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Short report

Integration of multiple memories in sensory preconditioning

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ABSTRACT

The present study demonstrates that humans' response to a single stimulus (S1) is determined by what follows S1's associates. The experiment used a sensory preconditioning (SPC) design where S1 was associated with both S2 and S3 on separate trials before establishing relationships between these latter stimuli with an outcome or its absence in a second phase. When S2 and S3 were associated with the same consequence, either an outcome or its absence, strong consequence-based responding to S1 was observed in a reaction time test. Participants responded quickly to indicate that the outcome was, or was not, predicted by S1. When S2 predicted the outcome and S3 did not, SPC was weaker although participants were not slower to respond to S1. Implications on the understanding of the mechanisms that allow for the response to S1 to emerge are discussed.

1. Introduction

Sensory preconditioning (SPC; e.g., Brogden, 1939) consists of pairing two neutral stimuli (S1–S2) in phase 1 of an experiment and then pairing S2 with an unconditioned stimulus (US; S2-US) in phase 2. In this paradigm, a conditioned response (CR) appropriate to the US is observed to S1, even though S1 itself has never been directly paired with the US.

Such a response is indicative of the integration (Matzel et al., 1988; Savastano & Miller, 1998; Arcediano & Miller, 2002) of the Phase 1 and Phase 2 memories. It is as if memories can be superimposed upon each other allowing for the response to S1 to emerge. A possible explanation is that S1 evokes an associative chain of memories at test (S1 → S2 → US) leading to the response (see Molet et al., 2012). Alternatively, S2 could evoke S1 during Phase 2, allowing a direct association to form between the representation of S1 and the US (e.g., see Hall, 1996; Holland, 2008).

In a conventional SPC procedure, S1 only has a single associate, S2. In a natural setting, stimuli are likely to have multiple associates, each of which can be associated with yet other stimuli. For example, S1 might be associated with both S2 and S3. Subsequently, S2 might be predictive of the US, while S3 is not. In such a situation, weaker SPC is expected compared to a condition in which S2 and S3 are both predictive of the US, either because S1 retrieved two conflicting associations regarding the US, or because the representation of S1 was paired with the US only in the presence of S2. We assume that if the weaker SPC is explained solely by the activation of two conflicting associations, the time to respond that S1 predicts the US should be increased in comparison to conditions in which S2 and S3 consistently predict the US or the absence of the US. The goal of the present study is two-fold. First, it attempted to examine the role of reaction time in the understanding of the mechanisms underlying SPC. Second, it sought to further validate a recently developed procedure which combines both response time and type of response when participants make predictions concerning S1's outcome (Craddock et al., 2012).

2. Experiment

The experiment was designed to assess how memories controlled by multiple associates of a single stimulus combine using a SPC design. In the first phase, S1 was paired with both S2 and S3 (simultaneous pairings; e.g., Recorla, 1980), on different trials in all conditions. Then, in a Consistent Outcome condition S2 and S3 were each paired with the same outcome stimulus (sequential pairings) in phase 2. Here, we would expect that S1 should elicit a response appropriate to expecting the outcome. In a No Outcome condition, S2 and S3 were presented in phase 2, but followed by nothing. A response to S1 on test appropriate to expecting no outcome is expected in this condition. The most interesting data

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Table 1
Design.

Condition	S2–S1 phase (simultaneous pairings)	S2/S3-Outcome and S2/S3-No outcome phase (sequential pairings)	Test
Consistent outcome	S1–S2 (Color1 + Letter1) S1–S3 (Color1 + Letter2)	S2-Outcome (Letter1 – Outcome) S3-Outcome (Letter2 – Outcome)	Color1? Letter1? Letter2?
Inconsistent outcome	S1–S2 (Color2 + Letter3) S1-S3 (Color2 + Letter4)	S2-Outcome (Letter3 – Outcome) S3-No outcome (Letter4 – No-outcome)	Color2? Letter3? Letter4?
No outcome	S1–S2 (Color3 + Letter5) S1–S3 (Color3 + Letter6)	S2-No outcome (Letter5 – No-outcome) S3-No outcome (Letter6 – No-outcome)	Color3? Letter5? Letter6?

will come from a third condition, which is the Inconsistent Outcome condition. During phase 2, S2 was followed by the outcome, while S3 was not. On test, S1 should yield lower associative strength with the outcome compared to the Consistent Outcome condition, and higher associative strength than in the No Outcome condition because of S2 and S3's conflicting outcomes.

