocking. As of yet, no data support this prediction.

In summary, according to the Contrast Hypothesis (Darredeau et al., 2009), multiple cues are contrasted to one another. This occurs regardless of the polarity of their contingencies. That is, individuals contrast the cues in all three conditions of competing contingencies: $\Delta P_X/\Delta P_A$ = 0.5/1.0, 0.5/-1.0, 0.5/0. When cues that have independent effects on the outcome have contingencies of the same polarity (0.5/1.0), the weaker target cue will be blocked. Enhancement of the target cue will occur when they are of opposite polarity (0.5/-1.0) Although the Rescorla-Wagner (1972) model predicts relatively more blocking when the two cues are correlated (0.5/1.0) than when they are not (0.5/-1.0), the overall effect of blocking of the moderate cue (X) is predicted regardless of the polarity of the contingency of A.

Thus, when one cue is generative and the other cue is preventive (opposite polarity competition treatment), the Rescorla-Wagner model (1972) and Cheng and Novick's (1990, 1992) Probabilistic Contrast model predict blocking whereas the Contrast Hypothesis (Darredeau et al., 2009) predicts enhancement. Previous research (Baetu & Baker, Manuscript in preparation; Darredeau et al., 2009) has found enhancement, and this supports the Contrast Hypothesis over the two older theories. However, other research (Baker et al., 1993) has found blocking in the cross polarity condition ($\Delta P_X/\Delta P_A = 0.5/-1.0$). However, there is no theory that can explain why both blocking and enhancement of the target cue occur when a moderate positive cue competes with a strong negative cue (Baetu & Baker, Manuscript in preparation;

Darredeau et al., 2009). In this thesis I discuss how the auto-associator (Baetu & Baker, 2009) can be used as a parsimonious associative model that accounts for both blocking and enhancement.

## 1.7 The auto-associator

The auto-associator is a parallel-distributed-processing connectionist network model that was developed to explain how individuals reason about sequences of events (causal chains) (Baetu & Baker, 2009). Whereas Bayesian models of induction consider probabilities (Tenenbaum, Griffiths & Kemp, 2006), the auto-associator considers the associative strength between cues (Baetu & Baker, 2009). Figure 4 illustrates Baetu and Baker's (2009) example of a six-unit auto-associator, which consists of a single layer of interconnected units. In this model, there is a unit representing each cue: A, B, C, the general context, the context specific for co-occurrence of A and B and the context for the co-occurrence of B and C. Each arrow between the units represents an association that may develop between cues. As with the Rescorla-Wagner (1972) model, the auto-associator uses the delta rule to measure change in associative strength (Baetu & Baker, 2009).

### 1.7.1 Perceptual learning

Relying on theories of perceptual learning (Atkinson & Estes, 1963; Pearce, 1987, 1994) implemented in an associative framework, the auto-associator proposes a possible mechanism for contrast between cues (Baetu & Baker, 2009). According to Configural theory (Pearce, 1987, 1994) the presence of common features (elements) between different cues facilitates generalization between them, whereas a lack of common elements between cues facilitates discrimination. As such, the ability to discriminate between cues varies depending on the degree to which cues share common elements.

Other research has shown that causal reasoning is influenced by the similarity between cues (Liljeholm & Balleine, 2008) and the ability to discriminate between potential causes of an effect has important implications for conditions in which multiple cues are presented simultaneously. If a cue that is a stronger predictor of an outcome ($\Delta P_A = 1.0$) or its absence ($\Delta P_A = -1.0$) competes with a moderate predictor ($\Delta P_X = 0.5$) and both cues are easily discriminated between, I would expect the weaker cue to be respectively blocked or enhanced by the stronger cue. Conversely, if there is generalization between two similar cues, one cue's relationship with the outcome is perceived to be similar to the other cue's relationship with the outcome. In this case there should be less competition between cues and the blocking and enhancement should be reduced.

### 1.7.2 Inhibitory associations and prediction error

Baetu and Baker's (2009) auto-associator provides a theoretical framework for cue competition. According to this model, cue competition is the result of a mechanism of inhibitory associations that are formed due to negative prediction error. To illustrate, consider the example of two cues, XC and AC. These two cues share C as a common element but each has its own element (X, A).

When XC and AC are presented one at a time (regardless of the outcome), excitatory associations are formed between the elements of each compound cue whereas C predicts X and C also predicts A. Once these associations have formed, when XC is presented by itself, the common element C retrieves the memory of the unique element, (A) and the individual expects to see element A. However, because on XC trials A is expected but does not occur, there is a negative prediction error ($\Sigma V > \lambda$ and therefore $\Delta V$ decreases). By definition, the unique elements of each CS are never shared/presented simultaneously ($\Delta V = 0$). As such, after a decrease in $\Delta V$ the net associative strength between X and A will be *negative*. That is how inhibitory associations are formed between X and A (the unique elements).

The inhibitory associations between these unique elements (X and A) may be a mechanism that underlies the ability to discriminate between the compound cues (Baetu & Baker, 2009). Because one cue predicts a decrease in the likelihood of the other there is discrimination between cues AC and CX. Put another way, there is a reduced n generalization between them.

Generalization will occur between XC and AC due to their shared common element C (Pearce 1987, 1994). As a result of this generalization, when presented with only XC or AC, one may not be able to distinguish between each cue's unique relationship with the outcome. Therefore, cue competition (e.g., blocking, enhancement) will be reduced.

In the cross-polarity condition ($\Delta P_X/\Delta P_A$ = 0.5/-1.0) the target cue X has an excitatory association and A has an inhibitory association with the outcome. After repeated presentations of X, the X-Outcome relationship should gain associative strength whereas after presentation of the A-Outcome relationship loses associative strength (Rescorla & Wagner, 1972). While the competing cue (A) predicts a decrease in the likelihood of the outcome, the inhibitory associations formed between unique elements "reverses" this, resulting in the inhibition of an inhibitory association. The inhibition of an inhibitory association means that X indirectly "boosts" its own excitatory connection with the outcome. As such, X is perceived as to be a better predictor of the outcome compared to its objective contingency (e.g., causal ratings of X are enhanced). According to this mechanism the auto-associator can account for enhancement in 0.5/-1.0.

## 1.8 Objectives

The series of three experiments presented in this thesis used a computerized causal reasoning task called "Alien Life". Participants were asked to determine the relationship between the environments of different planets (cues) and the detection of aliens on that planet (outcome). One aim of this research was to see if judgments of a moderate positive target cue are increased (enhanced) or decreased (blocked) in the presence of a stronger cue of opposite polarity. To do so I measured competition between cues in three different conditions of contingency. Another aim was to determine if similarity between cues could affect cue competition. Cue elements and context salience were used to manipulate the similarity between cues. From these results, the goal was to have a better understanding of how cue competition occurs. The objective was to use these results to determine which theoretical prediction about cue competition is best supported and to better understand the role of relative validity in cue competition.

## 1.9 Figures

| | Outcome | No Outcome |
|---|---|---|
| Cue | A | B |
| No Cue | C | D |

**Figure 1.** 2x2 Binary contingency table used to calculate ΔP for binary probabilistic relationships. The frequencies of each type of trial is depicted in each of the different cells (A, B, C, D). Each cell illustrates one of the four possible events for binary relationships. The normative statistic for contingency (ΔP) is calculated using these cell frequencies [ΔP = P(O|C) – P(O|~C) = A/(A+B) – C/(C+D)].

| | O | ~O |
|---|---|---|
| C | **15** | **5** |
| ~C | **5** | **15** |

$$
\begin{aligned}
\Delta P &= (O|C) - P\,(O\,|{\sim}C) \\
&= A/(A+B) - C\,(C+D) \\
&= 15/(15+5) - \ 5/(5+15) \\
&= 0.75 - 0.25 \\
&= 0.50
\end{aligned}
$$

| | O | ~O |
|---|---|---|
| C | **60** | **20** |
| ~C | **20** | **60** |

$$
\begin{aligned}
\Delta P &= (O|C) - P\,(O\,|{\sim}C) \\
&= A/(A+B) - C\,(C+D) \\
&= 60/(60+20) - \ 20/(20+60) \\
&= 0.75 - 0.25 \\
&= 0.50
\end{aligned}
$$

**Figure 2.** Two binary contingency tables with different cell frequencies. The calculation of contingency is shown for each table

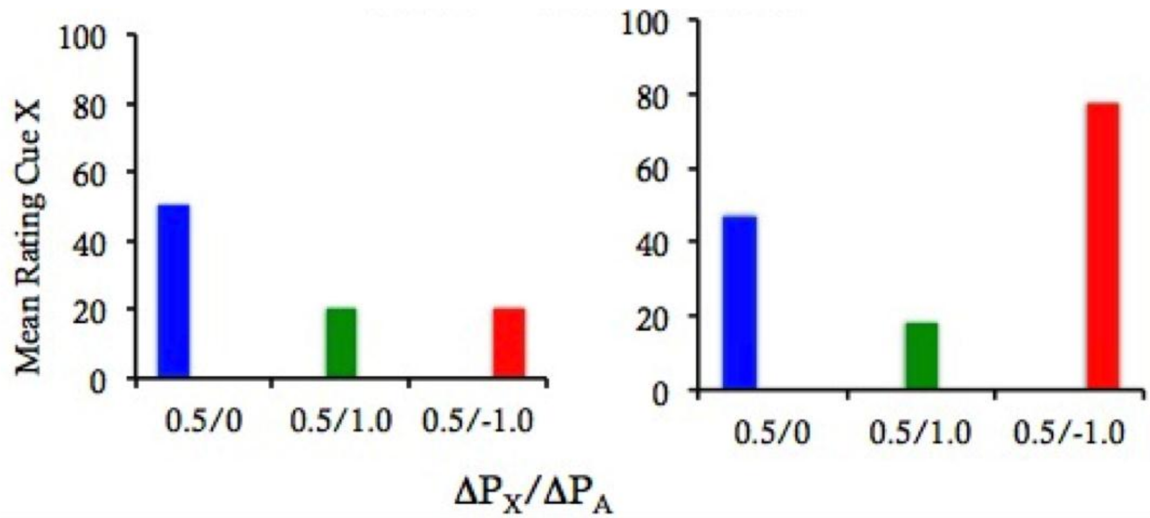



**Figure 3.** Comparison of theoretical predictions about the effects of cue competition on the target cue X in three conditions of competing contingencies: ($\Delta P_{X/}$ $\Delta P_A$) 5/0, 0.5/1.0, 0.5/-1.0. Left: Predictions made by the Rescorla-Wagner (1972) model and the Probabilistic Contrast model (Cheng & Novick, 1990, 1992) are shown in the graph on the left. Both theories predict fairly accurate judgments of the target cue when $\Delta P_A$= 0 and reduced estimates of the target cue with $\Delta P_A$= 1.0 and with $\Delta P_A$= -1.0. The associative theory posits that the mechanism for this cue competition is due to changes in associative strength and surprise/redundancy (a weaker cue provides less information about the likelihood of the outcome and is therefore redundant). The rule based model assumes that the mechanism is contrast between conditional contingencies. Estimates of the target cue can be reduced but not beyond zero. Right: Predictions from Darredeau et al.'s (2009) Contrast Hypothesis. In all conditions the cues are contrasted to each other and therefore the stronger cue will "push" estimates of the weaker cue in the direction opposite of the stronger cue's own contingency. Cue X should be judged fairly accurately in 0.5/0. In 0.5/1.0, the theory predicts that X should be reduced (blocked) and that this blocking can occur beyond zero (not depicted in this image). Finally, in the cross-polarity condition (0.5/-1.0) the Contrast Hypothesis predicts that ratings of X will be enhanced.

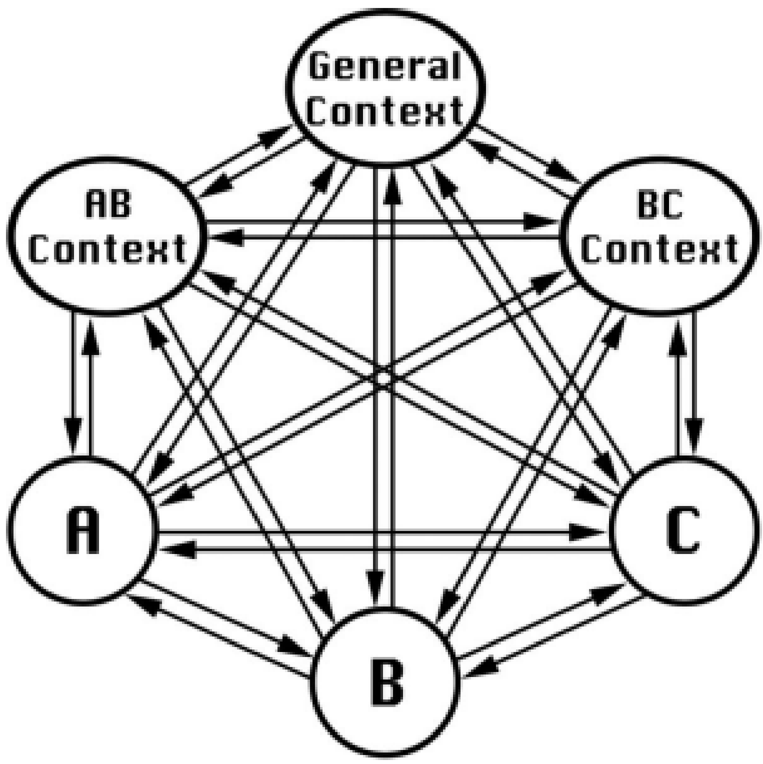



**Figure 4.** Illustration of the auto-associator. Taken from Baetu & Baker (2009). In this example there are six units (A, B, C, AB Context, BC Context, General Context), where each represents a cue in the environment. The contextual cues for AB and BC trials are cues that are present when A and B are presented together and when B and C are presented together. The arrows indicate all of the unidirectional associations or connections that can develop between the six units.

# Chapter 2

## Cue competition depends on contingency

## 2.1 Introduction

The objective of the first experiment in this thesis was to see how judgments of a moderate cause are influenced by the presence of a cue that either has a stronger generative or a preventive causal relationship with the outcome. When a target cue with a moderate contingency (e.g., $\Delta P_X = 0.5$) is presented with a stronger cause of opposite polarity (e.g., $\Delta P_A = -1.0$), participants' judgments of the target cue can be increased (Baker et al., 1993, Experiment 5; Baker et al., 2000, Experiment 2; Darredeau et al., 2009) and can also be decreased (Baker et al., 1993; Baker, Vallée-Tourangeau & Murphy, 2000; Vallée-Tourangeau, Murphy & Baker, 1998). Therefore the purpose of Experiment 1 was to see whether judgments would be increased (enhanced) or reduced (blocked) in the $\Delta P_X/\Delta P_A = 0.5/-1.0$ condition. The other goal of Experiment 1 was to investigate the effects of cue elements and of context salience on cue competition. Ultimately, I sought to determine whether my results would support the predictions about cue competition made by associative theories, normative rule-based theories, or the Contrast Hypothesis.

If judgments of a target cue are blocked in the $\Delta P_X/\Delta P_A = 0.5/1.0$ condition it supports the assumptions that cue competition is a result of redundancy or competing information. Indeed this is what the Rescorla-Wagner (1972) model predicts. However, the theory assumes that blocking cannot go beyond zero: a decrease in associative strength implies that the cue provides less information than the stronger cue. If estimates are decreased beyond zero the cue is judged as a preventive cause, not as providing no information about the outcome. The Probabilistic Contrast model (Cheng & Novick, 1990, 1992) also assumes that if an individual calculates conditional contrasts when the confound cue is 1.0 or -1.0, judgments of X will be reduced but not below zero.  On the other hand, if cue competition occurs when cues are contrasted to each other (Darredeau et al., 2009) then judgments of X would be reduced in 0.5/1.0 and increased in 0.5/-1.0.

This is the first study to simultaneously manipulate cue elements and context salience in order to understand cue competition in causal reasoning. To do so, Experiment 1 included three factors: one independent measure and the other two as repeated measures. One group received training in a salient context and the other in a non-salient context. All participants were exposed to two sets of three contingencies with the target cue (X) and the competing cue (A) ($\Delta P_X/\Delta P_A$). There was a control condition (0.5/0) in which the competing cue had a non-contingent relationship with the outcome, a same polarity competition treatment (0.5/1.0), and an opposite polarity competition treatment (0.5/-1.0). All participants saw two manipulations of cue elements within each contingency treatment: one in which cues shared a feature (the common element), which was represented by one of the five light indicators that was illuminated on every trial, and one in which the cues consisted of their own unique light indicators and did not have a common element.

Forty-seven participants were exposed to trials with a salient context manipulation and forty-nine participants were exposed to trials using a non-salient context. The salient context was represented by one of the five light indicators "lit" or illuminated (coloured) on every trial (Figure 1). I measured participants' judgments of three cues' relationship with the outcome. These were: Cue X (the target cue), Cue A (the stronger competing cue), and the Context.

## 2.2 Methods

### 2.2.1 Participants

Ninety-six McGill Undergraduate students were recruited from the McGill Psychology Participant Pool. Course credit was given for participating. All participants gave informed consent and were debriefed following the experiment.

### 2.2.2 Apparatus

Experiment 1 used “Alien Life I”, a computerized causal reasoning task programmed in RealBasic. The task was presented to each participant in a quiet laboratory setting using one of three iMac desktop computers.

### 2.2.3 Procedure

Participants were seated at a computer and told to complete the experiment at their own pace and that they were not competing with anyone. When the experimenter left the room, the participants began the experiment by reading a set of instructions presented on the computer screen. The task took approximately forty-five minutes to complete.

