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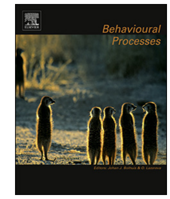

Implicit relational learning in a multiple-object tracking task

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ABSTRACT

We studied implicit relational learning by embedding contextual relational information into a multiple-object tracking task. In two experiments, participants were instructed to track two or four out of eight moving objects and report at the end of the trial whether a single cued object was among those they tracked (yes/no task). The stimulus display also contained two background strips of different width. In the informative condition, the location of the cued object predicted the correct choice: If the answer was "yes", then the cued object was always located next to the narrower strip; otherwise, it was always located next to the wider strip (or vice versa). In the random condition, the location of the object did not predict the correct choice. Participants in the informative condition consistently displayed lower tracking accuracy than in the random condition, possibly due to attentional demands introduced by implicit relational task. At the same time, participants in the informative condition demonstrated no awareness of the task structure; instead, their reports were consistent with the attempts to track moving objects. Our task can provide a suitable model for studying implicit relational learning in adult participants that is essential for establishing generality of factors affecting relational learning.

1. Introduction

Sensitivity to relational information underlies many distinct cognitive abilities such as acquisition of language, analogical reasoning, mathematical competence, and social skills (Christie, 2017; Collins and Laski, 2015; Gentner et al., 2011; Gentner and Kurtz, 2006). Although undoubtedly facilitated by language, this sensitivity appears to be also present in individuals with limited verbal capacity (e.g., Walsh et al., 2014) as well as in nonhuman animals (see Lazareva and Wasserman, 2017, Zentall et al., 2008, for reviews). Thus, understanding factors that facilitate or impair our sensitivity to relational information when we learn and respond to relationships without verbalizing them (termed *implicit learning*) is especially important for establishing the basic building blocks of relational learning.

Although many implicit learning tasks already exist, most of them concentrate on participants' memory of a specific pattern, location, or a sequence (see Cleeremans et al., 1998, for a review). For example, in the serial reaction time task participants are instructed to respond as quickly and as accurately as possible to the stimulus presented in one of the possible locations (Hunt and Aslin, 2001; Nissen and Bullemer, 1987). Unbeknownst to the participants, the locations of the stimuli follow a set pattern across the trials; this pattern facilitates the participants' performance even though they are unable to verbalize its details. Similarly, in a contextual cueing task participants' task is to locate a target item among several distractors, with some stimulus displays repeating across multiple trials (Chun and Jiang, 1998; Ogawa et al., 2009). The participants become progressively better at locating the target on those repeated displays while remaining unaware of their repetition.

In contrast, the goal of our study was to develop an implicit *relational* task that would afford examining participants' attention to relationships among the components of the stimulus displays instead of the specific patterns or locations. To do so, we chose to capitalize on our earlier research using relational learning in a transposition task.

1.1. Relational learning in a transposition task

In one representative version of the transposition task (Fig. 1A), we trained pigeons to select a smaller (or a larger, depending on a counterbalancing) of the two circles (Lazareva et al., 2005). For example, in Experiment 1, some subjects were trained to discriminate S1+ S2− and S5+ S6− (where numbers indicate an increasing circle diameter and plus and minus denote reinforcement and nonreinforcement, respectively). Upon completion of this training, the subjects received several novel, nondifferentially reinforced pairs selected such that a choice of relationally correct stimulus was difficult to explain by appealing to the prior history of reinforcement. For example, the testing pair S2–S6 was comprised of the two previously nonreinforced stimuli suggesting little preference for either stimulus whereas the testing pair S4-S5 paired the previously reinforced stimulus S5 with the novel

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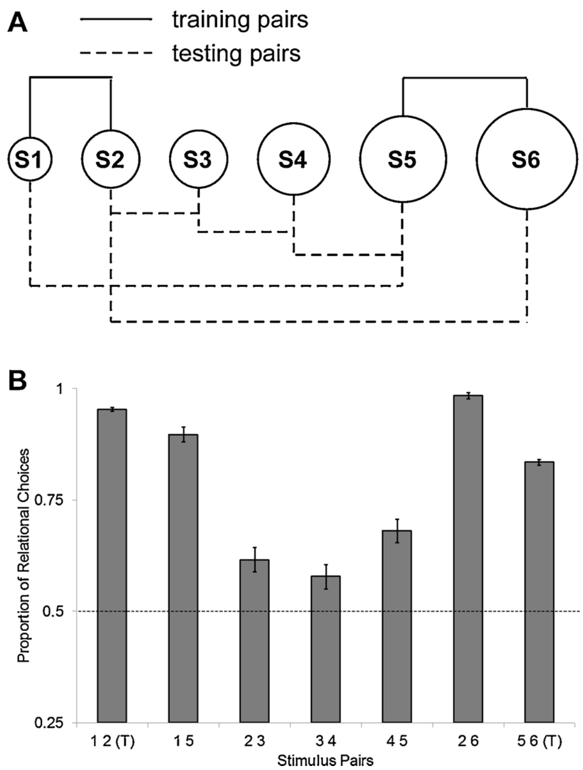

Fig. 1. A: Design of the Experiment 1 in Lazareva et al. (2005). B: Mean proportion of correct choices to the testing pairs in Experiment 1 (Lazareva et al., 2005). Note higher accuracy to the more discriminable pairs (e.g., S1–S5 and S2–S6) than the less discriminable pairs (S3–S4). Error bars represent standard error of mean.

stimulus S4 indicating possible preference for a larger stimulus S5 instead of a relationally correct stimulus S4.

