Cue-Interaction Effects in Contingency Judgments Using the Streamed-Trial Procedure

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Abstract

We previously described a procedure that permits rapid, multiple within-participant assessments of the contingency between a cue and an outcome (the "streamed-trial" procedure, Crump, Hannah, Allan, & Hord, 2007). In the present experiments, we modified this procedure to investigate cue-interaction effects, replicating conventional findings in both the one- and two-phase blocking paradigms. We show that the streamed-trial procedure is not restricted to the geometric forms used as cues and outcomes by Crump et al., and that it can incorporate the conventional allergy stimuli, where food is the cue and an allergic reaction is the outcome. We discuss the value of the streamed-trial procedure as a method for advancing our theoretical understanding of cue-interaction effects.

Cue-Interaction Effects in Contingency Judgments Using the Streamed-Trial Procedure

There are many experiments in which a participant is asked to assess the contingency or causal relationship between two events, a cue and an outcome. Typically, a discrete trial format is used. On each trial a cue may, or may not, be presented, following which an outcome may, or may not, be presented. For example, the cue may consist of information that a hypothetical individual has or has not eaten shrimp, and the outcome consist of information that the individual has or has not suffered an allergic reaction (Wasserman, 1990).

More generally, the stimuli presented to a participant can be summarized as a 2 x 2 matrix (see Table 1). On each trial, a cue either is presented (*C*) or is not presented (~*C*), and an outcome either occurs (*O*) or does not occur (~*O*). The letters in the cells (*a, b, c, d*) represent the joint frequency of occurrence of the four cue-outcome combinations in a block of trials. Conventionally, the contingency between the cue-outcome pairs over trials is defined by ΔP (Allan, 1980):

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After a series of trials on which each of the four cue-outcome combinations is presented with a pre-defined probability, the participant is asked to indicate the strength of the relationship between the cue and the outcome. For example, on a 100-point scale, the participant rates the strength of the relationship between eating shrimp and the occurrence of an allergic reaction. Usually the rating is about the causal relationship between the cue and the outcome (e.g., rate the degree to which eating shrimp causes an allergic reaction) or about the contingency between the cue and the outcome (e.g., rate the strength of the association between eating shrimp and an allergic reaction).

Many cue-outcome pairings are usually presented to the participant in order to ensure that sufficient information is provided about the actual contingency. Depending on the nature of the visuals used to represent cues and outcomes, a series of trials can take many minutes. For example, with presentation times of two seconds for the cue, two seconds for the outcome and a two second inter-pair interval, a series of 40 pairings takes over five minutes. In some experiments, a prediction response is required between presentation of the cue and presentation of the outcome. On each trial, the participant must predict whether an outcome will or will not occur given that a cue has or has not been presented. Obtaining prediction responses further lengthens each trial. One drawback to lengthy contingency assessment procedures is that few ratings can be obtained from a participant during a typical session limiting the experimenter's ability to make within-participant comparisons.

To increase the number of experimental observations, Crump, Hannah, Allan, and Hord (2007) developed the streamed-trial procedure in which it takes seconds, rather than minutes, to define a contingency value. By the rapid sequential presentation of cue-outcome pairs, an entire series of cue-outcome pairs can be telescoped into a single streamed trial. The streamed trial used by Crump et al. is depicted schematically in Figure 1A. The cue and the outcome were colored geometric forms. Each 100-ms presentation consisted of one of four cue-outcome combinations (Figure 1B), and presentations were separated by a black screen of 100-ms duration. A stream of these cue-outcome combinations defined the contingency value.

Crump et al. (2007) established that two central findings obtained with traditional contingency assessment tasks were also seen with the streamed-trial procedure. The most basic finding is that participants' ratings are usually correlated with ΔP; another common finding is that ratings, while correlated, also systematically depart from ΔP (see Allan, 1993; Shanks, 1993). One such departure has been termed the outcome density effect. For a fixed ΔP, ratings often are not constant but increase with the probability of the outcome, $P(O)$. In their experiment, Crump et al. varied both ΔP and $P(O)$. They showed that ratings varied systematically with ΔP, but were also influenced by $P(O)$; that is, the outcome density effect was obtained with the streamed-trial procedure.

In the present paper we modify the streamed-trial procedure for the investigation of cue-interaction effects7. Cue-interaction effects have been of central interest in the contingency and causality judgment literature for much of the last 20 years (for recent reviews see Allan & Tangen, 2005; De Houwer & Beckers, 2002; Penn & Povinelli, 2007). These effects arise from pairing multiple cues with a common outcome. It is well established that participants behave as if the cues interacted with one another, rather than treating them independently of one another. For example, when two cues (a target cue and a companion cue) are paired with a common outcome, the typical finding is that the rating of the relationship between the target and the outcome varies inversely with the strength of the relationship between the companion and the outcome. Cue-interaction effects have been central to the evaluation of competing theoretical accounts of contingency assessment.

Elsewhere we have suggested that the streamed trial procedure is valuable for assessing theoretical analyses of contingency assessment (Allan, Hannah, Crump, & Siegel, in press). However, to be a truly useful theoretical tool, we must demonstrate that the procedure can be used to investigate cue interaction. The primary purpose of the present experiments is to show that the streamed-trial procedure can be extended to the study of cue interaction. Cue-interaction effects have been shown using a variety of paradigms: one-phase blocking (e.g., Baker, Mercier, Vallee-Tourangeau, Frank, & Pan, 1993; Spellman, 1996a), two-phase blocking (e.g., Dickinson, Shanks, & Evenden, 1984; Shanks, 1985), relative cue validity (e.g., Wasserman, 1990), and overshadowing (e.g., Waldmann, 2001).

[1] We use the one-phase blocking paradigm in Experiments 1 and 2, and the two-phase blocking paradigm in Experiment 3; these two paradigms are the most commonly used in cue-interaction experiments.

A second purpose of the present experiments is to demonstrate that the streamed-trial procedure need not be restricted to the geometric forms used by Crump et al. (2007). We begin with these forms as cues and outcomes in Experiment 1. In Experiments 2 and 3, we use conventional allergy stimuli (e.g., Wasserman, 1990), where food ingestion is the cue and an allergic reaction is the outcome.

Experiment 1: One-Phase Blocking with Geometric Forms

In the one-phase blocking paradigm, two cues, a target cue (C_T) and a companion cue (C_C), are paired with a common outcome across trials. The two cues result in four possible cue combinations: both cues may be present ($C_T\, C_C$), both cues may be absent ($\sim C_T \sim C_C$), the target cue may be present and the companion cue absent ($C_T \sim C_C$), or the target cue may be absent and the companion cue present ($\sim C_T\, C_C$). For each cue combination, the outcome either occurs (O) or does not occur ($\sim O$), resulting in eight possible cue-outcome combinations, as is depicted in Table 2. The usual finding is that ratings of C_T depend on the contingency between C_C and the outcome (e.g., Baker et al., 1993; Spellman, 1996a, 1996b; Tangen & Allan, 2003, 2004). Tangen and Allan (2004), for example, showed that for a fixed contingency of 0.5 between C_T and the outcome, ratings of C_T were lower when the contingency between C_C and the outcome was perfect ($\Delta P = 1.0$) than when there was no contingency between C_C and the outcome ($\Delta P = 0.0$). In the present experiment, we use contingency matrices from Tangen and Allan to investigate cue-interaction effects in the streamed-trial procedure.