Participants were instructed to imagine themselves as astronauts visiting six different planets. Their goal was to use the information about the planet’s environment to determine whether or not alien life forms would be found on that planet. On the computer screen’s virtual spaceship display, participants viewed five light indicators labeled A-E, each of which signaled a different environmental variable. On each trial various combinations of light indicators were illuminated (Figure 1). A single light indicator was used to represent each of the three cues (X, A, Context) used in this experiment. One indicator represented Cue X and another represented Cue A. As shown in Figure 1 each cue was a single panel and therefore consisted of a single element.

In "Alien Life I" some participants were exposed to a salient context and others were shown a non-salient context. These manipulations are described below. Recall that in animal conditioning and human causal reasoning, the context refers to a set of stimuli that comprise the background of an event. For example, these background stimuli can be the characteristics (smell, size, color) of a testing chamber used in fear conditioning. To account for the fact that the context consists of all stimuli, some of which are similar and some that are not, Experiment 1 operationalized context salience with one light indicator that was either present on all trials (salient context) or absent (non-salient context) (Figure 1).

Forty-seven participants were exposed to the salient context. On every trial this light indicator was illuminated to represent the salient context. Participants were shown the same salient context (e.g., the same indicator was used) within each planet. However, the indicator that represented the salient context differed for each of the six conditions (e.g., planet 1 used 'B', planet 2 used 'C'). Participants in the salient context group viewed trials of either one (X or A or context), two (XA, X and Context, A and Context) or three (X with A and Context) illuminated indicators. Forty-nine participants viewed trials with the non-salient context; no single indicator was always illuminated. Participants in this group saw trials that had either one (X or A), two (XA) or zero (context alone) illuminated indicators.

Both groups of participants saw forty-eight training trials for each of the six planets they visited. Each planet represented a different condition. To control for variance participants were randomized to one of twenty-four ordered presentations of the conditions. To account for order effects within each group of participants, the training trials were presented in three counterbalanced blocks of sixteen trials per block. Each training trial showed a different set of on/off indicators above the question: “Do you think a life form will be detected?” They answered by using the mouse to click either “yes” or “no”. Following this feedback (“correct” or “incorrect”) was provided. The presence of the outcome was an image of an alien form shown at the bottom of the screen whereas the absence of the outcome showed a blank box (Figure 2). Each of the six planets had different coloured light indicators, different background images and different images for the alien life form found on that planet.

In all treatments the target cue (X) had a moderate contingency with the outcome ($\Delta P_X$ = 0.5). The contingency of the competing cue (A) was either strongly positive ($\Delta P_A$ = 1.0), strongly negative ($\Delta P_A$ = -1.0) or zero/null ($\Delta P_A$ = 0) as a control condition. All participants were exposed to the three types of competing contingencies (0.5/0, 0.5/1.0, 0.5/-1.0) when Cue X and Cue A shared a common element (CE) and when they had only their own unique elements (UE). Thus overall, each participant viewed six conditions: three for common elements (0.5/0 CE, 0.5/1.0 CE, 0.5/-1.0 CE) and three for unique elements (0.5/0 UE, 0.5/1.0 UE, 0.5/-1.0 UE). Each of these six conditions was presented as a different planet in “Alien Life I”.

Participants were randomly assigned to one of twenty-four ordered presentations of the six conditions/planets. The presence of the outcome (alien life form detected) occurred on twenty-four of the forty-eight training trials (per condition). Figure 2 shows the frequency of each type of trial ($\Delta P_X/\Delta P_A$: 0.5/0, 0.5/1.0, 0.5/-1.0), the conditional probabilities (P O|$X_{ALONE}$ and P O|$A_{ALONE}$) and conditional contingencies ($\Delta P_{X\ NO\ A}$ and $\Delta P_{X\ GIVEN\ A}$) for each condition. Following the training trials in each condition participants were given three test trials. On these trials they were presented with certain cues and asked to rate the degree to which they believed these cues predicted either the presence (alien life form detected) or the absence of the outcome (absence of alien life). Participants rated the likelihood of the outcome by using a mouse to select a position on a visual analogue type of rating scale that ranged from -100 to +100. There were written instructions for what the negative, zero, or positive ratings implied about the outcome (-100 being fully preventive, 0 being no relationship, +100 being fully generative) (Figure 3). The range of the scale was chosen to map the contingencies ($\Delta P$ from -1.0 to 1.0) and measure any ratings below zero.

## 2.3 Results

### 2.3.1 Ratings of Cue X

Figure 5 illustrates participants' ratings of the causal relationship between Cue X and the outcome. In the control condition, the competing cue had a zero relationship with the outcome ($\Delta P_A$=0). On these trials, participants were fairly accurate at judging the moderately positive relationship between X and the outcome. Compared to the control condition, there were reduced estimates of Cue X's relationship with the outcome when the competing cue was a perfect excitatory cue (0.5/1.0). In this condition, judgments of X were reduced below the X-axis, into the range of negative values. In contrast, when the competing cue was a perfect inhibitory cue (0.5/-1.0) ratings of X were higher than those in the control condition. This pattern of effects of cue competition on estimates of X was the same whether or not the cues shared a common element.

Both groups of participants exposed to the different contexts (Non-Salient Context, Salient Context) underestimated X's ability to predict alien life when the competing cue was a perfect generative cause, and overestimated X's relationship with the outcome when the competing cue was a fully preventive cause (Figure 5). However, compared to estimates in the Non-Salient Context, the magnitude of differences was reduced in the Salient Context: Figure 4 shows that the absolute values of X were smaller in each of the three contingencies. These reduced values give the impression that the cue competition was attenuated in a salient context. In contrast, the elements manipulation did not seem to have an effect on cue competition. There was no change due to elements in ratings of X between groups in either the mean values in each contingency or the pattern of ratings by contingency. A series of statistical analyses confirmed these impressions. First, a 2(3x2) mixed design analysis of variance (ANOVA) with context salience as the independent measure (Non-Salient, Salient) and contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and Cue Elements (UE, CE) as repeated measures was used to look at the effects of each factor among all participants. As shown in Figure 5 judgments of X differed by contingency ($F(2,188) = 273.218$, $p < 0.001$). The test confirmed that judgments of the target cue did not differ due to the element manipulation ($F(1,94) = 0.301$ $p = 0.584$). Context salience did not change the pattern of ratings of X ($F(1,94) = 3.027$, $p = 0.085$) but as shown in Figure 4, the magnitude of change in ratings due to contingency were reduced in each contingencies for the salient context ($F(2,188) = 48.255$, $p < 0.001$). Based on this interaction I subsequently used repeated measure ANOVAs to determine the pattern of change and verify the reliability of effects in each group.

**Non-Salient Context.** Ratings of X in the non-salient context were analyzed with a two-factor 3 (0.5/0, 0.5/1.0, 0.5/1.0) by 2 (UE, CE) ANOVA for contingency and cue elements. The analysis confirmed the impression that ratings differed due to contingency ($F$(2,96) = 321.009, $p$ < 0.001) but that there were no differences due to the element manipulation (no main effect nor any interaction with contingency) (Maximum $F$(2,96) = 2.446, $p$ = 0.092). As shown in the right panel of Figure 4, ratings of X were reduced in 0.5/1.0 and increased in 0.5/-1.0 compared to judgments in 0.5/0.Two 2x2 ANOVAs confirmed the reliability of these impressions. Compared to the control contingency 0.5/0, estimates of X were significantly blocked and significantly enhanced in the 0.5/1.0 and 0.5/-1.0 conditions, respectively (Minimum $F$(1,48) = 71.467, $p$ < 0.001). Because the experiment did not include a condition with a contingency for X other than 0.5, I verified that the ratings of X in 0.5/0 were statistically higher than a value of zero. In the non-salient context, judgments of X were reliably above zero with both UE and CE (Minimum $t$(48) = 7.742, $p$ < 0.001). Enhancement of X in 0.5/0 was also confirmed for both cue elements conditions in the salient context (Minimum $t$(46) = 3.197, $p$ = 0.003).I also compared the effect of elements in the blocking effect and in the enhancement effect. Compared to judgments in control (0.5/0) the reductions in 0.5/1.0 did not different between UE and CE groups: there was neither a main effect for elements nor an interaction (Maximum $F$(1,48) = 0.905, $p$ = 0.346) Compared to judgments in control the increased estimates of X in 0.5/-1.0 differed only due to the interaction between cue elements and contingency ($F$(1,48) = 6.526, $p$ = 0.014), there was no main effect ($F$(1,48) = 0.095, $p$ = 0.759).

**Salient Context.** As in the non-salient context, it appeared that contingency was the only factor to influence participants' causal estimates of X (Figure 5, right panel). I first used a 3 by 2 repeated measures ANOVA for contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and cue elements (UE, CE) and the test confirmed this impression. There was a main effect of contingency ($F$(2,92) = 40.155, $p$ < 0.001) but no effect of the element manipulation $F$(1,46)= 0.192, $p$ = 0.664) nor a contingency by element interaction ($F(2,92) = 0.092$, $p = 0.912$). Similar to ratings within the Non-Salient Context, 2x2 repeated measure ANOVAs confirmed reliable blocking of X in 0.5/1.0 ($F(1,46) = 37.871$, $p < 0.001$) as well as a trend towards significance for enhancement in 0.5/-1.0 ($F(1,46) = 3.787$, $p = 0.058$). As depicted in Figure 4 and as expected from previous analyses, the common element manipulation did not have any effect on ratings of X in the salient context (Maximum $F(1,46) = 0.064$, $p = 0.802$).

### 2.3.2 Ratings of Cue A

As with the target cue, contingency also affected judgments of the competing cue: shown in Figure 6, participants' estimates of A closely matched the respective objective contingencies of 1.0 and -1.0 and estimates were reduced in the 0.5/0 condition when the target cue was the stronger/more informative cue.

I verified that the ratings of A in 0.5/0 were significantly lower than zero by comparing participants' estimates in 0.5/0 to a value of zero. In the non-salient context A was reliably reduced (e.g., blocked past zero) in both conditions of elements (Minimum $t(48) = -4.004$, $p < 0.001$). In the salient context estimates of A were significantly reduced past zero only in the UE condition ($t(48) = -2.211$, $p = 0.032$). The very small reduction past zero in the CE 0.5/0 for a salient context is illustrated in Figure 6: this was not a significant reduction ($t(46) = -0.863$, $p = 0.393$).

A mixed design 2(3x2) ANOVA with context as the independent measure (Non-Salient, Salient) and contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and cue elements (UE, CE) as repeated measures confirmed that estimates were significantly different in the three contingencies ($F(2,188) = 876.934$, $p < 0.001$). The analysis also confirmed that ratings of A were not changed by the elements manipulation ($F(1,94) = 0.050$, $p = 0.823$) nor was there a difference between groups ($F(1,94) = 0.087$, $p = 0.769$). However, the mean values of A in each contingency were reduced in the salient context (Figure 4). ANOVA confirmed the significance of this interaction between context salient and contingency ($F(2,188) = 11.518$, $p < 0.001$). No other interactions between factors were significant (Maximum $F(2,188) = 0.781$, $p = 0.459$).

**Non-Salient Context.** Statistical analyses confirmed the impressions of the significant effects for contingency and the interaction between context salience and contingency. The analyses also confirmed the reliable lack of change due to elements. Figure 6 (left panel) shows that the mean estimates of A in the non-salient context were different in each of the three contingencies. A 3x2 ANOVA confirmed this impression ($F(2,96) = 1194.089$, $p < 0.001$). The common element manipulation did not change values of A nor the pattern of ratings of A by contingency (Maximum $F(1,48) = 0.324$, $p = 0.724$). Subsequent 2x2 ANOVAs confirmed that the effects of contingency on cue competition were reliable. In comparison to the control contingency (0.5/0) judgments of A were respectively significantly increased and decreased in the 0.5/1.0 and 0.5/-1.0 conditions (Minimum $F(1,48)= 232.463$, $p < 0.001$). No other results were significant (Maximum $F(1,48)= 0.454$, $p = 0.504$).

**Salient Context.** As with the non-salient context, judgments of A in the salient context differed by contingency (Figure, 6 left panel). A 3x2 repeated measures ANOVA for contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and elements (UE, CE) was used to verify the main effect for contingency ($F(2,92) = 223.021$, $p < 0.001$). The statistical test also confirmed that the element manipulation did not have an effect on the means or pattern of means in the different contingencies (Maximum $F(2,122) = 1.387$, $p = 0.255$). Individuals gave fairly accurate estimates of the causal relationship for A in both the 0.5/1.0 and 0.5/-1.0 conditions (Figure 6). Two 2x2 ANOVAs confirmed that in comparison to 0.5/0 where estimates were negative, ratings were reliably even further reduced in 0.5/-1.0 and increased in 0.5/1.0(Minimum $F(1,46) = 122.402$, $p < 0.001$). As is illustrated in Figure 6 and as expected from the 3x2 ANOVA, the 2x2 ANOVAs confirmed that the common element manipulation did not change ratings in 0.5/1.0 or 0.5/-1.0 (Maximum $F(1,46) = 1.900$, $p = 0.175$).

### 2.3.3 Ratings of Context

Participants in both groups (non-salient and salient contexts) judged the causal relationships based on the different competing contingencies of X and A (Figure 7) and therefore I assumed that judgments of the context were made in contrast to judgments about the other cues. In both groups ratings of the context were slightly reduced past zero in 0.5/0, further reduced past zero in 0.5/1.0 and increased past zero in 0.5/-1.0.

I used *Post-hoc* one-sample t-tests to determine whether the reductions past zero in 0.5/0 were significant. The tests confirmed that the context was reliably blocked past zero in 0.5/0 for all four conditions (UE and CE in both non-salient and salient contexts). These results provide additional evidence in support of both the contrast mechanism for cue competition as well as the associative explanation for how the context can lose associative strength in the presence of stronger competing cues (Minimum $t(46) = -2.705$, $p = 0.01$).

A 2(3x2) mixed design ANOVA with context salience as the independent measure (Non-Salient, Salient) and contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and elements (UE, CE) as repeated measures confirmed that judgments of the context differed due to contingency ($F(2,188) = 841.202$, $p < 0.001$). Figure 6 also illustrates that participants' judgments of the salient context are lower than judgments of the non-salient context. The 2(3x2) ANOVA confirmed that this apparent decrease was not significant ($F(1,94) = 4.596$, $p = 0.035$). As with cues X and A, the common element manipulation did not change ratings of either contexts ($F(1,94) = 0.005$, $p = 0.942$) nor were there any other interactions due to the manipulation for a common element (Maximum $F(1,94) = 3.721$, $p = 0.057$)

**Non-Salient Context.** The left panel of Figure 7 shows that judgments of the non-salient context differed in each of the three contingency conditions. The context was judged as a slightly inhibitory cue in 0.5/0, a strong inhibitory cue in 0.5/1.9 and a strong excitatory cue in 0.5/1.0. A 3x2 within subjects ANOVA confirmed that these differences were significant ($F(2,96) = 503.357$, $p < 0.001$). As shown in the left panel of Figure 6 there was no difference in mean estimates or in the pattern of estimates between the UE and CE conditions (Maximum $F(2,96) = 1.811$, $p = 0.185$). Judgments of the non-salient context in both 0.5/1.0 and 0.5/-1.0 were each compared to judgments in 0.5/0. Two 2x2 ANOVAs confirmed the significant change in judgments of the context shown in Figure 7, where estimates were lower in 0.5/1.0 compared to control and higher in 0.5/-1.0. Compared to ratings in 0.5/0 ratings of the non-salient context were higher in 0.5/-1.0 and lower in 0.5/1.0 (Minimum $F(1,48) = 84.567$, $p < 0.001$). These results are consistent with the Contrast Hypothesis (Darredeau et al., 2009) because it appeared that the stronger cue (A) pushed judgments of the context in the direction opposite to its own contingency.

**Salient Context.** Participants' ratings of the salient context differed in each of the three contingencies (Figure 7, right panel). Participants judged the salient context to be a slightly preventive cause in 0.5/0, a stronger preventive cause in 0.5/1.0 and a strong generative cause in

0.5/-1.0. A 3x2 within subjects ANOVA was used to confirm the main effect of contingency ($F(2,92) = 349.606$, $p = 0.001$). This is the same pattern of ratings due to contingency as in the non-salient context. Although the judgments in each contingency appear slightly lower in the salient context (Figure 7), prior analyses showed that this between-groups difference was not significant ($F(1,94) = 4.596$, $p = 0.035$).

I subsequently used two 2x2 repeated measure ANOVAs for contingency and cue elements to look at the change in causal estimates of the salient context in each contingency. The tests confirmed that compared to ratings in 0.5/0 the context was blocked (significantly lower than control) in 0.5/1.0 and enhanced (significantly higher than control) in 0.5/-1.0 (Figure 7) (Minimum $F(1,46) = 79.951$, $p < 0.001$). These results support the hypothesis that cue competition occurs due to a mechanism of contrast between cues and the associative explanations for how the context can influence learning by developing its own associations with the outcome. This can account for blocking of the context in 0.5/1.0 due to a decrease in associative strength, e.g., $V_{CONTEXT} < V_{CONTEXT\ AND\ CUE\ A}$ then $\Delta V_{CONTEXT}$ decreases from baseline (e.g., in 0.5/0). The same principle applies to how the context can be enhanced A is fully preventive ($\Delta P_A = -1.0$): $V_{CONTEXT} > V_{CONTEXT\ WITH\ A}$ then $\Delta V_{CONTEXT}$ increases from what it was in 0.5/0. As illustrated in Figure 7, participants' did not give equivalent ratings of the salient context when X and A shared common elements compared to when they did not (e.g., the gray bars show a lower mean value in 0.5/1.0 CE compared to 0.5/1.0 UE). I used a 3x2 ANOVA to analyze these differences due to elements. The test confirmed that participants' ratings in each contingency were different in the UE and CE conditions ($F(2,92) = 4.057$, $p = 0.020$).