As Fig. 1B indicates, pigeons responded relationally to all of the five testing pairs. Moreover, their performance was strongly affected by the discriminability of the two testing stimuli: The birds were more accurate when the testing pair was comprised of the highly dissimilar stimuli (e.g., S1–S5) than when it was comprised of similar stimuli (e.g., S3–S4). This result, confirmed in our follow-up studies (Lazareva et al., 2008; Lazareva et al., 2014), suggested that relational responses were more easily instantiated when the stimuli were highly discriminable.

Can the same trends be observed in human behavior? In our pilot, unpublished study, we attempted to replicate the design of Lazareva et al. (2005) with human participants. However, we found uniformly high accuracy to all testing pairs (an average of 97.2% correct) with no reliable trends. In addition, our participants displayed high awareness of the task structure; in other words, they were able to verbally state that they were selecting a smaller (or a larger) circle in the novel, testing pairs. Therefore, we decided to embed transposition task into a multiple-object tracking task in which participants are instructed to track a subset of moving objects (targets) and ignore the rest of the moving objects (distractors; see Scimeca and Franconeri, 2015, for a review).

1.2. Combining multiple-object tracking task and relational learning task

We selected the multiple-object tracking task for embedding the relational transposition task because previous research indicated that it requires sustained attention to the visual displays and that it is quite challenging for most adults. Typically, participants are able to track four or fewer objects (Pylyshyn and Storm, 1988; Yantis, 1992), although later studies suggest that under certain circumstances tracking capacity can be as high as eight or nine objects (Alvarez and Franconeri, 2007). At the same time, participants in a multiple-object tracking task are able to attend to contextual cues (e.g., predictable trajectories of the objects) unrelated to the main tracking task, while remaining unaware of doing so (Ogawa et al., 2009).

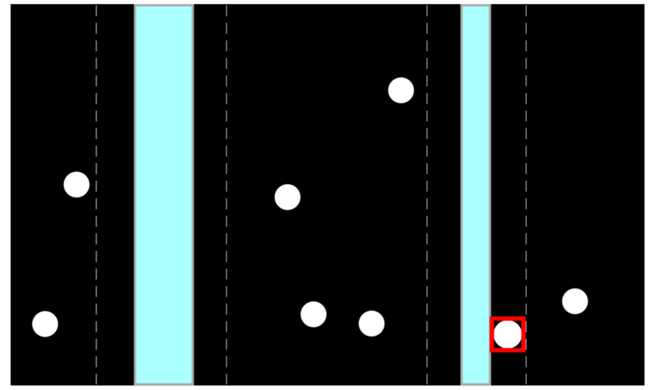

Fig. 2. The final screen of a trial where participants are prompted to make a yes/no decision. Regardless of target/distracter status, the cued object always stopped within the areas indicated by dashed lines. The dashed lines were not visible to the participants and are used here for illustration only. In Informative condition, the position of the object relative to the strip determined the correct choice. For example, if the object was next to a narrower strip, then the correct answer was always "yes" (or vice versa, depending on group assignment). In Random condition, the location of the cued object was unrelated to the correct choice.

In our version of the task, the participants were instructed to track two or four out of eight objects shown on a computer monitor. The stimulus display also contained two blue background strips of different widths (Fig. 2); however, the participants were not informed about them nor instructed to attend to them. At the end of the trial, one of the objects was cued and the participants had to respond whether this object was a target or a distractor (yes/no task). In the informative condition, the location of this cued object with respect to the background strips predicted the correct answer: For example, the target was always located next to the narrow strip and the distractor was always located next to the wide strip (or vice versa in a counterbalanced version of the task). In other words, participants in the informative condition could respond correctly by simply analyzing the final display instead of tracking objects during the trial. In the random condition, the target and the distractor could be located next to either background strip; these participants had to track the objects during the trial to respond correctly.

The goal of the Experiment 1 was to establish implicit relational learning in this version of the multiple-object tracking task by comparing tracking accuracy in the informative condition and in the random condition. We expected that implicit relational information would improve participants' tracking accuracy resulting in a higher accuracy in the informative condition. In addition, the participants were asked to complete a postexperimental awareness questionnaire to provide a measure of awareness (see Appendix B in Supplementary material).

Furthermore, Experiment 1 was designed to establish whether participants in the informative condition attempted to track the objects. To do so, we included a two-object group in which participants had to track two out of eight objects and a four-object group in which they had to track four out of eight objects. If the participants in the informative condition attempted to track the objects, then we would observe a decrease in tracking accuracy from the two-object group to the four-object group. Alternatively, if the participants based their decision on the final screen instead of tracking the objects, then we would observe similar accuracy in both groups.

In the Experiment 2, we manipulated presence/absence of the background strips. For example, the background strips might have been