In the original description of the streamed trial procedure, participants judged the relationship between a blue square and a red circle in a rapidly presented stream of squares and circles (Crump et al., 2007). To study one-phase blocking, we added a second cue, a blue triangle. As illustrated in Figure 2, cues were blue squares and triangles and the outcome was a red circle. Either square or triangle could function as C_T or as C_C in any given stream. In keeping with the previous research of Tangen & Allan (2004), the ΔP value between C_T and the outcome was always 0.5, whereas the ΔP value between C_C and the outcome was either 0 or 1. At the end of each stream, participants rated the relationship between one of the cues and the outcome. Importantly, participants were not told in advance of each stream which of the cue-outcome relationships (C_T or C_C) would require a rating; instead, participants were signaled to rate either cue-outcome relationship after the stream was presented.

Method

Participants, stimuli and apparatus. Forty-three McMaster University undergraduates took part in the study in exchange for partial course credit. A streamed trial is depicted schematically in Figure 2A. The cue-outcome pairings were created by the factorial combination of three pairs of events: red circle/no circle, blue square/no square, and blue triangle/no triangle. The eight possible cue-outcome pairs are depicted in Figure 2B. The location of each shape, when it was present, was constant across all frames: the red circle was centered above the blue shapes, the blue square was on the left, and the blue triangle was on the right. The geometric forms were presented on a grey background (8.8

cm in height and 7.0 cm in width). The blue square measured 2.1 cm in height and width; the blue triangle measured 2.7 cm at its base and extended 2.3 cm in height; the red circle measured 2.5 cm in diameter. The stimuli were presented on an eMac G4 with a 17" CRT display, set approximately 60 cm from the participant. MetaCard software controlled stimulus presentation and data collection.

Procedure. The participants were told that their task was to rate the strength of association between a blue shape (cue) and a red shape (outcome) presented in a rapid stream. Each streamed trial consisted of a sequential display of 48 presentations of the eight cue-outcome combinations, with each presentation lasting 100 ms. Cue-outcome frames were separated by a black frame. Streams were composed so that one blue shape, the *target cue*, always had a contingency of 0.5 with the circle, while its *companion cue* had either a contingency of 1.0 (*companion*$_{1.0}$ *stream*) or 0.0 (*companion*$_{0.0}$ *stream*) with the circle. Target cues in streams containing a companion$_{1.0}$ cue are denoted target$_{0.5/1.0}$ cues, and target cues in streams containing a companion$_{0.0}$ cue are denoted target$_{0.5/0.0}$ cues. Table 3 displays the programmed frequencies of cue-outcome combinations used to define the companion$_{1.0}$ and companion$_{0.0}$ streams.

There were two conditions that differed in the duration of the black inter-frame interval (IFI). For Condition 100 (n = 22), the IFI was 100 ms (the value used by Crump et al., 2007) for a stream duration of 9.5 seconds. Because the information being presented in a stream was more complex in the present experiment than in Crump et al., we also included a longer IFI. For Condition 250 (n = 21), the IFI was increased to 250 ms, for a stream duration of 16.55 seconds.

Participants were asked to rate the strength of association between either C_T and the outcome or C_C and the outcome immediately after viewing each stream. To indicate the required judgment, we presented participants with a *report signal*, consisting of a small picture depicting one of the cue-outcome pairs. For example, if C_T was a square, and a C_T judgment was required, then a picture depicting a blue square (cue) and the red circle (outcome) was presented. For half of the streams the report signal indicated C_T, and for the other half it indicated C_C. A scrollbar appeared below the report signal. The left pole of the scrollbar was marked " -100", the right pole was marked "+100", and the midpoint was marked "0". Participants were told that a perfect negative association should be scored as -100, a perfect positive association should be scored as +100, and that no association between cue and outcome should be scored as 0. The scrollbar was always initialized to the "0" midpoint. Participants were not under time pressure to make their rating. They indicated that they had completed their rating by clicking a button on the screen, and then the next streamed trial was presented.

An experimental session consisted of 80 streamed trials, broken into five blocks of 16 streams. In each block, there were eight $\text{companion}_{1.0}$ and eight $\text{companion}_{0.0}$ streams. For half of the streams, C_T was a square, and for the other half C_T was a triangle. Thus, there were eight combinations of events: two companion contingencies (0.0, 1.0), two target forms (square, triangle), and two cue reports (C_T, C_C). The order of these eight combinations was randomized within blocks, with the constraint that each was sampled twice in each block.

Results and Discussion

Each participant made 20 C_C ratings and 20 C_T ratings for each condition in the design. Mean participant ratings were computed, and these participant means were pooled to generate condition means. C_C ratings provide a manipulation check to ensure that participants are responding differently to the two contingencies. Mean C_C ratings are shown as a function of C_C contingency ($\Delta P = 0.0$ and $\Delta P = 1.0$) in Figure 3A for Condition 100 and in Figure 3B for Condition 250. For both conditions, participants rated companion$_{1.0}$ cues higher than companion$_{0.0}$ cues.

Mean C_T ratings are shown as a function of C_C contingency in Figure 4A for Condition 100 and in Figure 4B for Condition 250. Even though C_T contingency was constant at $\Delta P = 0.5$, C_T ratings were higher when C_C was not a predictor of the outcome ($\Delta P = 0.0$) than when C_C was a perfect predictor of the outcome ($\Delta P = 1.0$). This cue-interaction effect was present for both IFI conditions.

To confirm the trends seen in Figures 3A and 3B, a mixed-design ANOVA was performed on the C_C ratings. There was one between-subject factor (IFI condition: 100 or 250) and two within-subject factors (C_C contingency: 0.0 or 1.0, and C_C shape: square or triangle). The main effect of IFI was not significant, $F(1, 41) = 1.03$, $p > .05$. The main effect of C_C contingency was significant, $F(1, 41) = 178.04$, $p < .001$ and did not interact with IFI condition, $F(1, 41) = .31$, $p > .05$. $\text{Companion}_{1.0}$ cues were rated higher (66.3 and 65.7 for Conditions 100 and 250 respectively) than $\text{companion}_{0.0}$ cues (-7.4 and -14.4 for Conditions 100 and 250 respectively). The main effect of shape was significant, $F(1, 41) = 4.57$, $p < .05$, indicating that overall C_C ratings were lower for the square (24.2) than for the triangle (30.8). However, as revealed by significant interactions of shape with C_C contingency, $F(1,41) = 7.00$, $p < .01$, and shape with C_C contingency and IFI, $F(1, 41) = 7.85$, $p < .01$, the effect of shape on C_C ratings was restricted to $\text{companion}_{0.0}$ streams in Condition 100 where the ratings for the triangle were higher than for the square.

To confirm the trends seen in Figures 4A and 4B, a similar ANOVA was performed on the C_T ratings. The main effect of IFI was not significant, $F(1, 41) = .14$, $p > .05$. The main effect of C_C contingency was significant, $F(1, 41) = 31.85$, $p < .001$ and did not interact with IFI condition, $F(1, 41) = .23$, $p > .05$. $\text{Target}_{0.5/1.0}$ cues were rated lower (-16.4 and -15.1 for Conditions 100 and 250 respectively) than $\text{target}_{0.5/0.0}$ cues

(24.7 and 19.5 for Conditions 100 and 250 respectively). The main effect of shape was significant, $F(1, 41) = 14.0$, $p < .001$. C_T ratings were lower for the square (-2.28) than for the triangle (8.65). However the effect of shape did not interact with companion contingency, $F(1, 41) = 3.19$, $p > .05$. The size of the cue-interaction effect was the same for the two shapes.

The results from this experiment using the streamed-trial procedure replicate the one-phase blocking data reported by Tangen and Allan (2004) using the traditional contingency task. Target cue ratings depended on the companion cue contingency: the higher the contingency of the companion cue, the lower the rating of the target cue. The independence of the size of the cue-interaction effect[2] from IFI duration is consistent with data reported by Allan et al. (in press) who found that performance in the simple streamed-trial procedure (with only one target cue) was not affected by temporal parameters.