Furthermore, Figure 7 (right panel) shows that *the difference* between ratings in 0.5/0 and 0.5/1.0 is lower in the common element condition, and a 2x2 ANOVA for contingency (0.5/0, 0.5/1.0) and cue elements (UE, CE) confirmed that there was a main effect for the element manipulation whereby the common elements reduced the blocking effect ($F(1,46) = 4.744$, $p = 0.035$). The enhancement effect was also attenuated. There is less of an increase in ratings in 0.5/-1.0 from 0.5/0 is lower in CE than UE (Figure 6, right panel). This is likely due of the difference in judgments in 0.5/0 between the CE and UE conditions: the salient context is rated as more preventive 0.5/0 CE than in 0.5/0 UE. The 2x2 ANOVA for contingency (0.5/0, 0.5/-1.0) and cue elements (UE, CE) confirmed the significant interaction between contingency and cue elements in the cross-polarity competition treatment compared to control ($F(1,46) = 10.312$, $p = 0.002$). These changes are likely due to the fact that the salient context is rated as more preventive 0.5/0 CE than in 0.5/0 UE. *Post-hoc* analyses with paired samples t-tests confirmed that estimates of the salient context in 0.5/0 were significantly lower in the CE condition ($t(46) = 2.973$, $p = 0.005$) than in the UE condition.

## 2.4 Discussion

Judgments of a weaker moderate positive cue are almost universally reduced in the presence of a stronger positive cue. The associative explanation for why this occurs is that the weaker cue (e.g., $\Delta P_X = 0.5$) provides less information about the outcome than the strong cue (e.g., $\Delta P_X = 1.0$). Indeed, if one cue always predicts the absence of the outcome but the other cue only sometimes predicts the absence of the outcome, it is easier to learn about the strong relationship. According to the Rescorla-Wagner (1972) model and Probabilistic Contrast (Cheng & Novick, 1990, 1992), in the presence of a fully generative or preventive cue the ratings of a moderate cue are reduced towards zero, either due to loss in associative strength or the contrast between conditional probabilities (e.g., see equation ii on page 21: $\Delta P$ (O|XA) – $\Delta P$ (O|A) = 1.0 – 1.0 = 0)

As well, participants have been shown to underestimate the effect of a moderate excitatory cue when the stronger competing cue is inhibitory. Both associative and inferential/statistical models of learning predict all of these effects. When X was more informative about the probability of the outcome than A, judgments of A were decreased. Theories of learning differ on the mechanisms they propose to explain these effects. Cue competition has been attributed to: contrast mechanisms (Darredeau et al. 2009), changes in associative strength (Rescorla & Wagner, 1972) or computed probabilistic conditional contrasts (Cheng & Novick, 1992). However judgments of the A→Outcome relationship were reduced past zero (Figure 5). Darredeau et al.'s (2009 contrast mechanism is the only theory, of the three, that accounts for this.

According to the Rescorla-Wagner (1972) model, the weaker cue can lose associative strength until it has zero associative strength. Cheng and Novick's (1990; 1992) Probabilistic Contrast theory posits that individuals will compute a conditional contingency of the target cue (X), and this will also approach zero. This will occur regardless of whether the strong competing cue is excitatory ($\Delta P_A = 1.0$) or inhibitory ($\Delta P_A = -1.0$). A reduction in judgments of X past zero (judgments of Cue X as inhibitory) when $\Delta P_A = 1.0$ is also inconsistent with the predictions made by the Rescorla-Wagner model (1972) and the Probabilistic Contrast model (Cheng & Novick, 1990, 1992, 1997).

The reduction in judgments of X, whereby it appears that X is "blocked" past zero by A, is however, consistent with a contrast mechanism whereby cues are judged in contrast to each other and causal estimates are pushed in the opposite direction from that of the stronger contingency (Darredeau et al., 2009). Judging cues relative to each other in this way means that participants' judgments are not limited to their subjective zero. Thus, a stronger cue (e.g., $\Delta P_A$ = 1.0) can push judgments of a target cue that has a moderately positive contingency (e.g., $\Delta P_X$=0.5) *into the range of negative values*, indicative of an inhibitory cause (e.g., $\Delta P_X$= -0.8).

Enhancement of the target cue in the opposite polarity competition treatment ($\Delta P_X$ = 0.5/$\Delta P_A$ = -1.0) has previously been observed (Baetu & Baker, Manuscript in preparation; Darredeau et al., 2009). As with a reduction in judgments past zero in 0.5/1.0, enhanced ratings in 0.5/-1.0 are not consistent with predictions made by associative or statistical/normative theories. Nor is this finding consistent with other research that has found a reduction in causal estimates of the target cue in the opposite polarity condition (Baker et al., 2009). However, increased ratings of the target cue in 0.5/-1.0 can be accounted for by Darredeau et al.'s (2009) proposal that contrast between cues is responsible for cue competition and thus a stronger cue will "push" judgments of the weaker cue in the opposite direction.

Participants' judgments of the context also provide evidence that cues are judged in contrast to another. Regardless of any other factor, altering the contingency of Cue A had an effect on participants' judgments of the context. When A predicted the outcome the context was judged to be a strong inhibitory cue. Conversely, when A predicted the absence of the outcome the context was judged as strongly excitatory.

Experiment 1 also showed that for each of the three types of competing contingencies, participants' ratings of each cue (X, A and context) were attenuated in the salient context and unaffected by the elements manipulation. One theory is that the attenuation of blocking and enhancement in a salient context occurs via an associative mechanism in which a salient context reduces the associative strength between the other cues (X and A). In this case, a salient context will become a better predictor of the outcome, and thus participants can use the context as a cue to judge the relationship, opposed to using the different contingencies. This reduces participants' ability to discriminate between the different contingencies (0.5/0, 0.5/1.0 and 0.5/-1.0).

Three conclusions can be derived from Experiment 1. There was evidence that cue competition includes a mechanism of contrast (i.e., cues are contrasted to each other). Specifically, a stronger generative cue reduced judgments of the weaker generative target cue. A change in the polarity of the stronger cue affected ratings of the target cue in the opposition direction. A stronger preventive cue increased judgments of the weaker generative target cue. Secondly, an increase in the salience of the context can reduce all judgments. Third, whether the target and competing cues share a single element common does not affect participants' judgments of each cue's relationship with the outcome. However, this is not in accordance with the idea that generalization between cues should reduce the effects of cue competition (Pearce, 1987; 1994). A potential reason for this was explored in Experiment 2A.

## 2.5 Figures

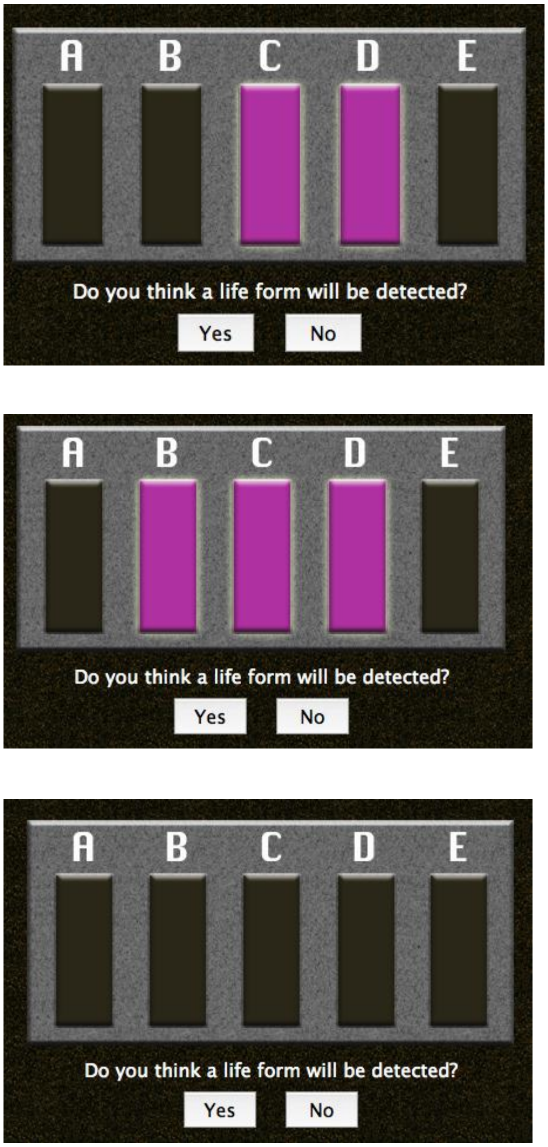
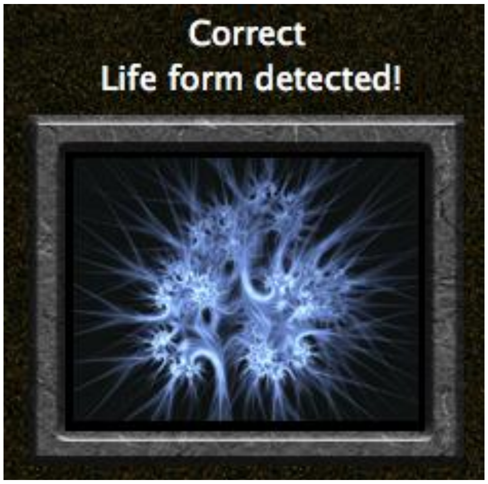



**Figure 1.** Experiment 1. Three images each representing different types of trials in Experiment 1. Illuminated light indicators (A-E) showed colour, in this image they are grey compared to the black indicators which are unlit. Top: Trial with the salient context and one cue. The salient context is indicator D and Cue X is indicator C. This image can also represent an XA trial in the non-salient context, if X is indicator C and A is indicator D. Middle: Salient context (D) with both cues (Cue X is indicator C, Cue A is indicator B). Bottom: Non-salient context presented alone.



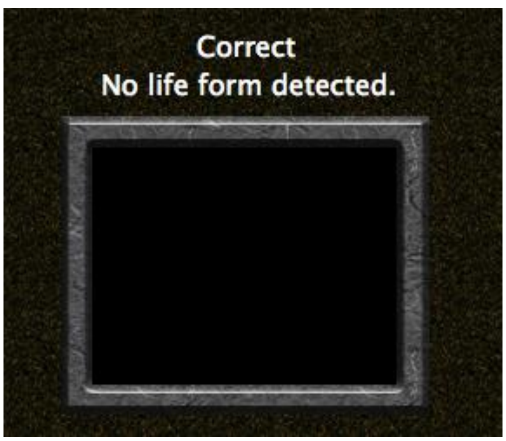




**Figure 2.** Experiment 1. On different trials the outcome was either the presence (left) or absence (right) of an alien life form.

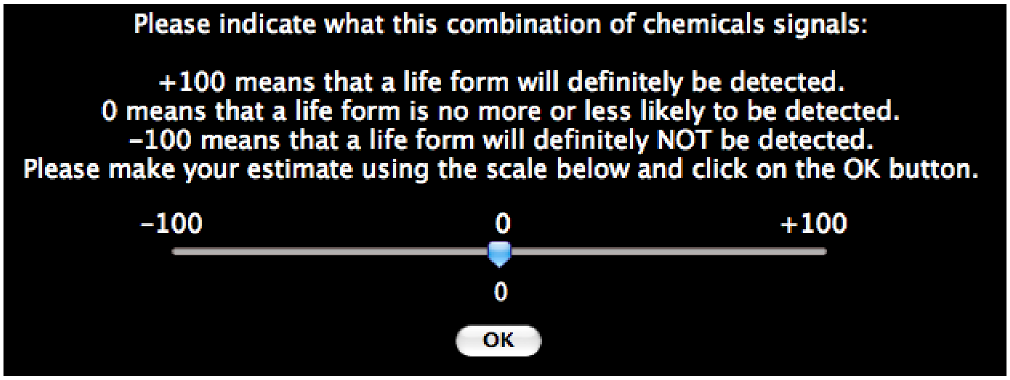



**Figure 3.** Rating scale used to measure participants' judgments on test trials.

| | Same Polarity | | Opposite Polarity |
|---|---|---|---|
| Target Contingency ($\Delta P_X$) | 0.5 | 0.5 | 0.5 |
| Competing Contingency ($\Delta P_A$) | 0 | 1.0 | -1.0 |
| Frequency of Trial Type | | | |
| X+ | 9 | 0 | 18 |
| X- | 3 | 6 | 0 |
| A+ | 3 | 6 | 0 |
| A- | 9 | 0 | 18 |
| AX+ | 9 | 18 | 0 |
| AX- | 3 | 0 | 6 |
| Context+ | 3 | 0 | 6 |
| Context- | 9 | 18 | 0 |
| P (O I $X_{ALONE}$) | 9/12 = 0.75 | 0/6 = 0 | 18/24 = 0.75 |
| P (O I $A_{ALONE}$) | 3/12 = 0.25 | 6/6 = 1.0 | 0/18 = 0 |
| $\Delta P_{X\ NO\ A}$ | 9/12 - 3/12 = 0.50 | 0/6 - 0/18 = 0 | 18/24 - 0 = 0.75 |
| $\Delta P_{X\ GIVEN\ A}$ | 18/24 - 6/24 = 0.50 | 18/24 - 6/24 = 0.50 | 18/24 - 6/24 = 0.50 |

**Figure 4.** Frequency of each type of trial for each contingency ($\Delta P_X$/$\Delta P_A$: 0.5/0, 0.5/-1.0), the conditional probabilities (P O|$X_{ALONE}$ and P O|$A_{ALONE}$) and conditional contingencies ($\Delta P_{X\ NO\ A}$ and $\Delta P_{X\ GIVEN\ A}$) for each overall $\Delta P_X$ and $\Delta P_A$ per condition.

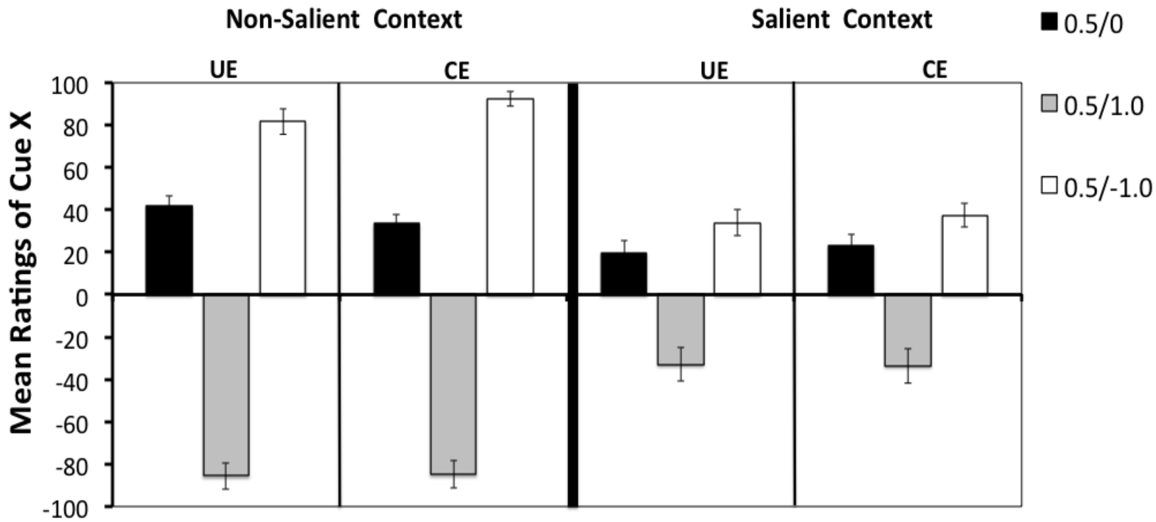



**Figure 5.** Experiment 1. Participants' (n = 49) ratings of Cue X in the non-salient context are shown in the left panel. Participants' (n = 47) ratings of Cue X in the salient context are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share a single common element or did share a single common element (UE and CE, respectively). Error bars represent the standard errors of the mean.

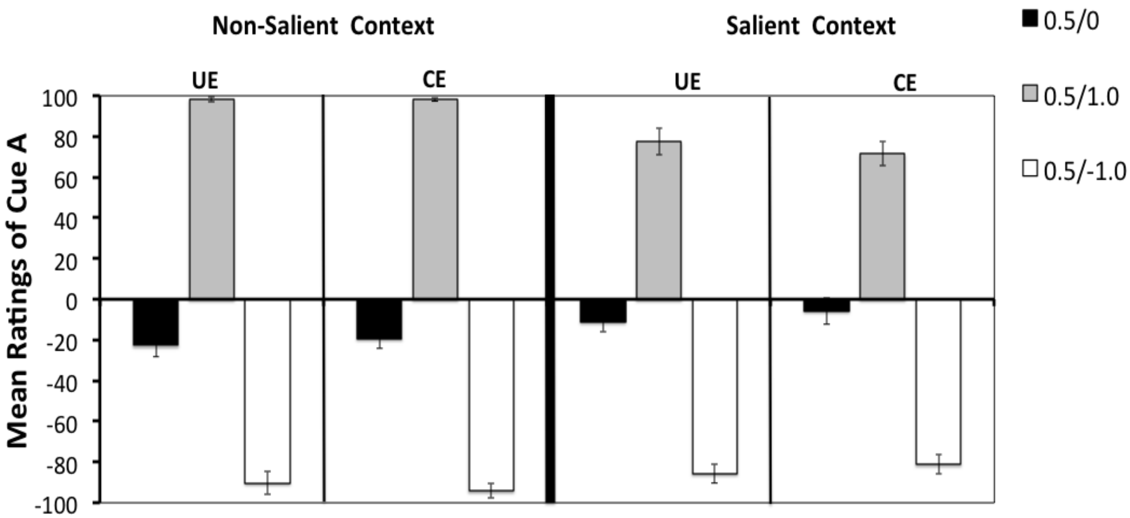



**Figure 6.** Experiment 1. Participants' ratings of Cue A in the non-salient context are shown in the left panel. Ratings of Cue A in the salient context are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share a single common element or did share a single common element (UE and CE, respectively). Error bars represent standard errors of the mean.

