

## FUNCTION TRANSFORMATION WITHOUT REINFORCEMENT

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In studies of function transformation, participants initially are taught to match stimuli in the presence of a contextual cue, X; the stimuli to be matched bear some formal relation to each other, for example, a relation of opposition or difference. In a second phase, the participants are taught to match arbitrary stimuli (say, A and B) in the presence of X. In a final test, A often displays behavioral functions that differ from those of B, and can be predicted from the nature of the relation associated with X in the initial training phase. Here we report function-transformation effects in the absence of selection responses and of their reinforcers. In three experiments with college students, exposure to relations of difference or identity modified the responses given to later stimuli. In Experiment 1, responses to a test stimulus A varied depending on preexposure to pairs of colors that were distinct from A but exemplified relations of difference or identity. In Experiment 2, a stimulus A acquired distinct functions, depending on its previous pairing with a contextual cue X that had itself been paired with identity or difference among colors. Experiment 3 confirmed the results of Experiment 2 with a modified design. Our data are consistent with the notion that relations of identity or difference can serve as stimuli for Pavlovian processes, and, in compound with other cues, produce apparent function-transformation effects.

*Key words:* function transformation, Pavlovian conditioning, stimulus relation, stimulus compound, keyboard typing, humans

How environmental correlations affect performance, and what effects they produce, have been central issues in Pavlovian conditioning. A recurrent finding of Pavlovian research is that stimulus correlations promote *functional equivalence* with respect to responding (Tonneau, 1993): Two stimuli, A and B, that have been correlated with each other, either directly or through a network of stimulus pairings (e.g., AC, CB, where C is a stimulus distinct from A and B), acquire similar behavioral effects. Dogs salivate to tones paired with meat delivery, for example (Pavlov, 1927), and pigeons direct drinking movement at keys paired with water (Jenkins & Moore, 1973).

Beyond promoting the transfer of responding from one stimulus (A) to another (B), pairing two stimuli also may promote their functional equivalence with respect to subsequent conditioning (Hall, 1996). In a study by Holland (1981), for example, rats were poisoned in the presence of a stimulus (A)

previously paired with food (B); in a test of conditioned aversion, the rats behaved as if the food had been poisoned, even though the stimulus actually present during poisoning was not the food (B) but its associate (A). Thus, the initial AB correlation made pairing A with a toxin functionally equivalent to pairing B with a toxin. Ward-Robinson and Hall (1996, 1999) found similar results with conditioned suppression in rats: Pairing two stimuli, A and B, and then pairing A with a shock, conditioned B to the shock.

Dwyer, Mackintosh, and Boakes (1998) reported a more complex finding. In their study, a cue (A) was paired with peppermint (B) and a context (C) was paired with sucrose (D); then A was paired with C. As a result, rats increased their consumption of peppermint (B), as if the latter had been conditioned to sucrose (D). In this experiment, exposure to AB and CD compounds made later AC correlations functionally equivalent to BD correlations, with effects similar to the direct conditioning of B to D. These data and similar ones (see Gallistel & Gibbon, 2000, pp. 316–320) imply that the Pavlovian conditioning of two stimuli can take place without any need for pairing these stimuli to each other (Dwyer, 2000).

Results such as those of Ward-Robinson and Hall (1996) contradict the claim by some

Parts of these data were presented at the annual meeting of Sociedad Mexicana de Análisis de la Conducta, San Luis Potosí, México (September 2005).

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doi: 10.1901/jeab.2006.49-05

operant theorists (e.g., Hayes et al., 2001, p. 46) that function transfer from A to B through CA and CB pairings cannot be due to Pavlovian conditioning. Pavlovian results on functional equivalence in animals (Dwyer et al., 1998; Holland, 1981, 1990) also support a Pavlovian interpretation of the cases of function transfer reported in the human operant literature (Tonneau, 2001). Operant studies of function transfer typically involve an initial stage in which choices among various stimuli are reinforced; the stimuli matched to one another (directly or not) are then shown to be functionally equivalent (e.g., Gatch & Osborne, 1989; Wulfert & Hayes, 1988). The schedules of stimulus matching used in these studies, however, occasion numerous pairings among stimuli, which may in turn produce function transfer through a Pavlovian process (e.g., Boelens, 1990; Hall, Mitchell, Graham, & Lavis, 2003).