Experiment 2: One-Phase Blocking with Allergy Stimuli

In Experiment 1, we demonstrated cue-interaction effects in the streamed-trial procedure with the same stimuli used by Crump et al. (2007). These colored geometric forms, however, are very different from the more meaningful visual images used in conventional cue-interaction experiments. In Experiment 2, we adapt the streamed-trial procedure for stimuli typically used in contingency assessment studies (foods and allergic reactions).

Method

Participants, stimuli and apparatus. Twenty McMaster University undergraduates took part in the study in exchange for partial course credit. The apparatus was identical to that used in Experiment 1.

Stimuli consisted of colored jpeg graphics of nine different foods, and two pictures of an arm. The arm was shown either with a rash, signifying an allergic reaction, or without the rash, signifying no allergic reaction. The complete set of stimuli is reproduced in Figure 5 – the nine foods in panel A and the two pictures of the arm in panel B. As in Experiment 1, cue pictures were presented at the bottom of the frame and outcome pictures were centered at the top of the frame.

Procedure. Participants were told that they would be viewing allergy tests from different patients. For each patient a combination of foods was given which either produced an allergic reaction or did not. An allergic reaction was depicted by a picture of an arm with a large rash on it; no reaction was depicted by a picture of the same arm without the rash. Participants were also told that the test was repeated many times for each patient, and that these multiple tests would be reproduced in a rapid time-lapse stream. That is, each stream represented the multiple tests of a single patient. Finally, participants were informed that at the end of each stream one of the foods tested on that patient would be shown, and that their task was to decide how strongly that food was associated with the patient's allergic reaction.

Since participants likely have a priori and idiosyncratic beliefs about the nature of the relationship between various foods and allergic reactions, two foods were randomly selected at the start of every stream from the pool of nine foods. The two selected foods were randomly assigned to cue designation (C_T, C_C), and position (left, right).

Each cue-outcome frame was presented for 250 ms and the IFI was 100 ms, resulting in a stream duration of 16.7 seconds. In all other respects, Experiment 2 was like Experiment 1.

Results and Discussion

Figure 3C shows mean C_C ratings as a function of C_C contingency. As in Experiment 1, Companion$_{1.0}$ cues (78.9) were rated higher than companion$_{0.0}$ cues (-7.8). Figure 4C shows mean C_T ratings as a function of C_C contingency. As in Experiment 1, target$_{0.5/1.0}$ cues (-26.1) were rated lower than target$_{0.5/0.0}$ cues (39.1). To confirm the trends seen in Figures 3C and 4C, two repeated-measures ANOVAs were performed, one on the C_C ratings and the other on the C_T ratings. For each ANOVA, there was one within-subject factor (C_C contingency: 0 or 1). For both ANOVAs, the main effect of C_C contingency was significant; companion $F(1,19) = 375.8$, $p < .001$ and target $F(1,19) = 57.1$, p < .001.

A comparison of Figure 4C with Figures 4A and 4B from Experiment 1 suggests that the cue-interaction effect with the allergy stimuli is at least as large as the cue-interaction effects with the geometric forms. A mixed-design ANOVA was performed on the C_T ratings from the two experiments. There was one between-subject factor with three levels (Condition 100, Condition 250, Experiment 2) and one within-subject factor (C_C contingency: 0 or 1). Only the main effect of C_C contingency was significant, $F(1, 60)$ =

77.3, $p < .001$. The streamed-trial procedure produces the same cue-interaction effects seen in conventional one-phase blocking paradigms regardless of the type of stimuli used.

Experiment 3: Two-Phase Blocking with Allergy Stimuli

As noted earlier, the one-phase blocking paradigm is one of a number of paradigms that have been used to investigate cue-interaction effects. In Experiment 3, we adapt the steamed-trial procedure with the allergy stimuli for the two-phase blocking paradigm.

The two-phase blocking paradigm was developed by Kamin (1969) to study cue interaction in rats. In phase 1 of his experiments, a single cue (for example, a tone) was paired with an outcome (for example, a shock). In phase 2, a new cue, the target cue (for example, a light), was added and the light-tone compound was paired with the shock. Kamin measured the animal's fear response to the added light cue and found a decrease relative to the fear observed in various control groups. He concluded that learning about the relationship between the tone and shock in phase 1 "blocked" the learning about the relationship between the added light cue and the shock in phase 2.

In the Kamin (1969) two-phase blocking experiments, the relationship between the cues and the outcome was deterministic. The single cue in phase 1 was presented on every trial and was always paired with the outcome; likewise the compound cue in phase 2 was presented on every trial and was always paired with the outcome.

Shanks and colleagues (1985; Dickinson et al., 1984) reported the first human data from the two-phase blocking paradigm. In the 1980s, researchers interested in human contingency assessment studied probabilistic relationships between the cue and the outcome (see Allan, 1993). Rather than using the deterministic relationships from the nonhuman literature, Shanks and colleagues modified the two-phase blocking paradigm so that the relationship between the cues and the outcome in both phases was probabilistic.[3]

Shanks and colleagues (1985; Dickinson et al. 1984) investigated two versions of the two-phase paradigm, forward and backward (or retrospective). The forward and backward versions differed in the order in which the single and compound cues were presented; the single-cue phase was presented first for the forward order, and presented second for the backward order. They reported cue-interaction effects[4] with both orders, and concluded that the size of the effect was the same for the two orders.

Shanks (1985) is the classic reference in the human contingency assessment literature for two-phase blocking, and it is important to establish that the streamed-trial procedure would yield similar results. Like Shanks and colleagues (1985; Dickinson et al. 1984), we constructed probabilistic relationships between cues and outcomes, and we examined both the forward and the backward orders. Shanks and Dickinson et al. reported that the probability of the outcome during the single-cue phase influenced the size of the cue-interaction effect: the more frequent the outcome, the greater the effect. We also varied the probability of the outcome during the single-cue phase.

Method

Participants, stimuli and apparatus. Seventy-five McMaster University undergraduates took part in the study in exchange for partial course credit. Stimuli and apparatus were identical to those used in Experiment 2.

Procedure. Table 4a presents the 2 x 2 contingency matrix for the two-phase blocking paradigm using our notation from the one-phase blocking paradigm: $C_T C_C$ denotes the presentation of the compound cue and $\sim C_T C_C$ denotes the presentation of the single cue.

In the single-cue phase, the target cue is never presented (cell *a* = cell *b* = 0), and the companion cue appears on every frame: i.e., $P(C_T C_C) = 0$ and $P(\sim C_T C_C) = 1.0$. Because the companion cue always appears, its contingency is undefined in this phase, just as the contingency for the target is undefined because it never appears. In the deterministic version, only cell *c* is presented – that is, the outcome always occurs. In the probabilistic version used in this experiment, both cells *c* and *d* are presented - that is, the outcome is probabilistic.

In the compound-cue phase, the target cue appeared with the companion on half the trials, and the companion appeared alone on half the trials: i.e., $P(C_T C_C) = P(\sim C_T C_C) = .5$.[5] The contingency between the target cue and the outcome, ΔP_T, is

$$\Delta P_T = P(O|C_T C_C) - P(O|\sim C_T C_C).$$

In the deterministic version, only cell a is presented. In the probabilistic version used in this experiment, all cells are possible during the compound-cue phase.