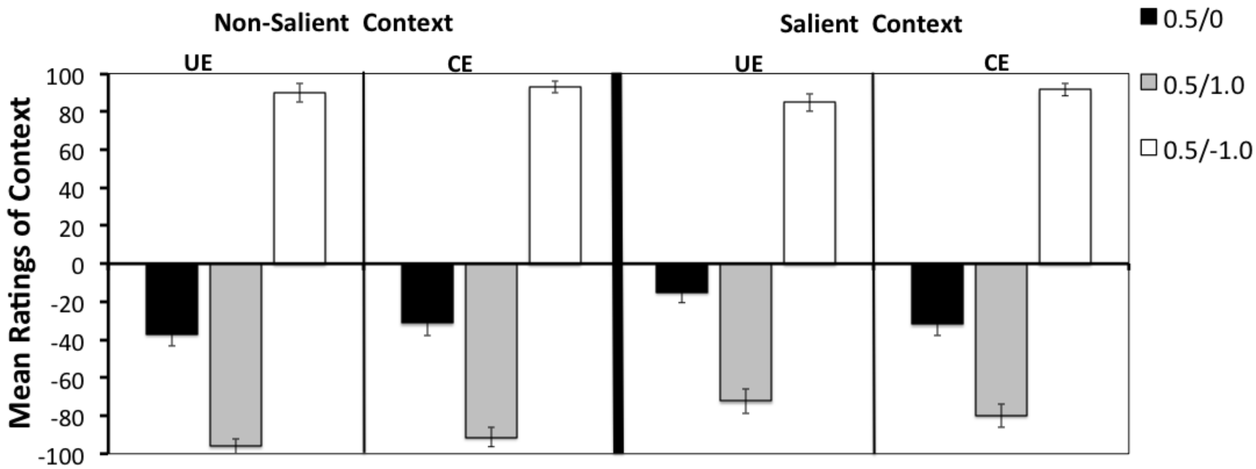



**Figure 7.** Experiment 1. Participants' (n = 49) ratings of the non-salient context are shown in the left panel. Participants' (n = 47) ratings of the salient context are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share a single common element or did share a single common element (UE and CE, respectively). Error bars represent the standard errors of the mean.

# Chapter 3

## Cue competition is influenced by the similarity of cues

## 3.1 Introduction

In Experiment 1 participants' judgments were influenced by contingency and context salience but not the presence or absence of a common element. The fact that a single common element did not affect learning is inconsistent with predictions made by certain theories of perceptual learning like Pearce's Configural theory (1987, 1994). However of note is that in Experiment 1 each cue consisted of only a single element (the single panel that was one of five light indicators). In reality, cues are made up many elements (e.g., an auditory CS has pitch, loudness, duration, etc.) and therefore cues with only one element are not ideal to evaluate the assumptions from stimulus sampling (Atkinson & Estes, 1963) and Configural theory (Pearce, 1987, 1994). This could explain why participants' judgments were unchanged by the common element manipulation. To evaluate this, and to see if learning would be affected by multiple cues, Experiment 2A used cues with multiple elements.

Experiment 2A also used the Alien Life paradigm. The major difference was that the target and competing cues had *multiple* elements. Cue X and Cue A were represented using different symbols. As with the indicators in Experiment 1, these sets of shapes represented information about the planet's environment and were presented on a virtual spaceship's display. Participants were exposed to presentations of the cues when the cues consisted of entirely unique elements (UE) and when they had shared some common elements (CE).

Shared features (common elements) between cues enable generalization whereas unique elements help us discriminate between cues (Pearce, 1987, 1994). Configural theory (Pearce, 1987, 1994) posits that the degree of generalization/discrimination between cues will vary depending on how similar/dissimilar the cues appear (Figure 1). The ability to generalize or discriminate among cues is useful given that 1) our environment consists of multiple stimuli/cues that compete for associative strength and 2) only a sub-sample of information about a stimulus/cue is perceived at a given point in time.

Experiment 2A used cues with multiple elements. Compared to the single element cues in Experiment 1, these elaborate stimuli were used to provide a more realistic model of the assumptions of stimulus sampling theory. This manipulation was used to see if generalization and discrimination would affect participants' judgments and what this could tell us about the mechanisms involved in cue competition. If people have trouble discriminating between two cues they will tend to treat them similarly and the impression of one cue will interfere with the impression of the other cue. This means that the cues can be judged as similarly predicting the presence/absence of the outcome. If this is true, the blocking effect and the enhancement effect would both be attenuated. Conversely, when cues consist of only unique elements, the causal relationships will be perceived as increasingly different. This should lead to an increase in the blocking effect (further reduced estimates) and an increase in the enhancement effect (further increased estimates). See Figure 2 for a graphical representation of these predictions for how generalization and discriminate can have opposing effects on cue competition.

Experiment 2A included two factors used as repeated measures (within subjects): contingency and cue elements. I measured participants' causal ratings to determine how contingency and cue elements could affect cue competition. As with Experiment 1, participants were instructed to rate causal relationships of X, A and the context with a rating scale that ranged from -100 to +100 (-100 for a fully inhibitory cue and +100 for a perfect excitatory cue). The target cue (X) was held constant as a moderately positive predictor of the outcome. The contingency of the competing (A) cue was either strongly positive ($\Delta P_A = 1.0$), strongly negative ($\Delta P_A = -1.0$), or in the control condition was null ($\Delta P_A = 0$). As opposed to using one element to represent X or A (Experiment 1), each cue was presented as a set of eight symbols acting as elements. With this design for “Alien Life IIA”, participants were exposed to three types of competing contingencies (0.5/0, 0.5/1.0, 0.5/-1.0) both when X and A shared two common elements and when they did not. Participants viewed six conditions: three where X and A shared two common elements (0.5/0 CE, 0.5/1.0 CE, 0.5/-1.0 CE) and three where X and A had no common elements (0.5/0 UE, 0.5/1.0 UE, 0.5/-1.0 UE). With the “Alien Life” paradigm that was used for Experiment 2A, each of the six conditions was represented as a different planet. Each condition/planet had its own set of elements to represent X and A, different images of alien life forms and different background images.

## 3.2 Methods

### 3.2.1 Participants

Sixty-two McGill Undergraduate students enrolled in a Psychology course (Animal Learning and Theory, PSYC 301) participated in Experiment 2A. Course credit was given for participation. All participants gave informed consent and were debriefed at the end of the experiment.

### 3.2.2 Apparatus

Experiment 2A used “Alien Life IIA”, a computerized causal reasoning task programmed in RealBasic. The task was presented to each participant in a quiet laboratory setting using one of three iMac desktop computers.

### 3.3.3 Procedure

Participants were seated at a computer and told to complete the experiment at their own pace, and that they were not competing with anyone. When the experimenter left the room, the participants began the experiment by reading a set of instructions presented on the computer screen. The task took approximately forty-five minutes to complete.

Participants were instructed to imagine themselves as astronauts visiting different planets. Based on a given planet's environment, they were asked to judge whether or not alien life forms would be detected. On the virtual spaceship display, participants were shown different symbols as cues to represent information about the planet's environment. Trials showed different symbols in differing positions (Figure 3).

In animal conditioning and human causal reasoning, the context refers to a set of stimuli that comprise the background of any event. For example, these background stimuli can be the characteristics (smell, size, color) of an animal's home cage or a testing chamber used in fear conditioning. Experiment 2A used a non-salient context: the virtual spaceship's display represented by the white rectangle where the cues (information about the planet's environment) appeared (Figure 4). On some trials the non-salient context was presented by itself without either X or A.

Sixty-two participants were randomly assigned to one of twenty-four ordered presentations of the six conditions: three for common elements (0.5/0 CE, 0.5/1.0 CE, 0.5/-1.0 CE) and three for unique elements (0.5/0 UE, 0.5/1.0 UE, 0.5/-1.0 UE). Each condition had forty-eight training trials. To control for any possible effects due to the order in which trials were presented, the forty-eight training trials were presented in three counterbalanced blocks with sixteen trials per block. On each of the forty-eight training trials, participants were presented with different combination of cues above the question: "Do you think a life form will be detected?" They answered by using the mouse to click either "yes" or "no". Following this, feedback ("correct" or "incorrect") was provided. The presence of the outcome was represented by an image of an alien life form shown at the bottom of the screen.

There were ten different types of trials. Figure 5 provides a schema for the types of trials participants were exposed to with the two manipulations for contingency and cue elements. On some trials only the target or the competing cue was presented, with (+) and without (-) the outcome: X+, X-, A+, A-. On other trials X and A co-occurred and either shared common elements (CE AX+, CE AX-) or consisted of unique elements (UE AX+, UE AX-). The non-salient context (Figure 4) was also shown without either X or A (Context +, Context -). The frequency of each type of trial is presented in Figure 4 of Chapter 2 (page 54).

After each of the six conditions, participants' judgments were measured using test trials that asked whether the participant believed a certain cue(s) had a generative, preventive, or no relationship with the outcome. Participants responded by using the mouse to mark a position on a visual analogue rating scale that ranged from -100 to +100. Instructions indicated what the negative, zero, or positive ratings implied about the outcome (-100 being fully preventive, 0 being no relationship, +100 being fully generative). The range of the scale was chosen to map the contingencies ($\Delta P$ from -1.0 to 1.0) and measure any ratings below zero.

## 3.3 Results

### 3.3.1 Ratings of X

Participants' judgments about the target cue (X) are illustrated in the left panel of Figure 6. The pattern of ratings was similar for the no common elements and the common elements conditions (UE and CE). In the control contingency ($\Delta P_X/\Delta P_A$) 0.5/0, judgments of X were fairly close to its objective contingency. When paired with a strongly positive Cue A ($\Delta P_A$=1.0) judgments of X were strongly negative and when paired with a strongly negative Cue A ($\Delta P_A$=-1.0) X was judged to be strongly positive. This pattern was similar with and without common elements; although estimates in the $\Delta P_A$=-1.0 condition were more extreme in the no common elements condition (UE) (Figure 6).

A two-factor repeated measures ANOVA [Contingency (0.5/0, 0.5/1.0, 0.5/-1.0), Cue Elements (UE, CE)] was used to confirmed that compared to the control contingency ratings of X were reduced (blocked) and increased (enhanced) when A was respectively a perfect generative cue or a perfect preventive cue. Judgments were significantly different due to the contingencies of the competing cues ($F(2,122) = 352.87$, $p < 0.001$). Figure 6 shows that when X is a stronger cue than A, judgments are fairly accurate. The judgments of X in 0.5/0 were significantly higher than zero in both UE and CE conditions (Minimum $t(61) = 6.764$, $p < 0.001$).

The impact of common elements on judgments is also illustrated in Figure 6. The absolute values of the estimates were smaller in the common elements condition compared to the no common elements condition. This effect of common elements to attenuate mean ratings was confirmed with the significant interaction between contingency and cue elements ($F(2,122) = 7.922$, $p < 0.001$). Although there was an interaction with cue elements, cue elements did not have a reliable main effect on judgments ($F(1,61) = 0.959$, $p = 0.331$). Figure 6 illustrates the lack of a main effect for cue elements ($F(1,61) = 0.959$, $p = 0.331$). Participants' judgments moved in opposite directions: up in 0.5/-1.0 and down in 0.5/1.0: therefore collapsing means in these two treatments would show no effect for the elements manipulation.

With the significant interaction (cue elements affected each level of contingency) further analyses were justified to look for specific differences. Two 2x2 ANOVAs were used to compare each contingency treatment ($\Delta P_A = 1.0$ and $\Delta P_A = -1.0$) to the control contingency: [Contingency (0.5/0, 0.5/1.0), Cue Elements (UE, CE)] and [Contingency (0.5/0, 0.5/1.0), Cue Elements (UE, CE)]. The blocking effect of X was significant ($F(1,61)=7.193$, $p = 0.009$) though the enhancement of X was not ($F(1,61)= 1.348$, $p = 0.250$).

Other analyses were used to examine how cue elements affected judgments. I used a within subject 2x2 ANOVA [Contingency (0.5/1.0, 0.5/-1.0), Cue Elements (UE, CE)] to determine whether the change in means due to the contingency of A was reliable. Indeed; the contingency and cue elements interaction was significant even when removing the control ($\Delta P_A = 0$) from the analysis ($F(1,61) = 12.227$, $p < 0.001$). *Post hoc* paired samples two-tailed t-tests used to verify the reliability of changes in cue competition due to contingency. When cues shared common elements, there was a reliable attenuation in both blocking and enhancement effects (Minimum $t(61) = 2.236$, $p = 0.029$).

### 3.3.2 Ratings of A

The participants' ratings about Cue A for Experiment 2A are shown in the left panel of Figure 7. When A was strongly positive ($\Delta P_X/\Delta P_A = 0.5/1.0$) participants fairly accurately estimated that A predicted the outcome (e.g., that alien life forms would be detected). Participants were also accurate at judging A as a preventive cause when A was strongly negative ($\Delta P_X/\Delta P_A = 0.5/-1.0$). In the control condition ($\Delta P_X/\Delta P_A = 0.5/0$) where cue X is more informative, participants judged A to be a preventive cause, not null. I used two one-sample t-tests to measure the value of A in 0.5/0 against the value of zero. Ratings of A were reliably below zero in both conditions of cue elements (Minimum $t(64) = -3.695$, $p < 0.001$. This result adds to the evidence in support of the hypothesis that cue competition is a result of contrast between cues.

As shown in Figure 7 the pattern and values of A differed in each of the three contingencies. A 3x2 repeated measures ANOVA for contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and cue (UE, CE) confirmed that the main effect of contingency was significant ($F(2,122) = 457.718$, $p < .001$). Subsequent pairwise comparisons were made with 2x2 ANOVAs comparing each contingency treatment (0.5/1.0 and 0.5/-1.0) to control (0.5/0). The ANOVAs confirmed that causal estimates of A were respectively reliably increased and decreased compared the control condition where X was the stronger cue (Minimum $F(1,61) = 122.655$, $p < .001$). There were no differences in ratings of A based on the manipulation of cue elements (Figure 7). The statistical tests confirmed that participants' estimates did not differ in the presence or absence of common elements ($F(1,61) = 1.190$, $p = 0.280$), nor was there an interaction between factors ($F(2,122)= 0.412$, $p = 0.663$). Finally, I used *Post-hoc* paired samples t-tests to confirm that there were no differences in blocking or enhancement of A in the UE and CE conditions (Maximum $t(61) = -0.607$, $p = 0.546$).

### 3.3.3 Ratings of the Non-Salient Context

The left panel of Figure 8 shows that the contingencies of X and A influenced participants' judgments about the non-salient context. Judgments were highly positive when Cue A was a perfect inhibitory cue and conversely highly negative when Cue A was a perfect excitatory cue. When A was null and X was moderately positive, judgments of the context fell below zero although not as much as when A was a perfect excitatory cue. I used a one-sample t-test to verify that the decrease was significantly below zero in each of the element manipulations; indeed the reduction was significant (Minimum $t(61) = -5.438$, $p < 0.001$).

Again, the assumption is that it is the contingencies of the competing cue(s) that influence judgments of the context. These results support the idea that cue competition occurs due to a mechanism of contrast, and also fit with associative explanations for how the context can lose associative strength with the outcome in the presence of a stronger cue, in this case X ($\Delta P_X = 0.50$)

A 3x2 repeated measures ANOVA [Contingency (0.5/0, 0.5/1.0, 0.5/0), Cue Elements (UE, CE)] confirmed the reliable change in ratings of the context due to the different $\Delta P_X/\Delta P_A$ conditions ($F(2,122) = 642.334$, $p < 0.001$). As shown in the left panel of Figure 8 there was no difference in ratings of the context in the UE and CE conditions nor did the elements manipulation change the effect of contingency (Maximum $F(1,61) = 0.634$, $p = 0.429$). Subsequent 2x2 ANOVAs comparing each contingency treatment (same polarity and cross polarity) to control (0.5/0) confirmed that blocking in 0.5/1.0 was reliable ($F(1,61) = 143.936$, $p < 0.001$) and that there were no change in ratings or pattern of ratings by contingency due to the elements manipulation (Maximum $F(1,61) = 1.045$, $p = 0.311$). The increased ratings of the context in 0.5/-1.0 were also reliable ($F(1,61) = 450.582$, $p < 0.001$) and no main effect of elements or contingency by elements interaction (Maximum $F(1,61) = 0.319$, $p = 0.574$). *Post-hoc* paired samples t-tests were used to verify the lack of change in the blocking and enhancement conditions in the UE and CE conditions. The reduced estimates of the non-salient context in 0.5/1.0 compared to control as well as the increased ratings in 0.5/-1.0 compared to control did not differ between the UE and CE conditions (Maximum $t(61)= -0.757$, $p = 0.452$).

## 3.4 Discussion

As in Experiment 1, Experiment 2A showed that contingency affects cue competition and changes how accurate participants are in their causal judgments. In the same polarity competition treatment (0.5/1.0) estimates of X were blocked past zero, whereas in the opposite polarity treatment (0.5/-1.0) estimates of X were enhanced. Both of these effects are consistent with the hypothesis that cue competition is a result of contrast between cues (Darredeau et al., 2009). However these effects cannot be accounted for by associative theories (e.g., Rescorla & Wagner, 1972) and normative rule-based theories (Cheng & Novick, 1990, 1992; Spellman, 1996).