We used a recently developed transformation rule to evaluate associative strength (Craddock et al., 2012). A strong association between events is hypothesized to result in a quick decision that the second event will be present. Weaker associations are assumed to be reflected in more uncertainty (i.e., longer response times and/or inconsistent predictions). The absence of association between a cue and an outcome is assumed to be reflected in a quick prediction that the second event will be absent.

The experiment was conducted within subjects with the different conditions outlined above created with different stimuli. The design is shown in Table 1. Colored squares (Color1–Color3) served as S1 stimuli. Letters (Letter1–Letter6) served as S2 and S3 stimuli. A picture of two rabbits served as the outcome. In the Consistent Outcome condition, Color1 was associated with both Letter1 and Letter2, which each predicted the outcome in phase 2. In the No Outcome condition, Color3 was associated with Letter5 and Letter6, which each predicted the absence of the outcome in phase 2. In the Inconsistent Outcome condition Color2 was associated with Letter3 and Letter4 and one of these stimuli was associated with the outcome and the other with the absence of the outcome in phase 2. On test the S1–S3 stimuli were presented and participants were required to respond "yes" or "no" by pressing keys on a keyboard to indicate whether the stimulus presented predicted the outcome or not.

2.1. Method

2.1.1. Participants

Sixteen French university students (8 males and 8 females; 18–29 years of age) volunteered.

2.1.2. Materials

The stimulus presentations were programmed using Python 2.7. Light gray randomly selected Latin letters in Helvetica 350 bold font were presented on a dark gray background of a computer screen. Three 8 cm × 8 cm blue, red, or green squares were used as the three color-stimuli mentioned in Table 1. The 2-s outcome stimulus was the one used by Craddock et al. (2012) and consisted of a vertical yellow stripe (19 cm × 7.5 cm) in the middle of the screen on which was drawn two rabbits.

2.1.3. Procedure

Before starting the experiment, each of the six letters was randomly assigned to one of the three colors. Phase 1 began with the computer instructing participants that they were to learn color-letter associations. Participants then received eight blocks of 2-s simultaneous pairings of S1 (colors) with each of S2 and S3 (Letters) in each condition with the order of the six stimulus presentations randomized within each block and between participants. The inter-trial intervals were 1.5 s. Each letter appeared either on the left (50% of the participants) or the right half of the computer screen. The colored squares were presented on the opposite side. For each participant, the letters always appeared on the same side of the screen.

At the start of phase 2, participants were instructed to learn which letters were followed by an image of two rabbits (Outcome). Afterwards, the letters appeared for 2-s in the same position on the screen as during Phase 1. There were six blocks of six randomized presentations of the letters either immediately followed by the outcome stimulus (image of two rabbits) or by no outcome (a blank screen) depending on the condition to which the letters were assigned. The inter-trial intervals were 1.5-s.

The only time participants were to respond was during the test. Participants were informed that they would have to indicate whether each stimulus predicted the rabbits. Participants were not told that their reaction time (RT) was being recorded but they were invited to respond as soon as they knew their answer. The instructions indicated that the first trial was for training: a symbol ('&') rather than a letter was tested. The test stimulus remained on the screen until the participant had responded then 'next trial' was displayed for 1.5-s. Participants indicated their choice by pressing the left or right arrow keys (counterbalanced as "yes" or "no" between subjects). Each of the six letters and the three color-stimuli was tested in a random order, in the same screen position they had during learning.

The type of response (i.e., 'yes' or 'no') and the RT to respond was recorded. Each of the nine RTs was divided by the largest RT of the nine (RTmax). Any 'yes' response RT was then transformed into [$-\ln(RT/RTmax)$], and any 'no' response RT into [$+\ln(RT/RTmax)$]. Hence, transformed data near zero (i.e., RT/RTmax near 1) denote slow, hesitating, responses, while positive or negative transformed data indicate that the participant answered 'yes' or 'no' without hesitation, respectively (see Craddock et al., 2012). Because a slight increase or decrease in a short RT is presumably more significant than an equivalent increase or decrease in a long RT (e.g., a difference of 2-s between two RTs is relatively more important when the RTs are short than when they are long), differences between short RTs were made more important than differences between long RTs, through the logarithmic transformation.

2.2. Results

The results were analyzed using nonparametric statistics (i.e., Wilcoxon test) due to some distributions not being normal. The effect sizes were calculated as Cohen's g where $g = 0.5(\#(x_{i1} < x_{i2}) - \#(x_{i1} > x_{i2}))/n$, (i.e., .one-half of Cliff's d. Cliff's d corresponds to the proportion of times when the difference between two repeated measures is strictly negative minus the