The basic design of the experiment is summarized in Table 4b. In the compound-cue phase, $P(O|C_T C_C) = .75$, $P(O|\sim C_T C_C) = .25$, and $\Delta P_T = .5$. The predictive strength of the companion cue during the single-cue phase was varied: $P(O|\sim C_T C_C) = .75$ (strong),

$P(O|{\sim}C_TC_C) = .5$ (medium), and $P(O|{\sim}C_TC_C) = .25$ (weak).

There were two orders, forward and backward. In the forward order, the single-cue phase preceded the compound-cue phase. In the backward order, the compound-cue phase preceded the single-cue phase. For both orders, the food used to designate C_C was the same food in both phases.

We also included two control treatments, one for each order, where the food used to designate C_C was different in the two phases. To be more concrete, consider a random selection of three foods (cabbage, corn, and beef) where beef is designated as C_T. In the control treatments, cabbage would be designated as C_C in one phase and corn would be designated as C_C in the other phase. In the experimental treatments, the same food (say cabbage) would be designated as C_C in both phases. The two orders and the two treatments resulted in four conditions: forward order (FO), backward order (BO), forward order control (FOC), and backward order control (BOC).

A streamed trial consisted of 64 frames, 32 for phase 1 and 32 for phase 2. Phases were blended seamlessly. Participants were not informed of the two-phase internal structure of the streamed trial, and they made their rating at the end of the stream. As in the previous experiments, they were presented with a report signal that indicated which food they were to rate. The signaled food was always C_T (i.e., the food that was presented only in the compound phase).

Figure 6 shows examples of the cue-outcome arrangements for the four treatment-order combinations. As in Experiment 2, cue pictures were presented at the bottom of the frame and outcome pictures were centered at the top of the frame. The foods for a stream were randomly selected, as was their designation as C_T and C_C. C_T was shown on the right side of the frame on half of the streams for each of the four conditions, and on the left side for the other half. The timing parameters were the same as in Experiment 2; each cue-outcome frame was presented for 250 ms and the IFI was 100 ms.

In all there were 12 conditions composed of two orders (forward and backward), two treatments (experimental and control), and three values of predictive strength, $P(O|{\sim}C_TC_C)$, in the single-cue phase (strong, medium, and weak). $P(O|{\sim}C_TC_C)$ was a between-subjects variable, and there were 25 participants in each group. Order and treatment were within-subjects variables. A session consisted of four blocks of 16 streamed-trials each. Each of the four within-subject conditions (FO, FOC, BO, BOC) was presented four times during each block in a randomly determined order.

Results and Discussion

Figure 7 shows the mean C_T ratings as a function of the value of $P(O|{\sim}C_TC_C)$ in the single-cue phase. The data for the forward orders (FO and FOC) are in the top panel and the data for the backward orders (BO and BOC) are in the bottom panel. In both panels, ratings are lower for the experimental treatments (FO and BO) than for the respective control treatments (FOC and BOC), and the difference in ratings between an experimental treatment and its control is about the same for the two orders. The experimental and control treatments also differ in that ratings decrease as $P(O|{\sim}C_TC_C)$ increases for the two experimental treatments but not for the two control treatments.

The trends seen in Figure 7 were evaluated by a 3 [$P(O|{\sim}C_TC_C)$: Low, Medium, High)] x 2 (order: forward, backward) x 2 (treatment: experimental, control) mixed-design ANOVA. The main effect of treatment was significant, $F(1, 72) = 41.31$, $p < .001$. For both orders, ratings were lower for the experimental treatment than for the control treatment, indicating that cue interaction was obtained for both orders. While the main effect of order was significant, $F(1, 72) = 41.97$, $p < .001$, it did not interact with treatment, $F(1, 72) = 1.52$, $p > .05$. The size of the cue-interaction effect (i.e., the size of the difference between a treatment condition and its control condition) was the same for the two orders.

Consistent with the findings of Shanks and colleagues (1985; Dickinson et al., 1984), the main effect of $P(O|{\sim}C_TC_C)$ was significant, $F(2, 72) = 5.10$, $p < .01$. It should be noted that in their studies the control treatment consisted of only the compound phase, and therefore the effect of $P(O|{\sim}C_TC_C)$ on the two treatments could not be compared. If the effect of $P(O|{\sim}C_TC_C)$ were the result of the predictive value of C_C, as hypothesized by Shanks and colleagues, then one would expect no effect in the control treatments. That is, $P(O|{\sim}C_TC_C)$ should affect the ratings in the experimental treatments (FO and BO) and should not affect the ratings in the control treatments (FOC and BOC). We conducted a linear trend analysis on $P(O|{\sim}C_TC_C)$ for each of the four treatment-order conditions. These comparisons are not orthogonal and the corrected critical $F(1, 72) = 6.563$ and 9.818 for = .05 and = .01 respectively. The linear trend was significant for the two experimental treatments, $F(1, 72) = 16.52$ for the FO condition and $F(1, 72) = 11.12$ for the BO condition. In contrast, the linear trend was not significant for the two control treatments, $F(1, 72) = 2.97$ for the FOC condition and $F(1, 72) = 1.92$ for the BOC condition. Thus, as expected, the difference between control and experimental treatments (i.e., cue interaction) increased as $P(O|{\sim}C_T C_C)$ increased for both the forward and the backward orders.

While there have been many studies of human contingency assessment with the two-phase blocking paradigm since the pioneering work of Shanks and colleagues (1985; Dickinson et al., 1984), the overwhelming majority have been deterministic.[6] Thus Experiment 3 provides one of the few replications with probabilistic pairings (see also Wasserman, Kao, Van Hamme, Katagiri, & Young, Experiment 4, 1996). Finally, Experiment 3 speaks further to the portability of the streamed-trials procedure for providing an efficient tool for measuring contingency assessment phenomena across a range of designs and stimuli.

General Discussion

The primary goal of the present set of experiments was to demonstrate that the streamed-trial procedure could be extended to the study of cue interaction. We showed that the streamed-trial procedure produced conventional cue-interaction effects both with the one-phase blocking paradigm (Experiments 1 and 2) and with the two-phase blocking paradigm (Experiment 3). Although there are many reports of cue interaction in the two-phase blocking with human participants, Experiment 3 is one of the few experiments to use probabilistic cues. The results were similar to the findings of Shanks and colleagues (1985; Dickinson et al., 1984) and Wasserman et al. (1996) using more traditional contingency assessment procedures, further validating the streamed-trial procedure as a tool for exploring cue interaction. We found cue-interaction for both forward and backward orders, and the size of the effect did not differ for the two orders. Moreover, our data confirm that the effect of manipulating the value of $P(O|{\sim}C_T C_C)$ in the single-cue phase was selective for the experimental treatments. The size of the cue-interaction effect increased with $P(O|{\sim}C_T C_C)$ for the two experimental treatments but not for the two control treatments. In the experimental treatments, ratings of C_T accompanied by a companion that was a strong predictor in the single-cue phase were lower than ratings of C_T accompanied by a companion that was a weak predictor in the single-cue phase.

A second goal of the present experiments was to demonstrate that the streamed-trial procedure need not be restricted to the geometric forms used by Crump et al. (2007) as cues and outcomes. We produced cue-interaction effects not only with geometric forms (Experiment 1), but also with the more conventional allergy materials (Experiments 2 and 3). We found that variation in stimulus material and also timing parameters had no effect on the size of the cue-interaction effect.

There are now a number of quantitative accounts of cue-interaction effects in human contingency assessment (see Allan & Tangen, 2005, and De Houwer & Beckers, 2002 for recent reviews). Contingency assessment can be conceptualized as involving two processes. The input process transforms the actual contingency to an internal or perceived value and the output process relates the internal value to the behavioral response. Some models posit that cue interaction occurs in the input process and usually assume, explicitly or implicitly, that the behavioral response is monotonically related to the internal value. Other models posit that cue interaction resides in the output process directly affecting the behavioral response.