Consistent with this hypothesis, Tonneau and González (2004) showed that stimulus pairings modeled after matching to sample, but in which matching responses and their operant reinforcers were removed, could produce function transfer in humans. The results of Tonneau and González highlight the methodological confounding of Pavlovian and operant variables in the human matching-to-sample studies that seem to support operant theories of function transfer (e.g., Hayes, 1991; Sidman, 2000). The evidence in favor of the latter can usually be reinterpreted in Pavlovian terms (Tonneau, 2001), whereas Pavlovian, stimulus-correlation accounts of function transfer apply not only to the findings of human instrumental studies, but also to the Pavlovian data that operant approaches fail to address (e.g., Holland, 1981, 1990).

Although Pavlovian principles provide a unified and parsimonious account of functional equivalence (Hall, 1996; Tonneau, 1993, 2001), some operant studies have uncovered phenomena of *function transformation* that directly challenge Pavlovian accounts of human behavior (Barnes-Holmes, Hayes, & Roche, 2001). The nature of the challenge is best understood by considering a simple case of function transformation. In a recent study, Whelan and Barnes-Holmes (2004, Experiment 1) established a cue, X, as a discriminative stimulus for matching geometric shapes that were the opposite of each other along

various physical dimensions. Separately, a stimulus, B, was established as a punisher for instrumental responding. When a stimulus A was later matched with B in the presence of X, A did not become a punisher, contrary to what might be expected on the basis of its association with B; rather, A became a reinforcer. Similar results have been reported after pretraining with relations of sameness, difference, opposition, and less-than or more-than (e.g., Barnes-Holmes, Hayes, Dymond, & O'Hara, 2001; Dymond & Barnes, 1995; Roche & Barnes, 1997). In each case, the functions acquired by a stimulus A matched with a target B in the presence of a cue X depended on which relation was associated with X during pretraining (Dymond & Rehfeldt, 2000).

The approach known as relational frame theory (RFT) has been said to explain such findings with relative ease (Barnes-Holmes, Hayes, & Roche, 2001). According to RFT (e.g., Hayes, 1991), generalized patterns of behavior known as *relational frames* or "arbitrarily applicable relational responding" (p. 25) can be reinforced in the presence of nonarbitrary stimulus relations and later be "brought to bear" (p. 25) on novel stimulus configurations to produce function-transformation effects. From the RFT perspective, therefore, the cues X employed in function-transformation studies are discriminative stimuli for relational framing (Barnes-Holmes, Hayes, Dymond, et al., 2001).

This explanation fails, however, because the contextual cues X employed in function-transformation studies are not discriminative stimuli for operants of the sort assumed by RFT (Tonneau, 2004). In the experiment by Whelan and Barnes-Holmes (2004) mentioned above, for example, the relational frame of opposition might consist of doing in the presence of A the opposite of what was done in the presence of B (see Dymond & Rehfeldt, 2000). This relational frame might occur in testing, and might well be an operant, but X could not be a discriminative stimulus for it because the operant in question was neither emitted nor reinforced in the presence of the cue X. What Whelan and Barnes-Holmes (p. 182) reinforced in the presence of X was the behavior of matching *stimuli* opposed to each other, not the relational act of making a *response* opposed to another response. This problem is a general one (Tonneau, 2004). In

function-transformation studies of RFT, contextual cues such as X are discriminative stimuli for nonrelational behaviors of stimulus matching that differ from the behaviors emitted on test trials.

To this logical failure of RFT concepts must be added the complexity of the matching-to-sample procedures employed to document function transformation (e.g., Dymond & Barnes, 1995). As a result, the reason that contextual cues (X) have the effects that they have remains unclear. Do such cues affect function transformation because they are discriminative stimuli for matching behavior, or merely because they are correlated, in a Pavlovian fashion, with relational properties of the environment (Tonneau, 2001)? This analytic difficulty is exacerbated when the designs employed involve indirect matching relations among multiple stimuli (e.g., Dymond & Barnes, 1995; Whelan & Barnes-Holmes, 2004, Experiments 2–4).