Participants were quite accurate in their causal estimates of the strong competing cue (A) when it was a perfect inhibitor or perfect predictor of the outcome. In the control condition ($\Delta P_X/\Delta P_A$ = 0.5/0) judgments of A were reduced below zero, supporting the Contrast Hypothesis (Darredeau et al., 2009) which assumes that a stronger cue (X) will push judgments of the weaker cue in the direction away from the stronger cue's contingency. Contingency also affected how participants judged the non-salient context. Ratings of the context were less than zero, strongly negative, and strongly positive in the 0.5/0, 0.5/1.0 and 0.5/-1.0 treatments, respectively. Thus, it appears that the contingencies of X and A affected the other cue, the context, likely by mechanism of contrast.

Research has frequently demonstrated the blocking effect that occurs when a moderately positive cue competes with a stronger generative cue (Baetu & Baker, Manuscript in preparation; Baker et al. 1993, Baker et al. 2000: Experiment 1; Darredeau et al., 2009). However, other research has shown ratings of a moderately positive target cue can be *increased* (enhanced) when the contingency of the competing cue is 1.0 (Baker et al., 1993, Experiment 5; Baker et al., 2000, Experiment 2, Vallée-Tourangeau, Murphy and Baker, 1998). Regardless of these discrepancies there is a great deal of evidence that participants judge causal relationships relative to each other.

Cue elements also had an effect on participants' ability to make accurate causal estimates. The goal of Experiment 2A was to use more than one element for each cue. This was done to test the hypothesis that the lack of effect for cue elements in Experiment 1 was because single element cues cannot be used to represent stimulus sampling. Indeed, with multiple elements the change in ratings of a moderate cue due to a stronger cue were affected by whether or not the cues shared common elements. Specifically, when cues share common elements the blocking effect and the enhancement effect are both attenuated. Based on Configural theory (Pearce 1987; 1994) my assumption is that the reduction in cue competition occurs due to generalization among cues that are similar because they share common elements. Or in other words, when cues are similar there is less discrimination between them and thus the contrast effects are reduced. Experiment 2B followed 2A to test if reduced judgments due to common elements would also occur if participants were exposed to a salient context.

## 3.5 Figures

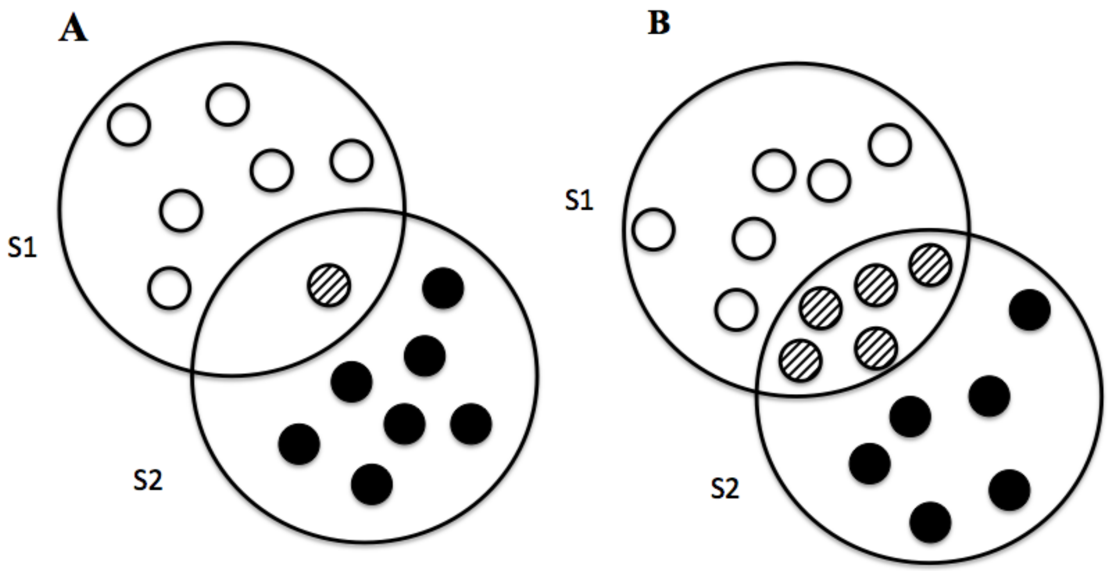



**Figure 1.** Representation of stimulus sampling and generalization between similar cues adapted from Gluck, MA (1992). The two stimuli are S1 and S2. Each stimulus is consists of a number of different elements. The black circles are elements unique to S2, white circles are unique to S1, and the striped circles are common to both stimuli. condition A shows that the two stimuli share a single common element whereas in condition B the stimuli share multiple common elements. According to stimulus sampling (Atkinson & Estes, 1963) and Configural theory (Pearce, 1987, 1994), unique elements between cues facilitates discrimination between cues, whereas cue similarity depends on the number of common elements. The more common elements the more generalization between cues. In this example there should therefore be more generalization between S1 and S2 in condition B. In Experiment 1, the manipulation with a single common element did not change judgments and it is assumed that this is because cues with only a single element are not ideal for evaluating stimulus sampling theories. Therefore the cue elements manipulation was improved with multiple elements in Experiments 2A and 2B.

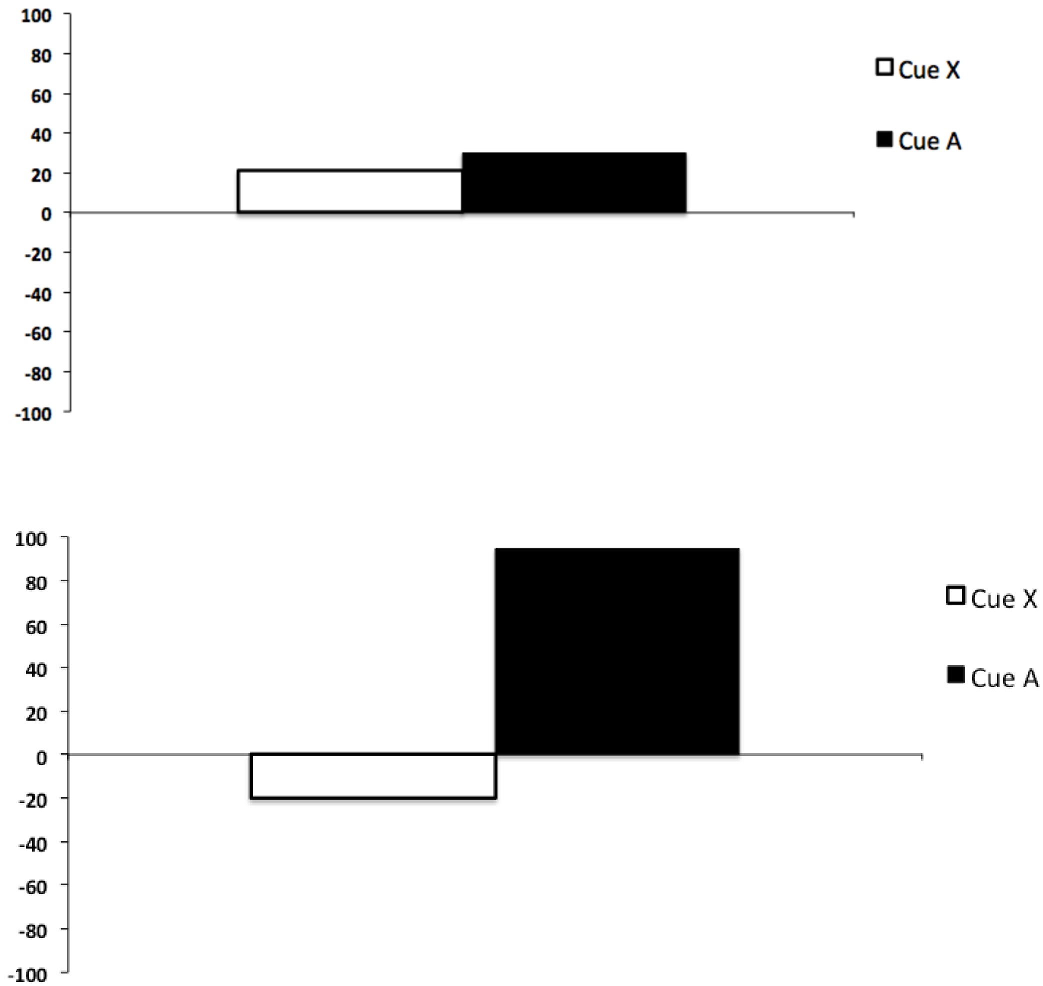



**Figure 2**. Theoretical causal judgments made for when two cues share multiple common elements (top figure) and when cues do not share any common elements (bottom graph). In top graph the judgments about the two cues perceived as similar (e.g., ratings of 21 and 30 on the rating scale). Generalization due to similar features (common elements): estimation of X's contingency is similar to the estimation of A's contingency. In the bottom graph the cues perceived as different (e.g., ratings of -20 and 95 on the rating scale). If there is discrimination due to different features (unique elements): results in discrepancy between judgments: Participants estimates (of X vs. A's relationship with the outcome) are very different, especially compared to the condition of common element

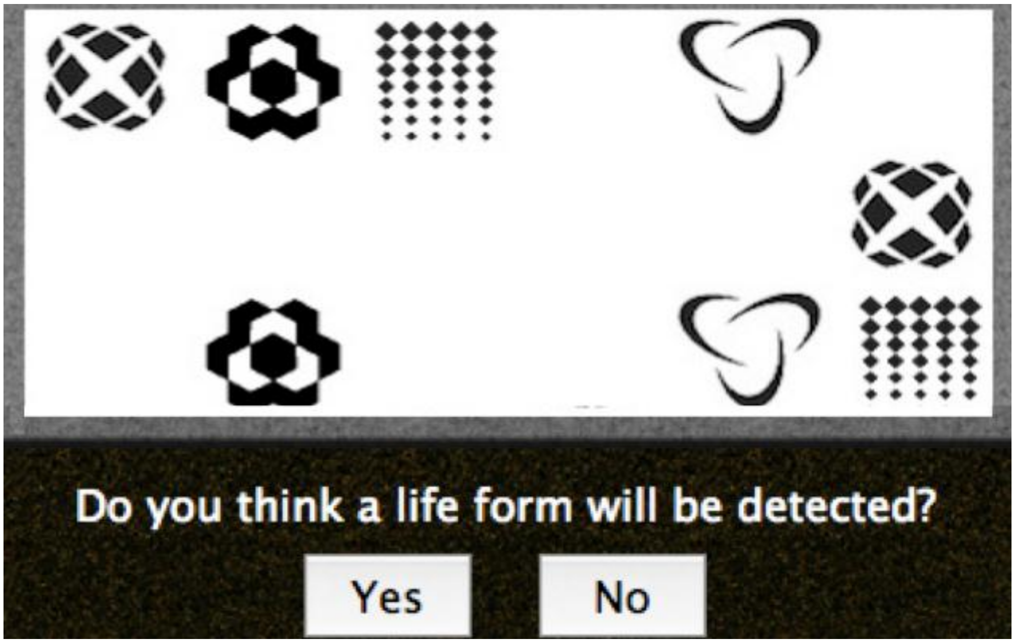



**Figure 3.** Experiment 2A. Example trial. Each trial showed eight symbols. Eight elements were used in order to represent the maximum sample size from stimulus sampling theory.
The example above shows a hypothetical presentation of a single cue, either X or A. When one cue was presented alone each element was shown twice. Compound (XA) trials also showed eight elements, some of which were common to both cues.


**Figure 4.** Experiment 2A. The non-salient context is presented alone without Cue X or Cue A. The non-salient context is the white box. In the Alien Life paradigm, this white box represents the virtual spaceship's monitor/screen that shows information about the planet's environment.

| | Cue X | Cue A | Cue AX | Context |
|---|---|---|---|---|
| Elements unique for X | ◆ | | ◆ | |
| Elements unique for A | | ◆ | ◆ | |
| Elements common to both X and A | ◆ | ◆ | ◆ | |
| Elements for Context | ◆ | ◆ | ◆ | ◆ |

**Figure 5.** Schema to explain trials presented with and without common elements. Trials consisted of either a single cue (X or A), both cues (XA) or the context alone. Elements were either unique to a single cue or there were two elements that were common to both X and A. The context consists of all cues.

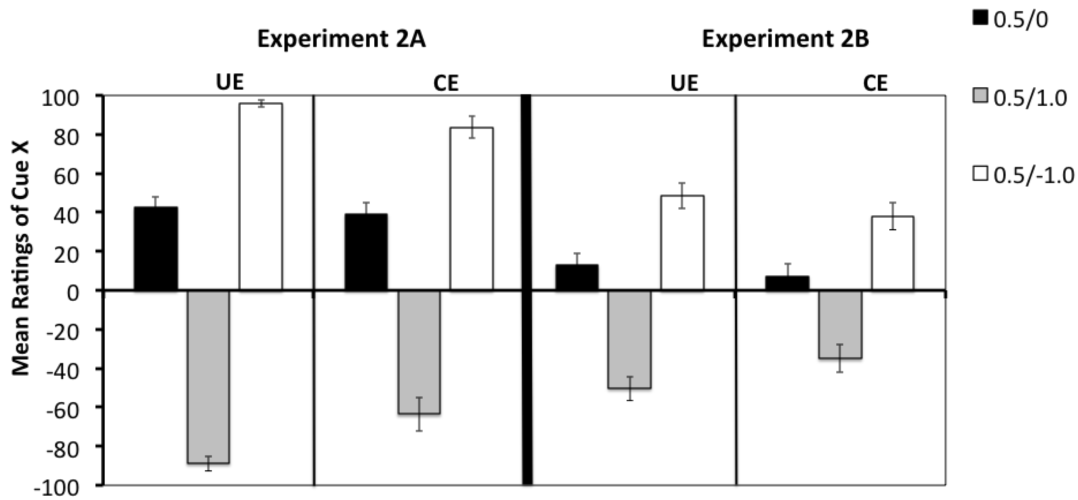



**Figure 6.** Experiments 2A and 2B. Participants' ratings of Cue X in the non-salient context (Experiment 2A) are shown in the left panel. Participants' ratings of Cue X in the salient context (Experiment 2B) are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share (UE) and did share common elements (CE). The error bars represent the standard errors of the mean.

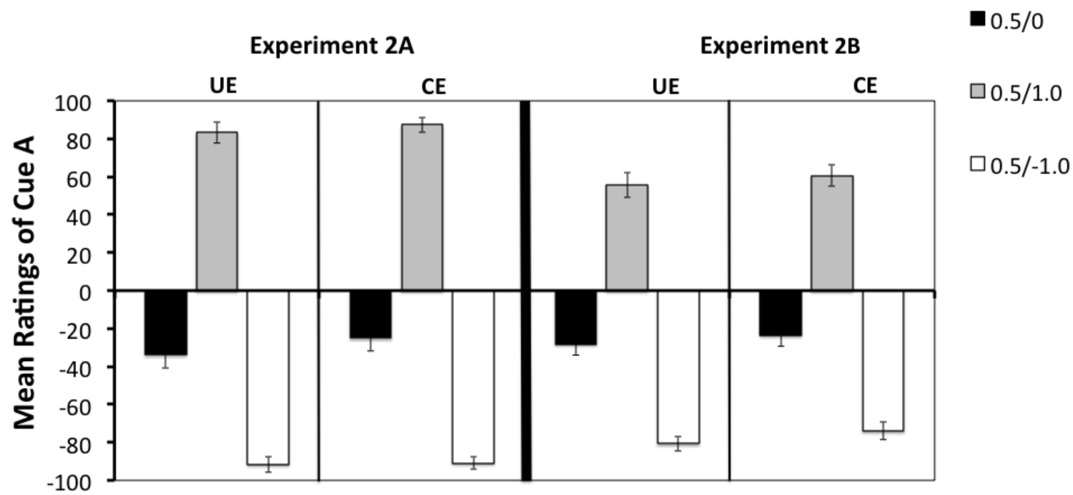



**Figure 7.** Experiments 2A and 2B. Participants' ratings of Cue A in the non-salient context (Experiment 2A) are shown in the left panel. Participants' ratings of Cue A in the salient context (Experiment 2B) are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share (UE) and did share common elements (CE). The error bars represent the standard errors of the mean.

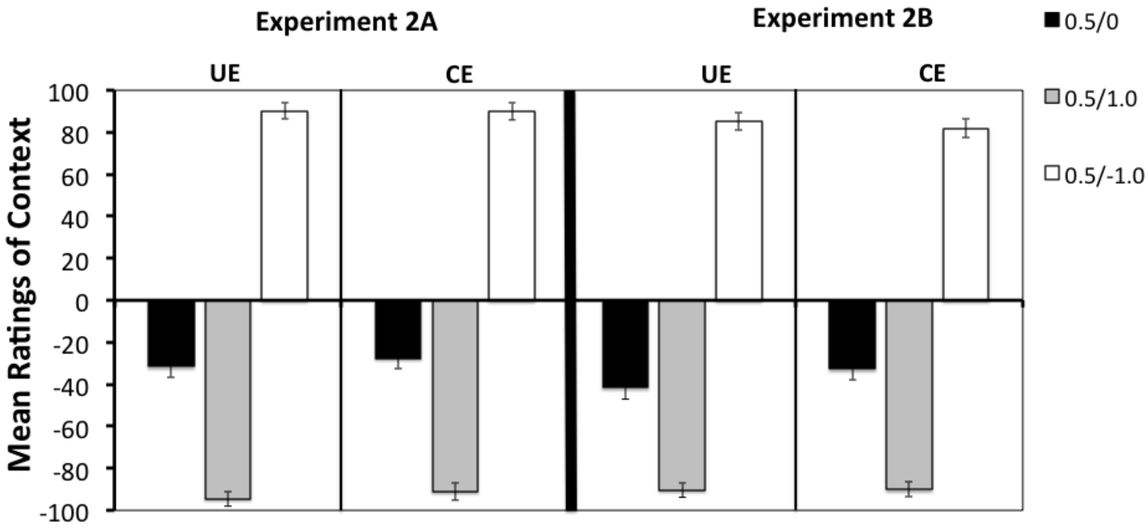



**Figure 8.** Experiments 2A and 2B. Participants' ratings of the Non-Salient context in Experiment 2A are shown in the left panel. Participants' ratings of the Salient Context in Experiment 2B are shown in the right panel. The bars show mean causal ratings for the three contingencies when cues did not share (UE) and did share common elements (CE). The error bars represent the standard errors of the mean.