Typically, the rating response has been interpreted as a measure of the input process. However, there is evidence that ratings conflate the input and output processes (e.g., Allan, Siegel, & Tangen, 2005; Perales, Catena, Shanks, & González, 2005). Consider the situation in which a participant gives a low rating of a C_T that was accompanied by a C_C that was reliably paired with an outcome (i.e., the participant displays cue interaction). C_C might affect the internal value of the perceived relationship between C_T and the outcome, or C_C might affect what is reported about the internal value. Whether the effect of C_C on ratings resides in the input process or the output process remains a central issue in the contingency assessment literature.

In the present series of experiments, we used ratings as the dependent variable since that was the measure used in the experiments we were attempting to replicate with the streamed-trial procedure. Now that it has been shown that the streamed-trial procedure with the rating response yields typical cue-interaction effects, future research can be directed at establishing whether cue interaction occurs during the input process or during the output process. The experiments reported by Allan et al. (in press) provide a method for doing so. Allan et al. reported a series of experiments with the streamed-trial procedure where the dependent measure was a binary response, rather than the rating response. At the end of the stream, the participant was asked to indicate whether the relationship between the cue and the outcome was strong or weak. Allan et al. demonstrated that the binary response in conjunction with the stream-trial procedure provided a methodology for determining whether an experimental manipulation affects the input process or the output process.

The streams in Allan et al. (in press) were like those illustrated in Figure 1; that is, there was only a single cue. However, the binary response could readily be substituted for the rating response used in the present cue-interaction experiments. The data reported by Allan et al. indicate that the streamed trial procedure, in conjunction with the binary response, would be valuable for assessing theoretical analyses of cue interaction and providing information about the locus of cue-interaction effects.

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Author's note

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Footnotes

[1]The labels for these cue-interaction paradigms are used as descriptors and should not be interpreted as carrying any theoretical connotation.

[2] One of the reviewers questioned whether the patterns of ratings in the one-phase blocking paradigm could be attributed to cue interaction understood as cue competition. That is, they

have questioned whether the cue-interaction effect in the one-phase blocking paradigm arises from cues competing with one another for control of learning (e.g., Rescorla & Wagner, 1972) or responding (e.g., Stout & Miller, 2007). The reviewer also noted that cue-interaction effects may arise from processing cue contingency when only one cue is present, along the lines of Spellman's (1996a, 1996b) conditional ΔP hypothesis. These are much-debated questions in the human contingency judgment literature, but are outside the scope of this paper. Our use of the term "cue interaction" is intended simply as a descriptor for the pattern of target cue ratings, and is not intended to imply a theoretical position regarding the mechanism underlying the phenomena.

[3] A few years later when Wasserman (1990) investigated relative cue validity with human participants, he also used a probabilistic version of the paradigm.

[4] Shanks and colleagues actually concluded that they had demonstrated backward blocking; specifically that the presentation of the single cue in phase 2 of the backward order affected retrospectively what had been learned about target cue in phase 1. Others (e.g., Wasserman & Berglan. 1998; Wasserman & Castro, 2005) have suggested that the "backward blocking" effect reported by Shanks and colleagues might also indicate "recovery from overshadowing". Given that our goal was to replicate the results reported by Shanks and colleagues with the streamed-trial procedure, we are using the theoretically neutral phase, cue-interaction.

[5] It should be noted that the compound-cue phase is not the same as the one-phase blocking

paradigm (see Table 2) where there are four possible cue combinations.

[6] Many of the studies of two-phase blocking have been conducted within the associative framework and have used the deterministic task [see research conducted by Matute and colleagues (e.g., Arcediano, Escobar, & Matute, 2001), De Houwer, Beckers and colleagues (e.g., Becker, De Houwer, Pineño, & Miller, 2005), Wasserman and colleagues (e.g., Wasserman & Berglan, 1998; Wasserman & Castro, 2005), and Le Pelley & McLaren (2003)].

Table 1

2x2 Matrix for Cue-Outcome Pairings in a Standard Contingency Task.

		O		*~O*
C		**a**		**b**
~C		**c**		**d**

Note – The letters in the cells (*a, b, c, d*) represent the joint frequency of occurrence of the four cue-outcome combinations.

Table 2

4x2 Matrix for Cue-Outcome Pairings in the One-Phase Blocking Paradigm.

		O		~O
$C_T C_C$		**a**		**b**
$C_T \sim C_C$		**c**		**d**
$\sim C_T C_C$		**e**		**f**
$\sim C_T \sim C_C$		**g**		**h**

Note – The letters in each cell (*a, b, c, d, e, f, g, h*) represent the joint frequency of occurrence of the eight cue-outcome combinations.

Table 3

Frequency of Cue-Outcome Presentations in a Streamed Trial, Experiments 1 and 2.

		Companion Streams		
Presentation type		$\text{companion}_{0.0}$		$\text{companion}_{1.0}$
$C_T C_C O$		9		18
$C_T {\sim}C_C O$		9		0
${\sim}C_T C_C O$		3		6
${\sim}C_T {\sim}C_C O$		3		0
$C_T C_C {\sim}O$		3		0
$C_T {\sim}C_C {\sim}O$		3		6
${\sim}C_T C_C {\sim}O$		9		0
${\sim}C_T {\sim}C_C {\sim}O$		9		18
# of presentations		48		48

Note. C_T is the target cue, C_C is the companion cue, and O is the outcome.

Table 4a

2x2 Matrix for Cue-Outcome Pairings in Two-Phase Blocking Paradigm in Experiment 3.

		O		$\sim O$
$C_T C_C$		**a**		**b**
$\sim C_T C_C$		**c**		**d**

Note – The letters in the cells (*a, b, c, d*) represent the joint frequency of occurrence of the four cue-outcome combinations.

Table 4b

Design of Experiment 3.

		Single-Cue Phase		Compound-Cue Phase				
Predictive Strength		$P(O \mid \sim C_T C_C)$		$P(O \mid C_T C_C)$		$P(O \mid \sim C_T C_C)$		ΔP_T
Strong		.75		.75		.25		.5
Medium		.50		.75		.25		.5
Weak		.25		.75		.25		.5

Figure Captions

Figure 1. (A) Schematic of the streamed-trial presentations used in Crump, Hannah, Allan, & Hord (2007). (B) The four possible cue-outcome combinations in a streamed trial. In the Crump et al. experiment, the square shown here in solid gray appeared in solid blue, and the striped, gray circle appeared in solid red.

Figure 2. (A) Schematic of the streamed-trial presentations for the one-phase blocking paradigm. (B) The eight possible cue-outcome combinations in a streamed trial. Lowercase letters within the main box in panel B refer to entries in Table 2. In the actual experiments, the square and triangle shown here in solid dark gray both appeared in solid blue, and the striped, lighter gray circle appeared in solid red. Frame presentation was 100 ms; inter-frame interval (IFI) was either 100 ms or 250 ms.

Figure 3. Ratings for $\text{companion}_{0.0}$ cues (dark bars) and $\text{companion}_{1.0}$ cues (light bars) for Experiment 1 (panel A: IFI = 100 ms; panel B: IFI = 250 ms), and Experiment 2 (panel C). Error bars = 1 *SE*.

Figure 4. Ratings for $\text{target}_{0.5/0.0}$ cues (dark bars) and $\text{target}_{0.5/1.0}$ cues (light bars) for Experiment 1 (panel A: IFI = 100 ms; panel B: IFI = 250 ms), and Experiment 2 (panel C). Error bars = 1 *SE*.