# Chapter 4

## Cue competition is influenced by the salience of the context

## 4.1 Introduction

The previous experiments found that causal judgments can be affected by the contingencies of the competing cues (Experiments 1 and 2A), multiple cue elements (Experiment 2A) and context salience (Experiment 1). The objective of Experiment 2B was to see if I could replicate the attenuation in cue competition due to common elements within a salient context. I also expected to replicate our results for the effect of contingency.

Experiment 2B included two factors as repeated measures: contingency and cue elements. I measured participants' causal judgments of each cue's relationship with the outcome. The target cue (X) was a moderately positive predictor of the outcome. The contingency of the competing (A) cue was fully positive ($\Delta P_A = 1.0$), fully negative ($\Delta P_A = -1.0$), or null ($\Delta P_A = 0$). Participants viewed six conditions: three where X and A had common elements (0.5/0 CE, 0.5/1.0 CE, 0.5/-1.0 CE) and three where X and A had no common elements (0.5/0 UE, 0.5/1.0 UE, 0.5/-1.0 UE). Each of these six conditions was represented as a different planet in the Alien Life paradigm. Each planet/condition had its own set of elements to represent the cues, its own background image and specific images of the alien life forms detected.

All participants in Experiment 2B were exposed to trials with a *salient* context. Compared to the non-salient context used in Experiment 2A (Figure PP below) the stimuli representing the salient context were included the white box (virtual spaceship's monitor) *and* three symbols presented within the box (Figure 1). As with cues X and A, the manipulation of the salient context used multiple (three) elements in order to be analogous to the multiple components that make up a context outside of the laboratory and to be able to evaluate the effects of generalization and discrimination between cues.

## 4.2 Methods

### 4.2.1 Participants

Ninety-one McGill Undergraduate students were recruited from the McGill University Psychology Participant Pool to participate in Experiment 2B. Course credit was given for participation. All participants gave informed consent and were debriefed at the end of the experiment.

### 4.2.2 Apparatus

Experiment 2B used "Alien Life IIB", a computerized causal reasoning task programmed in RealBasic. The task was presented to each participant in a quiet laboratory setting using one of three iMac desktop computers.

### 4.2.3 Procedure

Participants were seated at a computer and told to complete the experiment at their own pace, and that they were not competing with anyone. When the experimenter left the room, the participants began the experiment by reading a set of instructions presented on the computer screen. The task took approximately forty-five minutes to complete.

Participants were instructed to imagine themselves as astronauts visiting different planets. Based on a given planet's environment, they were asked to judge whether or not alien life forms would be detected. On the computer screen's virtual spaceship display, participants viewed sets of symbols that represented information about the planet's environment. Each trial showed various combinations of symbols presented in different places on the spaceship's monitor (e.g., Figure 2).

Ninety-one participants were randomly assigned to one of twenty-four ordered presentations of the six conditions: three for common elements (0.5/0 CE, 0.5/1.0 CE, 0.5/-1.0 CE) and three for unique elements (0.5/0 UE, 0.5/1.0 UE, 0.5/-1.0 UE). Each condition had forty-eight training trials that used three counterbalanced blocks with sixteen trials per block. On each training trial participants were shown different combination of cues above the question: "Do you think a life form will be detected?" They answered by using the mouse to click either "yes" or "no". Following this, feedback ("correct" or "incorrect") about their judgment was provided. The presence of the outcome was represented by an image of an alien life form shown at the bottom of the screen. The absence of the outcome was depicted with a blank box shown at the bottom of the screen.

Compared to the non-salient context used in Experiment 2A, the salient context in Experiment 2B was represented by the white panel of the virtual spaceship's monitor along with three symbols (elements) that were presented in various positions (Figure 2). Participants viewed ten types of trials. Some trial trials presented only the target (X) or the competing (A) cue both with (+) and without (-) the outcome: X+, X-, A+, A-. On other trials X and A were shown simultaneously and could either share common elements (CE AX+, CE AX-) or consist of unique elements (UE AX+, UE AX-). The salient context was also shown both with and without the other cues (Context +, Context -). The trial type frequencies are shown in Figure 4 of Chapter 2.

After each of the six conditions, participants' judgments were measured using test trials that asked whether the participant believed a certain cue(s) had a generative, preventive, or no relationship with the outcome. Participants responded by using the mouse to mark a position on a visual analogue rating scale that ranged from -100 to +100 (See Figure 2 in Chapter 2).

Instructions indicated what the negative, zero, or positive ratings implied about the outcome (-100 being fully preventive, 0 being no relationship, +100 being fully generative). The range of the scale was chosen to map the contingencies ($\Delta P$ from -1.0 to 1.0) and measure any ratings beyond zero.

## 4.3 Results

### 4.3.1 Ratings of Cue X

Participants' ratings of the causal relationship between Cue X and the outcome are shown in the right panel of Figure 6 in Chapter 3 (page 76). In comparison to ratings with the control competition treatment ($\Delta P_X / \Delta P_A$) 0.5/0, estimates of X were reduced (blocked) in the same polarity competition treatment (0.5/1.0) and increased (enhanced) in the opposite polarity competition treatment (0.5/-1.0).

Judgments of X in the *common elements* condition appeared *less* enhanced in 0.5/-1.0 as well as *less* blocked in 0.5/1.0 compared to these cue competition effects when there were no common elements (Figure 6). In the common elements condition ratings in each contingency were less extreme and closer to zero. Participants seemed to judge X similarly regardless of the different $\Delta P_A$ in each condition.. Conversely causal judgments were closer to the accurate objective contingencies when the cues did not share common elements.

To clarify, when cues shared common elements the absolute and mean values of judgments in each contingency were attenuated in comparison to estimates for cues with only unique elements. This impression was supported by the reliable interaction between cue elements and contingency ($F(2,180) = 3.433$, $p = 0.034$). So, although there was no main effect for cue elements $F(1,90) = 0.003$, $p = 0.956$) judgments in the *common elements* condition were *less extreme* (and therefore more similar to each other). This gives the impression that the cues were judged similarly even though they had different contingencies. To determine the specific pattern of change in this interaction, I then used two 2x2 ANOVAs to analyze ratings in each contingency treatment (0.5/1.0 and 0.5/-1.0) to the control (0.5/0) with CE and UE. Enhancement of X in 0.5/-0 and blocking of X in 0.5/1.0 were both reliable (Minimum ($F(1,90) = 29.926$, $p < 0.001$).

### 4.3.2 Ratings of Cue A

Participants' mean causal estimates of Cue A are shown in the right panel of Figure 7 of Chapter 3 (page 77). Judgments of A were affected by contingency and showed the same pattern of ratings as in the prior experiments (1 and 2A). Ratings were moderately reduced below zero in 0.5/0, and close to accurate in both 0.5/1.0 and 0.5/-1.0 conditions. To verify that participants' reduced estimates of A were significantly below zero, I used single sample t-tests comparing the estimate in each condition (UE and CE) and found that both values were reliably lower than zero (Minimum $t(90) = -4.026$, $p < 0.001$.)

I used a 3x2 repeated measures ANOVA [Contingency (0.5/0, 0.5/1.0, 0.5/-1.0), Cue Elements (UE, CE)] and confirmed these changes due to contingency were significant ($F(2,180) = 216.078$, $p < 0.001$). Subsequent 2x2 ANOVAs compared judgments in 0.5/0 to 0.5/1.0 and 0.5/0 to 0.5/-1.0. Ratings of A were reliably increased in 0.5/1.0 and decreased in 0.5/-1.0 (Minimum $F(1,90) = 87.198$, $p < 0.001$). As illustrated in the right panel of Figure 7 there did not appear to be a reliable change in ratings between elements. To test this I compared ratings in

0.5/1.0 and in 0.5/-1.0 to 0.5/0 when cues shared and did not share common elements. The elements manipulation did not change either of the competition effects (blocking in 0.5/-1.0 and enhancement in 0.5/1.0) (Maximum ($F(1,90) = 2.088$, $p = 0.152$) and *Post-hoc* paired samples t-tests confirmed that this was reliable (Maximum $t(90) = -1.436$, $p = 0.154$).

### 4.3.3 Ratings of the Salient Context

Participants' causal estimates of the salient context are shown in the right panel of Figure 8 (page 78). As with Cues X and A, judgments of the causal relationship between the salient context and the outcome differed depending on the competing contingencies ($\Delta P_X/\Delta P_A$). As shown in the right panel of Figure 8 the salient context was judged as a preventive cue in the control condition (0.5/0). Participants judged the context as even more likely to prevent the outcome in the same-polarity competition treatment (0.5/1.0). Conversely, when the stronger competing cue was fully preventive ($\Delta P_A = -1.0$) the context was judged to be an excitatory cue that predicted the outcome. Single sample t-tests comparing the estimates in 0.5/1.0 to zero were used to verify that the reduced estimates of the context were statistically significant and reliable. In both conditions for elements, the context was reduced below zero in 0.5/1.0 (Minimum $t(46) = -2.705$, $p = 0.01$). These results support Darredeau et al.'s (2009) proposed mechanism of contrast between cues.

Statistical analyses were used to confirm the significance of these impressions. I first used a two-factor 3x2 ANOVA [Contingency (0.5/0, 0.5/1.0, 0.5/-1.0), Cue Elements (UE, CE)]. Ratings differed reliably in each of three contingency treatments ($F(2,180) = 555.572$, $p < 0.001$). There was no difference in mean judgments due to elements ($F(1,90) = 0.441$, $p = 0.508$), nor did the elements manipulation change any of the ratings depending on contingency ($F(2,180) =$

1.358, $p = 0.260$). Therefore, contingency was the only factor to influence judgments of either the non-salient (Experiment 2A) or salient (Experiment 2B) contexts. Subsequent 2x2 ANOVAs were used to compare the ratings in each contingency treatment (0.5/1.0 and 0.5/-1.0) to control (0.5/0). The analyses confirmed that the effect of each contingency was reliable (Minimum $F(1,90) = 121.034$, $p < 0.001$).

As illustrated in Figure 8 (left panel), the elements manipulation had no effect on either magnitude or pattern of participants' ratings of the salient context. In other words, X and A's elements did not affect the blocking effect in 0.5/1.0 or the enhancement effect in 0.5/-1.0. Two 2x2 ANOVAs [Contingency (0.5/0, 0.5/1.0), Cue Elements (UE, CE)] and [Contingency (0.5/0, 0.5/-1.0), Cue Elements (UE, CE)] confirmed that contingency was the only factor to affect judgments (Minimum $F(1,90) = 121.034$, $p < 0.001$). There was no main effect of elements (Maximum $F(1,90) =1.521$, $p = 0.221$) nor any difference of elements depending on contingency (Maximum $F(1,90) =1.998$, $p = 0.161$). Finally, I verified that the lack of change in blocking and enhancement was reliable. Two *Post-hoc* paired samples t-tests revealed that the ratings of the context in 0.5/1.0 and 0.5/-1.0 did not differ between UE and CE conditions (Maximum $t(90) = 0.679$, $p = 0.499$).

## 4.4 Summary

Experiment 2B is the final experiment presented in this manuscript. Experiment 2B replicated evidence for cue competition due to contingency and cue elements previously found in Experiments 1 and 2A. All of the effects of contingency on cue competition provide support for Darredeau et al.'s (2009) theory that cue competition is a result of contrast between cues.

Estimates of each cue (X, A, Context) were made in comparison to the contingency of the other cues. For example, in 0.5/0 X is rated as moderately positive, A is rated as slightly negative and the context is also rated as slightly negative. In 0.5/1.0 X is rated as highly negative, A is rated as highly positive, and the context is rated as highly negative. In 0.5/-1.0 X is rated as highly positive, A is rated as highly negative and the context is rated as highly positive. Furthermore, blocking past zero and enhancement in the cross-polarity competition treatment (0.5/-1.0) can only be accounted for by the Contrast Hypothesis, not by the Rescorla-Wagner (1972) model or normative rule-based models (Cheng & Novick, 1990, 1992, 1997; Spellman, 1996).

As with the results from Experiment 2A, the results of Experiment 2B can be used to understand how perceptual learning can affect causal reasoning. When the target and competing cues shared two common elements, judgments of the target cue's relationship were decreased in each condition of contingency. I assume that this attenuation in cue competition effects (blocking, enhancement) occurs because participants generalize between similar cues. Conversely, when cues can be readily discriminated from each other because they do not share common elements, the effects of cue competition are stronger. However, the generalization/discrimination between cues only affected judgments of Cue X and not Cue A or the salient context. My analyses of the effects of contingency, cue elements and context salience on judgments of Cue A are limited by the fact that, unlike for X, there was no control contingency for A in which X had a null relationship with the outcome. Prior experiments (e.g., Baetu et al., 2005, Darredeau et al., 2009) have used such conditions.

## 4.5 Comparing Contexts: Experiment 2A vs. Experiment 2B

Experiment 1 found that ratings of the target cue were attenuated by a salient context. Specifically, all of the absolute and mean values of judgments in the salient context were lower than judgments in the non-salient context. The attenuation in participants' estimates occurred in each of the three conditions of competing contingencies. My impression from this is that compared to their judgments in a non-salient context, in the salient context participants did not differentiate as well between the different causal relationships (e.g judgments in 0.5/0 were similar to those made in 0.5/1.0). Experiments 2A and 2B also showed that judgments depended on contingency and that these judgments were reduced when cues shared common elements. Given that the context was non-salient in Experiment 2A and salient in Experiment 2B, I decided to compare the results of 2A and 2B to see if the salient context attenuated judgments.

### 4.5.1 Ratings of Cue X

Figure 6 (page 76) shows participants' ratings of X in the non-salient and salient contexts. In the salient context (2B) judgments of X appeared to be attenuated and less extreme than the differences in ratings in the different contingencies of the non-salient context (2A) ($F(1,151) = 34.423$, $P < 0.001$). I used *Post-hoc* one-way ANOVAs to each difference in ratings between groups (the between groups difference for each condition). In other words, I compared ratings in each of the six conditions between the two experiments (e.g., 0.5/0 CE in Experiment 2A to 0.5/0 CE in Experiment 2B). The tests confirmed that the reduced ratings in the salient context (2B) were reliable in each condition (Minimum $F(1,152) = 5.630$, $p = 0.019$).

### 4.5.2 Ratings of Cue A

Figure 7 (page 77) shows participants' estimates of A in the non-salient and salient contexts. Ratings do not appear to be lower in the salient context. I used a three factor 2(3x2) mixed ANOVA with context salience as the between subjects factor (Non-Salient, Salient) and contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and cue elements (UE, CE) as within subjects factors. The statistical test confirmed the impression from Figure 7 that there was no between groups effect of context salience ($F(1,151) = 0.974$, $p = 0.325$). However, context salience interacted with contingency: the effects of contingency were reduced in the salient context ($F(2,302) = 10.444$, $p < 0.001$). I then conducted two 2(2x2) ANOVA to compare each contingency treatment (0.5/1.0 and 0.5/-1.0) to the control contingency (0.5/0). The test confirmed that the interaction between context salience and contingency was due to a significant reduction in the increased ratings of A in 0.5/1.0 ($F(1,151) = 9.355$, $p = 0.003$) in the salient context; the decrease in ratings in 0.5/-1.0 condition did not differ between groups ($F(2,302) = 1.613$, $p = 0.206$). These effects were also confirmed with *Post-hoc* one-way ANOVAs that revealed context salience affected judgments of A in 0.5/1.0 for both UE and CE conditions (Minimum $F(1,152) = 9.288$, $p = 0.003$) and in judgments of A in 0.5/-1.0 only for the CE condition ($F(1,152) = 7.596$, $p = 0.007$). There were no changes between groups in any of the other conditions that participants were exposed to (Maximum $F(1,152) = 3.519$, $p = 0.063$).

### 4.5.3 Ratings of Context

Figure 8 (page 78) shows that there appeared to be little effect of context salience on judgments of the context. This impression was supported by my analyses. In the three way ANOVA with context salience as the between subjects variable (Non-Salient, Salient) and contingency (0.5/0, 0.5/1.0, 0.5/-1.0) and cue elements (UE, CE) as within subjects factors, only the effect of contingency of A was reliable ($F(2,302) = 1098.566$, $p < 0.001$). No other interactions with the context (Minimum $p = 0.312$) nor was the main effect of context reliable ($F(1,151) = 2.192$, $p = 0.141$).

## 4.6 Discussion

These results about the context support the hypothesis that competition between cues is a result of contrast where the stronger cue pushes judgments of the weaker cue in the opposite direction of the stronger cue's contingency (Darredeau et al., 2009). This explanation of cue competition can be used to account for why judgments of the context differed depending on the contingencies of Cue X and Cue A. A contrast between the context and other cues provides evidence in support of the early discovery that conditioned inhibition could be inhibited if a background cue that had an excitatory relationship with the outcome – in other words, a salient context – removed (Baker, 1977). Simply put, what animals learned about the context-outcome relationship influenced what they learned about each cue-outcome relationship.

In Experiment 1the effect of context salience was specific to contingency. Compared to a non-salient context, in a salient context there were significantly decreased effects of contingency on cue competition for cues X and A. My comparison of Experiments 2A and 2B confirmed the same effect for context salience on contingency within a larger sample of participants. There was a significant interaction between contingency and context salience for all cues: X, A, and the contexts in each experiment. In other words, a salient context reduced the mean values of participants' estimates of X, A, and the context in 0.5/0, 0.5/1.0 and 0.5/-1.0. How might this happen? The assumption is that this occurs in the same way that causal judgments can be reduced when cues share common elements. Thus, a reduction in ratings due to the interaction between contingency and context salience is much like a reduction in ratings due to the interaction between contingency and cue elements. The context can be thought of as a “super common element”. The assumption is that participants are more likely to notice a salient context and by noticing it they generalize between similar features. For instance, Experiment 2B manipulated the salient context in the same way as the common elements – with the presentation of various symbols. Thus it is likely that generalization occurred due to the similarities between the salient context and the cues themselves. A potential reason why this may be a limitation to this study is discussed in the following final chapter of this thesis. However, my finding that the context influenced participants’ judgments is supported by the large body of prior research that has shown that there are many ways that the context influences animal conditioning and human causal reasoning (Baker, 1977; Bouton, 1993a, 2004; Msetfi 2005, 2007, 2012; Rescorla, 1969).

## 4.7 Figures

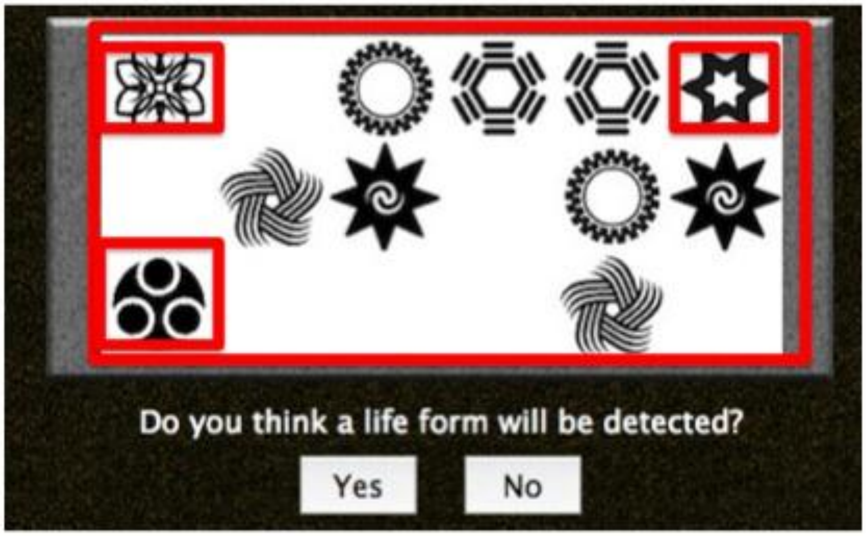



**Figure 1.** Experiment 2B. Example trial. The salient context is outlined. The salient context consists of the three elements as well as the "virtual monitor". Eleven elements were shown on single (e.g., A+/- or X+/-) and compound (AX+ or AX-) cue trials. Because the salient context consisted of three of the eleven elements, the other eight elements represented Cue X and/or Cue A.

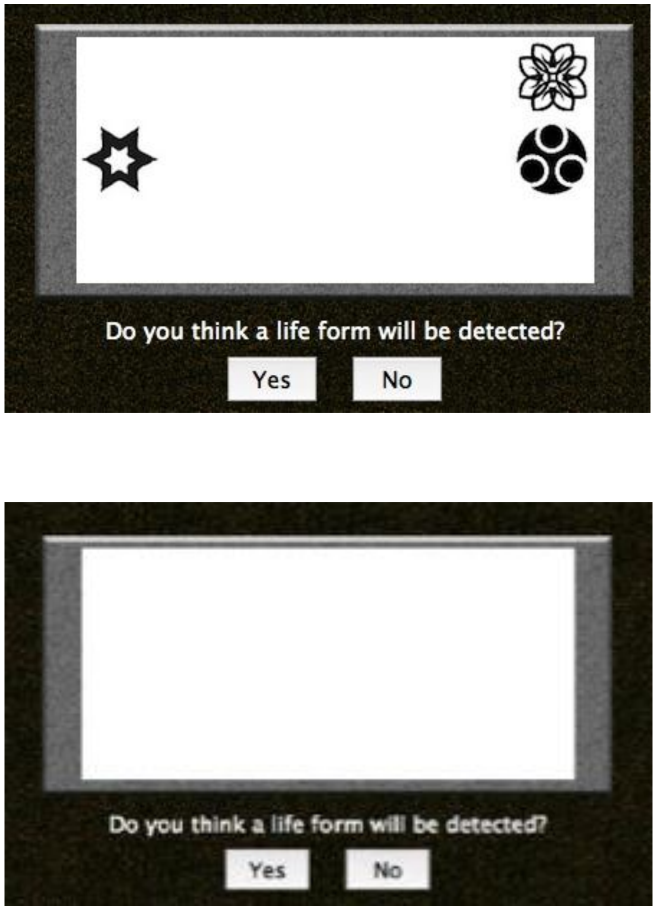



**Figure 2**. A comparison of trials that presented either the salient context (top) in Experiment 2B or the non-salient context (bottom) in Experiment 2A by itself.

# Chapter 5

## General Discussion

## 5.1 Summary

The goal of this thesis was to elucidate the mechanisms involved in cue competition to understand why ratings of moderate positive cue can sometimes be enhanced and sometimes be blocked in the presence of a stronger negative cue. Understanding how this occurs could give us a better understanding of how cues are judged in relation to each other (i.e., relative validity). In the first part of this chapter I briefly review my three overall findings about cue competition in causal reasoning. I also discuss the theories that can or cannot account for these results. Finally I discuss how a single associative model can be used to account for the contrast mechanism in cue competition.

## 5.2 Effects on cue competition

### 5.2.1 Contingency

There were three contingency effects: 1) A stronger cue of the same polarity reduced judgments of a moderate cue (blocking). 2) Blocking occurred past zero: estimates could be reduced to the point where a positive or null cue is rated as inhibitory. 3) Judgments of a moderately positive cue were increased (enhanced) in the presence of a stronger cue of opposite polarity. Researchers have found that estimates of a moderate cue in a cross-polarity contingency treatment (e.g., $\Delta P_X/\Delta P_A = 0.5/-1.0$) are increased (Baetu & Baker, Manuscript in preparation; Baker et al., 1993, Experiment 5; Baker et al., 2000, Experiment 2; Darredeau et al., 2009; Vallée-Tourangeau et al., 1998) although others have found that ratings of the target cue are decreased in this condition (Baker et al., 1993, Experiment 4; Baker et al., 2000, Experiment 1).

### 5.2.2 Common elements

When the target and competing cues shared two common elements, the absolute values of participants' estimates were reduced. Specifically, the cue competition effects that different contingencies had on judgments were reduced when cues shared common elements compared to when they did not. In this thesis I posit that the reduction in cue competition is due to cues being perceived as similar due to their shared features. In other words, decreased cue competition (e.g., changes in 0.5/0, decreased blocking and decreased enhancement) is a result of increased generalization among cues that share common elements.

### 5.2.3 Context salience

In a salient context the absolute values of participants' estimates in each contingency treatment (0.5/0, 0.5/1.0, 0.5/-1.0) were lower than when the context was non-salient. In other words, in a salient context judgments in the different contingency treatments appeared similar to one another as mean values of the estimates were pushed towards zero on the X-axis. In this thesis I discuss how this is an effect like that of common elements. In this case, a salient context causes generalization between different contingencies, and therefore specifically generalization between excitatory and inhibitory cues. If this is the case then excitatory cues are perceived as less positive and inhibitory cues are perceived as less negative.

## 5.3 Theoretical implications and applications

In the rest of this chapter I explain how these results about contingency, cue elements and context salience best support the Contrast Hypothesis (Darredeau et al., 2009) over other theories. I also discuss how the data support Configural theory (Pearce, 1987; 1994) therefore illustrating how perceptual learning can be involved in causal reasoning. Finally, I use Baetu and Baker's (2009) auto-associator to account for blocking and enhancement and to explain that contrast and generalization/discrimination between cues.

### 5.3.1 Cue competition

The Rescorla-Wagner (1972) model can predict some but not all of the results from these experiments. The model predicts that a weaker cue will be blocked by a stronger cue, which is what my experiments showed for Cue X in the same polarity competition treatment ($\Delta P_X/\Delta P_A$) (0.5/1.0), for Cue A in 0.5/0 and for the non-salient and salient contexts in 0.5/0 and 0.5/1.0. According to the model cue competition occurs due to changes in associative strength: when one cue gains associative strength with the outcome the other cue loses associative strength. The cue with more associative strength is the stronger cue (can also be called the blocking cue) and the theory assumes that an individual's mental representation of this cue-outcome relationship is stronger because this cue provides the most information about the likelihood of the outcome. It does not matter whether this strong cue is excitatory/generative or inhibitory/preventive – as long as it is stronger than the other cue, learning about the weaker cue (also called the blocked cue) is reduced. An advantage Rescorla and Wagner's (1972) model is that it uses a simple mathematical formula to predict change in associative strength.

$$\Delta V = \alpha \, \beta \, (\lambda - \Sigma V)$$

The change in associative strength for a cue is $\Delta V$ (change in predictive value). This formula considers all cues relationships with the outcome: $\Sigma V$ indicates the summation of each cue's associative strength. To calculate $\Delta V$ for a single cue, the formula subtracts all cues' summed associative strengths from asymptote of associative strength ($\lambda$). In the case where there is no outcome, there is no ability for an association to develop and therefore $\lambda$ equals zero. The linear operator ($\lambda - \Sigma V$) in the equation calculates prediction error: the difference in associative strength between the expected outcome ($\Sigma V$) and the actual outcome ($\lambda$). When there is an unexpected outcome prediction error is positive (e.g., $\Sigma V < \lambda$) and if an expected outcome is absent prediction error is negative (e.g., $\Sigma V > \lambda$). The model assumes that all cues compete for a limited amount of associative strength with the outcome and therefore cue competition is due to changes in associative strength.

These changes rely on prediction error because when a cue loses associative strength it is perceived as less informative. As with blocking (Kamin, 1969), learning about a weaker cue is reduced when there is a stronger cue that provides more information about the outcome. As such the model assumes that in ($\Delta P_X/\Delta P_A$) 0.5/1.0 and in 0.5/-1.0 estimates of X will be reduced toward zero (blocked) because X provides less information about the outcome in comparison to the fully generative (1.0) and preventive (-1.0) causes. This is how the model accounts for relative validity in cue competition (e.g., how cues are judged in relation to each other). Research supports the model's prediction for blocking in 0.5/1.0, but far fewer experiments have shown blocking of X in 0.5/-1.0 (Baker et al. 1993, Experiment 4; Baker et al. 2000, Experiment 1; Vallée-Tourangeau et al., 1998). A second limitation in explaining cue competition is that the model predicts a stronger cue can only reduce a weaker cue to the point where it has no associative strength (e.g., blocking cannot go beyond zero). This limit to reduced associative strength cannot account situations where a generative cause is judged to be preventive.

Normative rule-based theories such as Cheng and Novick's Probabilistic Contrast model (1990, 1992) and Spellman's (1996) account of how individuals make causal judgments also cannot account for my results of enhancement in the cross-polarity competition treatment nor can they account for blocking past zero. These theories assume individuals judge causality by calculating multiple conditional contingencies: the overall contingency

$$\Delta P = P(O|C) - P(O|{\sim}C) = A/(A+B) - C/(C+D)$$

along with *conditional* $\Delta$Ps. Individuals then contrast these conditional contingencies: they compare the likelihood of the outcome when both causes occur with the likelihood of the outcome when only one cause occurs. For example, consider the target cue/cause X with a confounding cue that always predicts the outcome $\Delta P_A = 1.0$. Because the confounding cause is fully generative, the outcome will occur regardless of whether or not X occurs. The probability of the outcome in the presence of A is subtracted from the probability of the outcome with XA. This means that the conditional contingency for X is zero due to the contrast between conditional contingencies. The conditional contingency for X is calculated with the formula:

$$\Delta P\ (O \mid XA) - \Delta P\ (O \mid A) = 1.0 - 1.0 = 0$$

Therefore, the model predicts that when $\Delta P_A = 1.0$ judgments of X trend towards zero, but will not go beyond zero.  The same thing occurs when the confounding stronger cause is fully preventive ($\Delta P_A = -1.0$):

$$\Delta P\ (O \mid XA) - \Delta P\ (O \mid A) = -1.0 - -1.0 = 0$$

With these calculations of conditional contrasts Cheng and Novick (1990, 1992) can account for the common result of blocking in 0.5/1.0, as well as the less common effect of blocking in 0.5/-1.0 (e.g., Baker et al., 1993, Experiment 4; Baker et al., 2000, Experiment 1;

Vallée-Tourangeau et al., 1998). However, this theory cannot explain blocking past zero or why judgments of a moderately positive cue are enhanced in the presence of a stronger negative cue.

### 5.3.2 Generalization and discrimination

In this thesis I present results that show that the presence of common elements significantly reduces cue competition in each of three contingencies (0.5/0, 0.5/1.0, 0.5/-1.0) and that the presence of a salient context significantly reduces all estimates. These effects can be explained using Pearce's (1987; 1994) Configural theory. Real world (e.g., outside of the laboratory) cues have multiple elements (some common to other stimuli and some unique). Stimuli (e.g., cues) are perceived to be similar when they share features (e.g., common elements). The higher the number of common elements, the more similar the cues appear. Stimulus sampling theory assumes that humans can only perceive $\leq 8$ cue elements at a given point in time. Because the real world consists of an abundance of stimuli, I assume that it would be advantageous to be able to quickly determine which cues are similar and which are not. The implication for animal conditioning and human causal reasoning is that accurate judgments of which cues are similar/different should facilitate making accurate judgments about different causal relationships (e.g., peanut butter and peanut brittle are both made with peanuts (common element) therefore both products should be avoided if you are allergic to peanuts). According to Pearce (1987, 1994) common elements facilitates generalization between similar stimuli and unique elements facilitates discrimination between dissimilar stimuli.

Applied to the experiments in this thesis, generalization between two cues that share common elements reduces the ability to differentiate between them and therefore the cues that each have a different relationship with the outcome are perceived as similar. For example, judging both cues to have a preventive relationship when only one cue predicts the absence of the outcome. As a result, the effect of contingency on cue competition should be reduced. This would explain why the absolute values of participants' judgments were reduced and how the estimates in 0.5/0, 0.5/1.0 and 0.5/-1.0 were all pushed towards the X-axis and there is less of a difference between participants' ratings compared to when the cues do not share common elements.

### 5.3.3 The Auto-associator

The auto-associator is a parallel-distributed-processing connectionist network model used to account for how individuals make causal judgments about chains of events where one cue depends on another (Baetu and Baker, 2009). As with other associative models the assumption is that the different cues compete with each other for a limited amount of associative strength with the outcome, and that changes in associative strength occur over time (Baetu and Baker, 2009). This model can account for blocking and enhancement and can therefore provide a single explanation for different effects of cue competition, thereby elucidating how cues are judged in relation to each other.

**Negative prediction error.** Consider two cues, XC and AC, which have a common element (C) as well as an element *unique* to each cue (X, A). When each cue is presented by itself it forms an excitatory relationship with the outcome (the outcome can be either the presence or the absence). Excitatory associations are also formed between the elements of each cue, and because of the shared common element C, there are excitatory associations where C seems to predict both X and A. Therefore, whenever C is present X is expected and whenever C is presented A is expected: e.g., when XC is presented, the individual expects A, but there is no

A with XC. Using an associative explanation, recall that negative prediction error is the result of an expected outcome not occurring, and this is what happens when XC is presented and the individual expects A. Using the Rescorla-Wagner model, the negative prediction error ($\Sigma V > \lambda$) results in a decrease of the associative strength ($\Delta V$) between C and A. By definition unique elements never occur together and therefore there is zero initial associative strength between unique elements ($\Delta V = 0$). Therefore when $\Delta V$ decreases inhibitory associations are formed between the unique elements (e.g., X predicts absence of A, A predicts absence of X) (Baetu & Baker, Manuscript in preparation).

These inhibitory associations facilitate discrimination between the compound cues and therefore there is a reduction in generalization between XC and AC (Baetu & Baker, Manuscript in preparation). As previously discussed, discrimination facilitates the effect of contingency on cue competition, in contrast to when generalization between similar cues reduces all judgments. In this way, the auto-associator (Baetu & Baker, 2009) can account for the reduced estimates when cues share common elements and when the context is salient. This is indeed what I found in Experiments 2A and 2B.

**Inhibitory associations between unique elements.** The auto-associator can also account for enhanced ratings of the target cue in the $\Delta P_X = 0.5/\Delta P_A = -1.0$ condition. In 0.5/-1.0, the moderate positive contingency for the target cue (X) has an excitatory association with the outcome whereas A has an inhibitory association with the outcome. Therefore X gains associative strength and A loses associative strength. But recall that there are inhibitory associations between the unique elements. Therefore although A is fully preventive, A's inhibitory association with X predicts a decrease in the likelihood of a preventive cause. In other words, the inhibitory associative relationship is inhibited. Put simply, the likelihood of the absence of the outcome is reduced. Therefore if A loses associative strength, X gains associative strength, indirectly increasing its excitatory association, and that is why ratings of X are enhanced.