Figure 5. The nine food pictures used to represent food cues (panel A), and the two reaction pictures used to represent allergy outcomes (panel B) in Experiments 2 and 3. The pictures were displayed in full color in the experiments, and without labels.

Figure 6. Trial presentation examples for Experiment 3 for the four treatment-order

conditions. Phase-one displays are illustrated in the left panel of each row, and phase-two displays are illustrated in the right panel.

Figure 7. Ratings of target cues in Experiment 3 as a function of the value of $P(O|{\sim}C_T C_C)$ in the single-cue phase. The data for the forward conditions (FO and FOC) are in the top panel and the data for the backward conditions (BO and BOC) are in the bottom panel. Error bars = 1 *SE*.

Figure 1

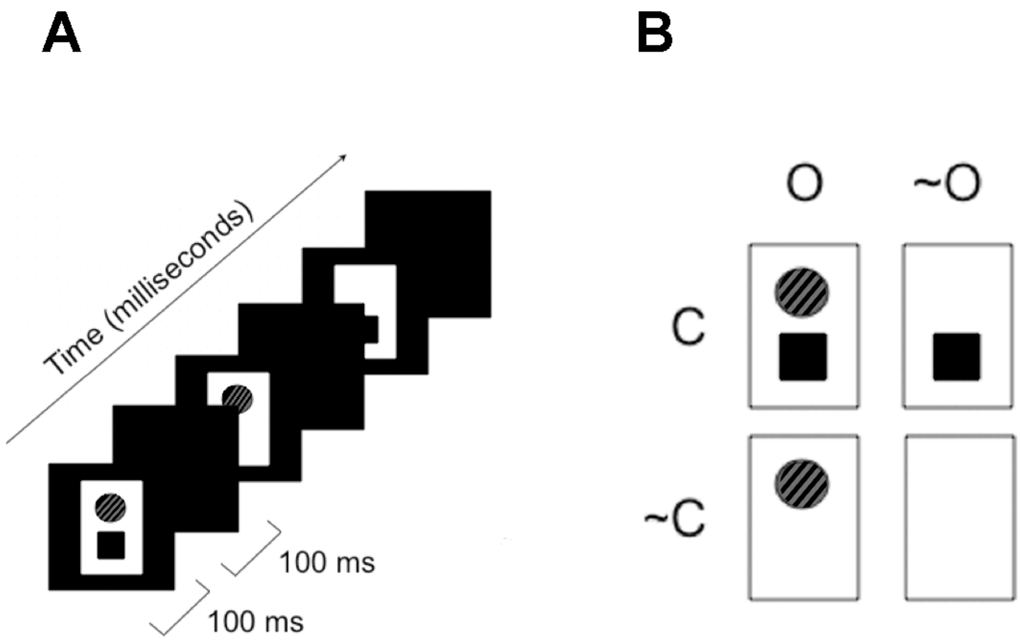


Figure 2

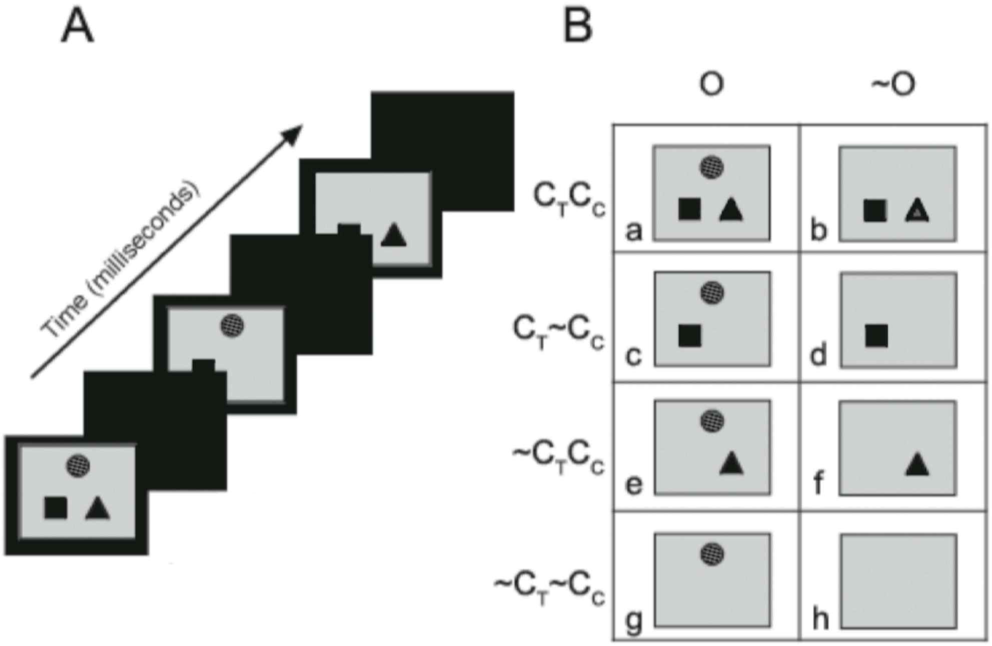


Figure 3

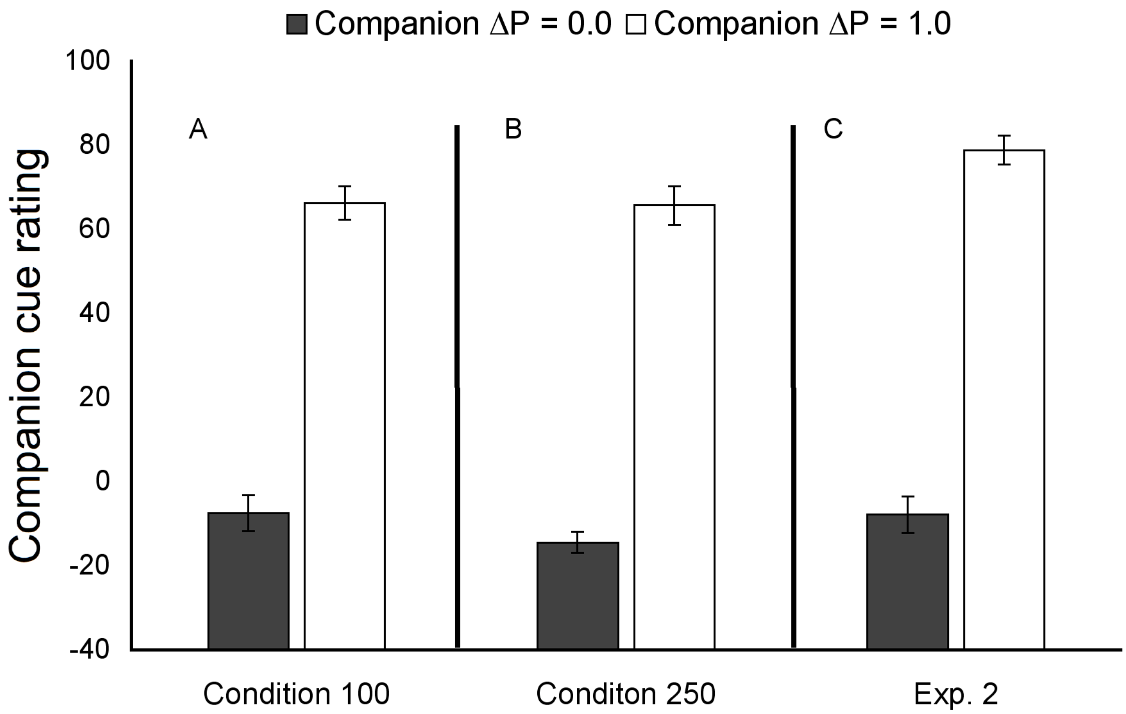

Companion ΔP = 0.0
Companion ΔP = 1.0
Companion cue rating
100
80
60
40
20
0
-20
-40
A
B
C
Condition 100
Conditon 250
Exp. 2