The same principle applies to account for blocking of X in 0.5/1.0, only in this case A is fully excitatory. In 0.5/1.0 both cues have excitatory associations with the outcome, only A's is increased. The increase in associative strength for the A-Outcome relationship means that X loses associative strength. But recall that there are inhibitory associations between X and A because of their unique elements. Therefore A reduces the likelihood of X and X reduces the likelihood of A. In other words, A decreases the likelihood of a moderate cause (0.5) and X is blocked. Since X loses associative strength, A gains associative strength with the outcome. This would also account for why participants ratings of A in 0.5/1.0 were reliably increased to compared to the 0.5/0 condition.

## 5.4 Discussion

The experiments in this thesis provide evidence that the mechanism for cue competition is one of contrast, and illustrates how both blocking and enhancement can occur. In this way, my objective to better understand how cues are judged relative to each other was achieved, and the experiments can be used to direct future research on the empirical findings of cue competition and not just the theoretical explanations. However, my experiments are not without certain limitations. For example, I did not manipulate the contingency of the target cue to be anything other than 0.5. Therefore my conclusions about cue competition are limited by the fact that I did not measure cue competition with a negative target cue or with more than one competitor as other experiments have (Baetu et al., 2005; Darredeau et al. (2009).

Because the manipulation for common elements was similar to the manipulation for context salience, future research should be directed towards testing other manipulations for context salience and cue elements can also reduce cue competition. Potential manipulations would be auditory and visual cues. Baker (1977), Bouton (1993b, 2004) and Msetfi and colleagues (2005, 2007, 2012) have shown that temporal manipulations of the context (e.g., length of the inter-trial interval) and outcome density (Baker et al., 1994, 2011) impact conditioning and causal reasoning. A causal reasoning task with both auditory and visual stimuli would be good analogue to Kamin's (1969) experiments.

It would also be interesting to see if contingency, cue elements and context salience would have the same effects on judgments in an instrumental casual reasoning tasks. Instrumental tasks are similar to operant conditioning in animals: the likelihood of the outcome is contingent on the action(s) of the individual. These actions may enable participants to test their assumptions in a way that they cannot in a passive learning task, and this hypothesis testing may be a reason why participants tend to be more accurate in instrumental causal reasoning tasks (Sobel & Kushnir, 2006; Waldmann & Hagmayer, 2005).

## 5.5 Conclusion

Ambiguous causal relationships are not an experimental construct used in laboratory experiments for human causal reasoning. Rather, most real world relationships are probabilistic and have graded effects, and so accuracy in causal reasoning is an adaptive process fundamental to cognition and behavior. That is why it is necessary to better understand the factors that influence the ability to provide accurate judgments. The presence of multiple causes/cues for a given effect/outcome is one factor that influences accuracy. Prior research on cue competition has focused mainly on the theoretical explanations and less on the empirical evidence and therefore this thesis aimed to determine the situations in which different phenomena of cue competition would occur, and use those results to try to understand how causal relationships are judged relative to each other. My results about the mechanisms involved in cue competition are consistent with The Contrast Hypothesis as opposed to older associative and normative rule-based theories. Cues are judged relative to each other by a mechanism of contrast where the stronger cue pushes judgments of the weaker cue in the direction that is opposite of the stronger cue's contingency. Causal estimates were attenuated when cues shared common elements and when the context was salient. These effects are likely due to generalization among similar stimuli reducing the effects of competing contingencies. The auto-associator can be used to describe how this generalization (and subsequent reduction in cue competition) occurs and can also account for the empirical evidence for how judgments can be increased (enhanced) and decreased (blocked).

# References


Allan, L. G. (1980). A note on the measurement of contingency between two binary variables in judgment tasks. *Bulletin of the Psychonomic Society, 15*, 59-81. doi:10.3758/BF03334492

Allan, L. G. (1993). Human contingency judgments: rule based or associative? *Psychological Bulletin, 114*, 435-448. doi:10.1037/0033-2909.114.3.435

Anderson, J. R., & Sheu, C. F. (1995). Causal inferences as perceptual judgments. *Memory & Cognition, 23*, 510-524. doi:10.3758/BF03197251

Atkinson, R. C., & Estes, W. K. (1963). Stimulus sampling theory. In R. D. Luce, E. Galanter, & R. R. Bush (Eds.), *Handbook of mathematical psychology* (121-168). New York: Wiley.

Baetu, I. (2010). *Associative and inferential accounts of extinction and blocking in causal learning* (Doctoral dissertation). Retrieved from Érudit, McGill University, 2010.

Baetu, I., Baker, A. G., Darredeau, C., & Murphy R. A. (2005). A comparative approach to cue competition with one and two strong predictors. *Learning & Behavior, 33*, 160-171. doi:10.3758/BF03196060

Baetu, I., & Baker, A. G. (2009). Human judgments of positive and negative causal chains. *Journal of Experimental Psychology: Animal Behavior Processes, 35*(2), 153-168. doi:10.1037/a0013764

Baetu I., & Baker, A. G. (2014). *Cue competition and enhancement with correlated and uncorrelated causes.* Manuscript in preparation. The University of Adelaide, Australia.

Baker, A. G. (1977). Conditioned inhibition arising from a between-sessions negative correlation. *Journal of Experimental Psychology: Animal Behavior Processes*, *3*(2), 144-155. http://dx.doi.org/10.1037/0097-7493.3.2.144

Baker, A. G., Berbrier, M. W., & Vallée-Tourangeau, F. (1989). Judgments of a 2x2 contingency table: Sequential processing and the learning curve. *The Quarterly Journal of Experimental Psychology B, Comparative and physiological psychology, 41*, 65-97.

Baker, A. G., Mercier, P., Vallée-Tourangeau, F., Frank, R., & Pan, M. (1993). Selective associations and causality judgments: Presence of a strong causal factor may reduce judgments of a weaker one. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 414-432. doi:10.1037/0278-7393.19.2.414

Baker, A. G., Msetfi, R. M, Hanley, N., & Murphy, R. (2010). Depressive realism: Sadly not wiser. In: M. Haselgrove, & L. Hogarth (Eds.), *Clinical applications of learning theory* (153-177). Hove, England: Psychology Press.

Baker, A. G., Murphy, R. A., & Vallée-Tourangeau, F. (1996). Associative and normative models of causal induction: Reacting to versus understanding cause. In D. R. Shanks, K. J.

Holyoak, & D. L. Medin (Eds.), *The psychology of learning and motivation, vol. 34* (1-45). San Diego, CA: Academic Press.

Baker, A. G., Murphy, R., Mehta, R., & Baetu, I. (2005). Mental models of causation: A comparative view. In A. J. Willis (Ed.), *New directions in human associative learning* (11-40). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Barberia, I., Baetu, I., Murphy, R. A., & Baker, A. G. (2011). Do associations explain mental models of cause? *International Journal of Comparative Psychology, 24*, 365-388.

Blanco, F., Matute, H., & Vadillo, M. A. (2009). Depressive realism: Wiser or quieter? *The Psychological Record, 59*, 551-562.

Bouton, M. E., & Brooks, D. C. (1993a). Time and context effects on performance in a Pavlovian discrimination reversal. *Journal of Experimental Psychology: Animal Behavioral Processes, 19*, 165–179. doi:10.1037/0097-7403.19.2.165

Bouton, M. E. (1993b). Context, time, and memory retrieval in the interference paradigms of Pavlovian learning. *Psychological Bulletin, 114*, 80–99. doi:10.1037/0033-2909.114.1.80

Bouton, M. E. (2004). Context and Behavioral Processes in Extinction. *Learning & Memory, 11*, 485-494. doi:10.1101/lm.78804

Bouton, M. E., & Swartzentruber, D. (1986). Analysis of the associative and occasion-setting properties of contexts participating in a Pavlovian discrimination. *Journal of Experimental Psychology: Animal Behavioral Processes, 12*, 333-350. doi:10.1037/0097-7403.12.4.333

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

Cheng, P. W., & Novick, L. R. (1990). A probabilistic contrast model of causal induction. *Journal of Personality and Social Psychology, 58*, 545-567. doi:10.1037/0022-3514.58.4.545

Cheng, P. W., & Novick, L. R. (1992). Covariation in natural causal induction. *Psychological Review, 99*, 365-382. doi:10.1037/0033-295X.99.2.365

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

Corlett, P. R., Murray, G. K., Honey, G. D., Aitken, M. R. F., Shanks, D. R., Robbins, T. W., . . . Fletcher, P. C. (2007). Disrupted prediction-error signal in psychosis: Evidence for an associative account of delusions. *Brain, 130*, 2387-2400. doi:http://dx.doi.org/10.1093/brain/awm173

Darredeau, C., Baetu, I., Murphy, R. A., Baker, A. G. (2009). Competition between multiple causes of a single outcome in causal reasoning. *Journal of Experimental Psychology, 35*, 1-14. doi:10.1037/a0012699

De Houwer, J. (2009). The propositional approach to associative learning as an alternative for association formation models. *Learning & Behavior*, *37*, 1-20. http://dx.doi.org/10.3758/LB.37.1.1

Den Ouden, H. E. M., Friston, K. J., Daw, N. D., McIntosh, A. R., & Stephan, K. E. (2009). A dual role for prediction error in associative learning. *Cerebral Cortex*, *19*, 1175-1185. doi:10.1093/cercor/bhn161

Dickinson, A., Shanks, D., & Evenden, J. (1984). Judgment of act-outcome contingency: The role of selective attribution. *The Quarterly Journal of Experimental Psychology*, *36*, 29-50. doi:10.1080/14640748408401502

Dickinson, A., Nicholas, D. J., & Mackintosh, N. J. (1983). A re-examination of one-trial blocking in conditioned suppression. *Quarterly Journal of Experimental Psychology*, *35*, 67-79. doi:10.1080/14640748308400914

Eysenck, H. J., Martin, I. (1987). Theoretical foundations of behavior therapy. New York: Plenum Press.

Goedert, K. M., Harsch, J., & Spellman, B. A. (2005). Discounting and conditionalization: Dissociable cognitive processes in human causal inference. *Psychological Science, 16*, 590-594. doi:10.1111/j.1467-9280.2005.01580

Goedert, K. M., & Spellman, B. A. (2005). Nonnormative discounting: There is more to cue interaction effects than controlling for alternative causes. *Learning & Behavior, 33*, 197-210. doi:10.3758/BF03196063

Gluck, M. A. (1992). Stimulus sampling and distributed representations in adaptive network theories of learning. In A. F. Healy, S. M. Kosslyn & R. M. Shiffrin (Eds.), *From learning theory to connectionist theory: Essays in honor of William K. Estes, Volume 1* (169-200). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Haselgrove, M., & Evans, L. E. (2010). Variations in selective and nonselective prediction error with the negative dimension of schizotypy. *The Quarterly Journal of Experimental Psychology, 63*, 1127-1149. doi:10.1080/17470210903229979

Kamin, L. J. (1969). Predictability, surprise, attention and conditioning In B. A. Campbell & R. M. Church (Eds.), *Punishment and aversive behavior* (64–99). New York, NY: Appleton Century-Crofts.

Kao, S. F., & Wasserman, E. A. (1993). Assessment of an information integration account of contingency judgment with examination of subjective cell importance and method of information presentation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1363-1386. doi:10.1037/0278-7393.19.6.1363

Liljeholm M., & Balleine, B. W. (2008). Mediated conditioning versus retrospective revaluation in humans: The influence of physical and functional similarity of cues. *The Quarterly Journal of Experimental Psychology, 62*, 470-482. doi:10.1080/17470210802008805

Matute, H., Arcediano, F., & Miller, R. R. (1996). Test question modulates cue competition between causes and between effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 182-196. doi:10.1037/0278-7393.22.1.182

McLaren, I. P. L., & Mackintosh, N. J. (2000). An elemental model of associative learning: I. Latent inhibition and perceptual learning. *Animal Learning & Behavior, 28*, 211-246. http://dx.doi.org/10.3758/BF03200258

McLaren, I. P. L., & Mackintosh, N. J. (2002). Associative learning and elemental representation II: Generalization and discrimination. *Animal Learning & Behavior, 30*, 177-200. http://dx.doi.org/10.3758/BF03192828

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

Morris R. W., Vercammen, A., Lenroot, R., Moore, L., Langton, J. M., Short, B., . . . Weickert, T. W. (2011). Disambiguating ventral striatum fMRI-related bold signal during reward prediction in schizophrenia. *Molecular Psychiatry, 17*, 280-289. doi:10.1038/mp.2011.75

Msetfi, R. M., Murphy, R. A., Simpson, J., & Kornbrot, D. E. (2005). Depressive realism and outcome density bias in contingency judgments: The effect of the context and inter-trial interval. *Journal of Experimental Psychology: General, 134*, 10-22. http://dx.doi.org/10.1037/0096-3445.134.1.10.

Msetfi, R. M., Wade, C., & Murphy, R. A. (2012). Context and time in causal learning: Contingency and mood dependent effects. PLoS ONE 8(5):e64063. doi:10.1371/journal.pone.0064063

Pearce, J. M. (1987). A model for stimulus generalization in Pavlovian conditioning. *Psychological Review, 94*, 61-73. doi:10.1037/0033-295X.94.1.61

Pearce, J. M. (1994). Similarity and discrimination: A selective review and a connectionist model. *Psychological Review, 101*, 587-607. doi:10.1037/0033-295X.101.4.587

Peterson C. R., & Beach, L. R. (1967). Man as an intuitive statistician. *Psychological Bulletin, 68*, 29-46. http://dx.doi.org/10.1037/h0024722

Rescorla, R. A. (1969). Pavlovian conditioned inhibition. *Psychological Bulletin, 72*, 77-94. http://dx.doi/org/10.1037/h0027760

Rescorla, R. A., & Wagner, A. R.  (1972). A theory of Pavlovian conditioning: variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. K. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (64–99). New York: Appleton-Century-Crofts.

Schultz, W. (1998). Predictive reward signal of dopamine neurons. *Journal of Neurophysiology, 80*, 1-27.

Shanks, D. R.  (1985). Forward and backward blocking in human contingency judgment. *The Quarterly Journal of Experimental Psychology, Section B: Comparative and Physiological Psychology, 37*, 1-21.

Shanks, D. R., Medin, D. L., Holyoak, K. J. (1996). *Causal learning*. San Diego, CA: Academic Press.

Shanks, D. R., Pearson, S. M., & Dickinson, A. J. (1989)., Temporal contiguity and the judgement of causality by human subjects. *The Quarterly Journal of Experimental Psychology, Section B: Comparative and Physiological Psychology, 41*, 139-159. doi: 10.1080/14640748908401189

Shanks, D. R. (1993). Associative versus contingency accounts of category learning: Reply to Melz, Cheng, Holyoak and Waldmann. *Journal of Experimental Psychology: Learning, Memory and Cognition, 19*, 1411-1423. http://dx.doi.org/10.1037/0278-7393.19.6.1411

Spellman, B. A. (1996). Acting as intuitive scientists: Contingency judgments are made while controlling for alternative potential causes. *Psychological Science, 7*, 338-342. doi:10.1111/j.1467-9280.1996.tb00385.x

Sobel, D. M., & Kushnir, T. (2006). The importance of decision making in causal learning from interventions. *Memory & Cognition, 34*, 411-419. doi:10.3758/BF03193418

Tenenbaum, J. B., Kemp, C., Griffiths, T. L., & Goodman, N. D. (2011). How to grow a mind: Statistics, structure and abstraction. *Science, 331*, 1279-1285. doi:10.1126/science.1192788

Van Hamme,  L. J., & Wasserman, E. A. (1994). Cue competition in causality judgments: The role of nonrepresentation of compound stimulus elements. *Learning and Motivation, 25*, 127-151. doi: 10.1006/lmot.1994.1008

Wagner, A. R., Logan, F. A., Haberlandt, K., & Price, T. (1968). Stimulus selection in animal discrimination learning. *Journal of Experimental Psychology, 76*, 171-180. http://dx.doi.org/10.1037/h0025414

Waldmann, M. R., & Hagmayer, Y. (2005). Seeing versus doing: Two modes of accessing causal knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 216-227. http://dx.doi.org/10.1037/0278-7393.31.2.216

Wasserman, E. A., Chatlosh, D. L., & Neunaber, D. J. (1983). Perception of causal relations in humans: Factors affecting judgments of response-outcome contingencies under free-operant procedures. *Learning and Motivation, 14*, 406-432. doi: 10.1016/0023-9690(83)90025-5

Wasserman, E. A., Elek, S. M., Chatlosh, D. J., & Baker, A. G. (1993). Rating causal relations: Role of probability in judgments of response-outcome contingency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 174-188. http://dx.doi.org/10.1037/0278-7393.19.1.174

Wasserman, E. A., Dorner, W. W., & Kao, S. F. (1990). Contributions of specific cell information on judgments of interevent contingency. *Journal of Experimental Psychology:*

*Learning, Memory, and Cognition, 16*, 509-521. http://dx.doi.org/10.1037/0278-7393.16.3.509

Yarlas, A. S., Cheng, P. W., & Holyoak, K. J. (1995). Alternative approaches to causal induction: The probabilistic contrast versus the Rescorla-Wagner model. In J. F. Lehman & J. D. Moore (Eds.), *Proceedings of the Seventeenth Annual Conference of the Cognitive Science Society* (431-436). Hillsdale, NJ: Erlbaum.