Figure 4

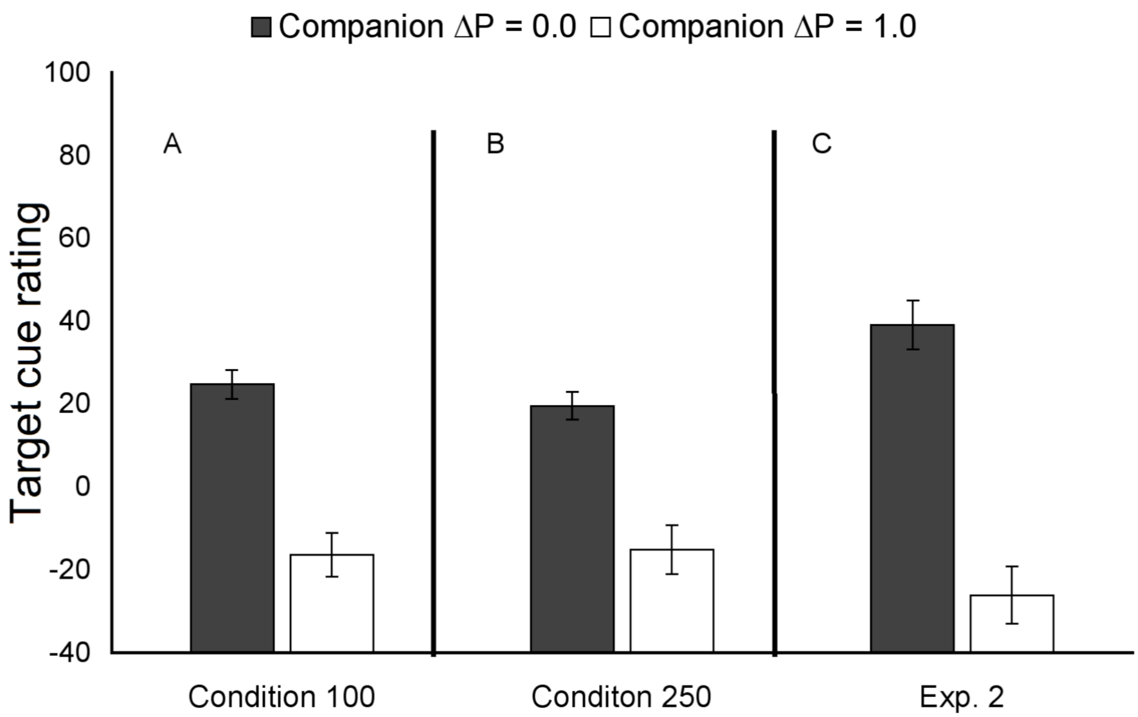

Companion ΔP = 0.0
Companion ΔP = 1.0
Target cue rating
100
80
60
40
20
0
-20
-40
A
B
C
Condition 100
Conditon 250
Exp. 2

Figure 5

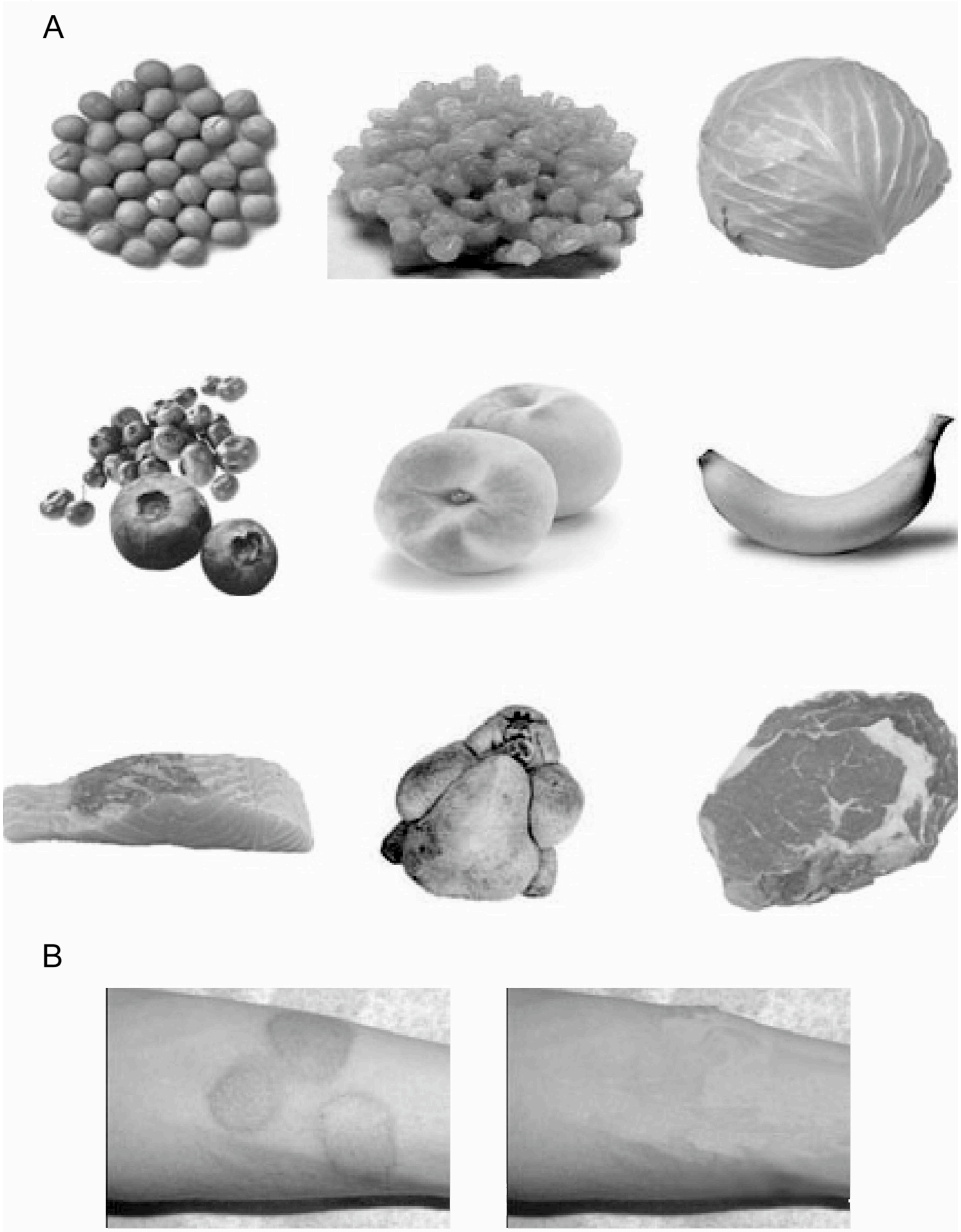


Figure 6

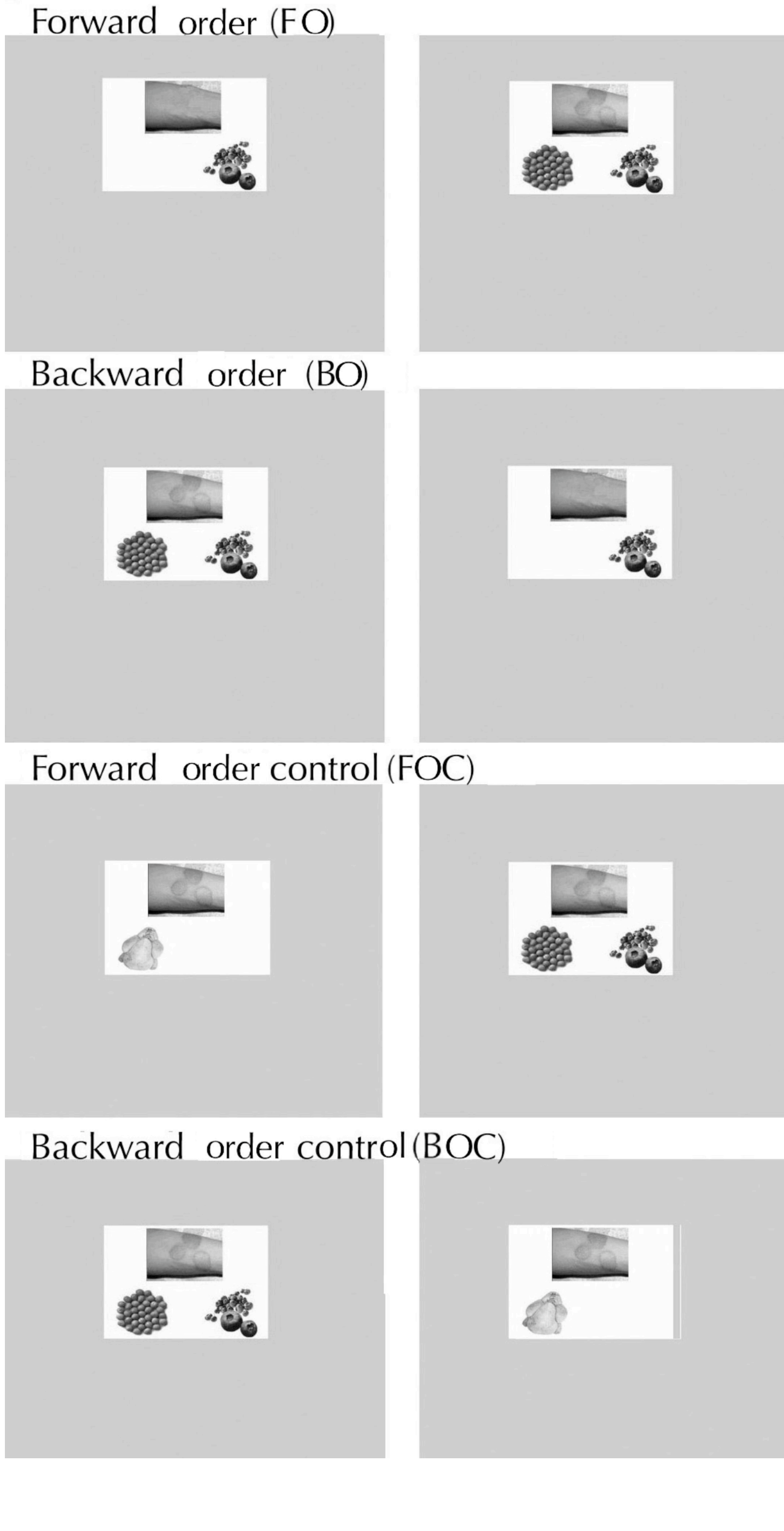
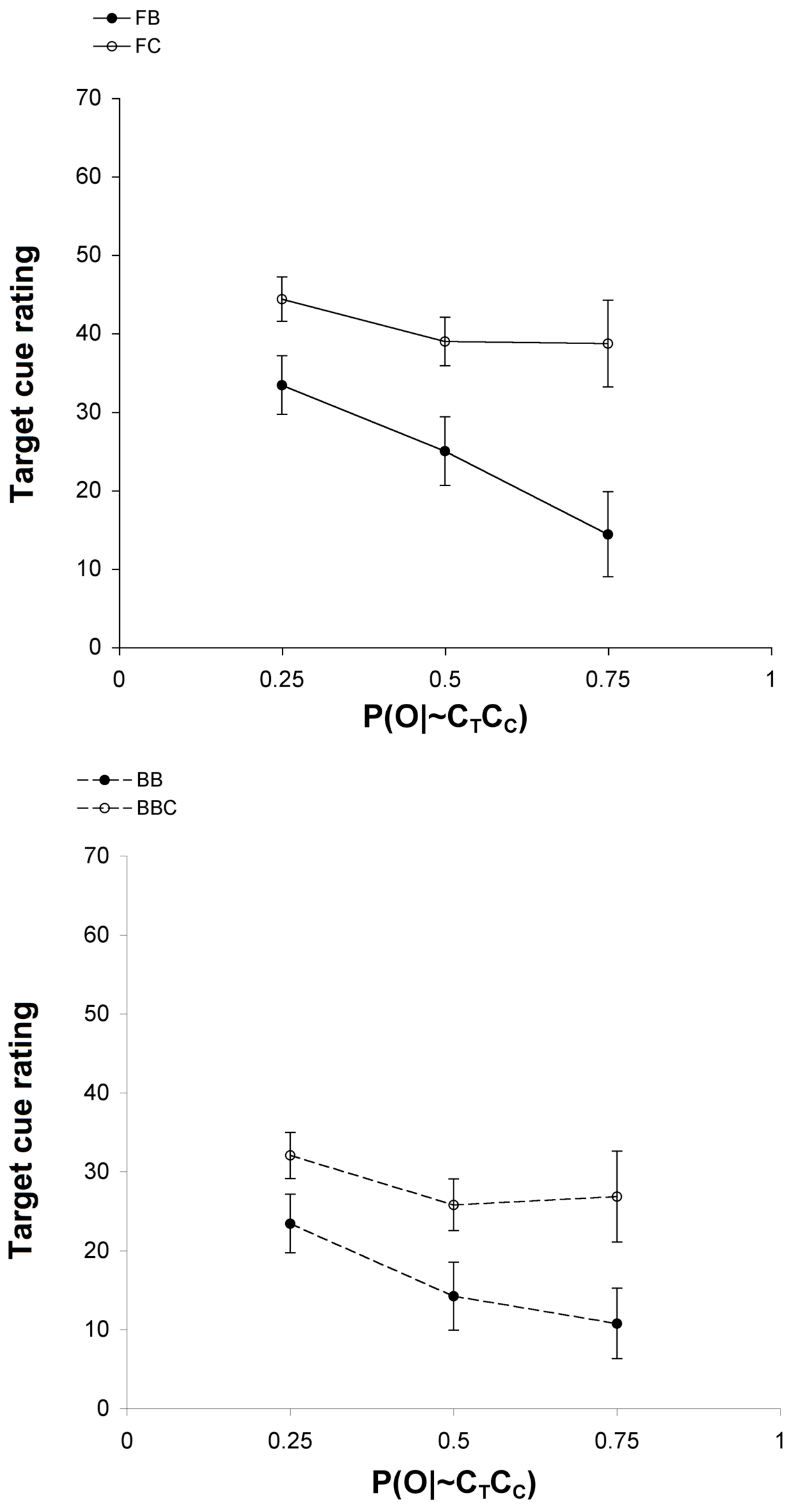

Forward order (FO)
Backward order (BO)
Forward order control (FOC)
Backward order control (BOC)

Figure 7


FB
FC
Target cue rating
70
60
50
40
30
20
10
0
0
0.25
0.5
0.75
1
P(O|~C$_T$C$_C$)
BB
BBC
Target cue rating
70
60
50
40
30
20
10
0
0
0.25
0.5
0.75
1
P(O|~C$_T$C$_C$)