In this article, therefore, we develop a different approach. By simplifying the procedures, we hope to obtain a better understanding of the role of contextual cues in function transformation. Our procedures are inspired by the hypothesis that through a Pavlovian process, contextual cues can become functionally equivalent to the stimulus relations with which they are paired (see Tonneau, 2001). If this hypothesis (which we explain below in more detail) is correct, then it should be possible to produce function-transformation effects through stimulus pairing instead of stimulus matching, hence, in the absence of selection responses and of their operant reinforcers.

## EXPERIMENT 1

An initial step toward documenting function transformation through stimulus pairings is to show that preexposure to a particular relation between two stimuli, A and B, can modify behavior with respect to a third stimulus, C. In Experiment 1, we exposed college students to a relation of identity or difference, and asked them to write a color name in the presence of a target color such as red. We assumed that preexposure to a relation of identity would bias responding toward the name of the target color (“red”), whereas preexposure to a relation of difference would bias responding toward another name. The experiment was

presented as a guessing game about balls hidden in boxes.

## METHOD

### *Subjects*

Ten students (age range: 18 to 23 years) participated as subjects. They were recruited in an introductory course on the history of psychology and had no knowledge of behavior analysis. Five subjects were randomly assigned to each of two experimental conditions, *Same* and *Different*. The subjects were debriefed collectively once the series of experiments was over.

### *Apparatus and Setting*

Each subject worked individually in a small, quiet room equipped with a laptop computer, a table, and a chair. Stimuli were presented via the computer’s monitor (1024 by 768-pixel resolution) and responses were made on the keyboard. Experimental events were controlled and recorded with a program written in Delphi 5.0™.

### *Procedure*

The experimenter led each subject to the room where the computer was located. Once the subject sat at the table, the experimenter read the following instructions, which were present on the monitor at the start of the session (in this article, all instructions and prompts have been translated from Spanish):

Hello! Thanks for participating. This experiment is not a test of intelligence or personality. This is a study about behavior in general, and your task is simple. You’ll need to watch the screen carefully. The computer will show you colored balls and also boxes that may be open or closed. From time to time, you’ll need to guess what color is inside a box. You’ll need to write your response in a frame like this one:



and press ENTER so that the computer registers your response. The computer will NEVER tell you whether your response is correct or not. You’ll need to guess. The experiment will last about 10 minutes. Press the space bar to start.

The experimenter responded to any uncertainty by re-reading the relevant portions of

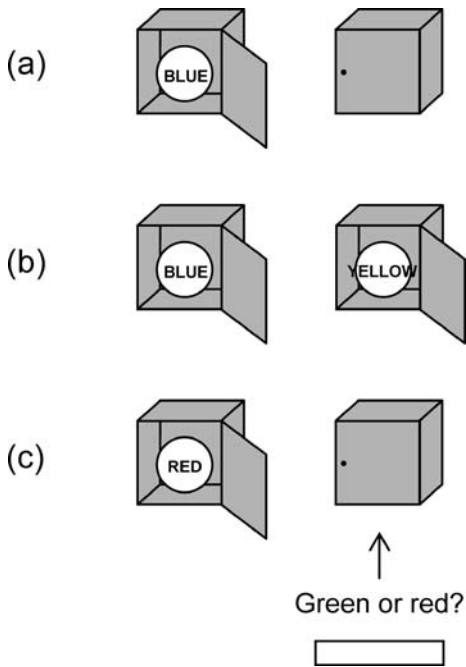


Fig. 1. Panels (a) and (b): Example of a relational trial from Experiment 1. Panel (c): Example of a test trial. In the experiment, the front panel of each box occupied  $2 \times 2$  cm, each ball was 1 cm in diameter, and the color names were replaced by actual colors. See text for more details.

the instructions, and left the room when the subject pressed the space bar. The experiment, completed in a single session that was only a few minutes long, was composed of four cycles. Each cycle was composed of two relational trials followed by two test trials, for a total of eight test trials.

Each relational trial started with a row of two boxes at the center of the screen. The box on the left was open, showing a colored ball inside it, whereas the box on the right was closed (Figure 1, panel *a*). After 2 s, the door of the latter opened to reveal a colored ball (Figure 1, panel *b*). The boxes and the balls remained visible for 5 s. Then the screen went blank for a 2-s intertrial interval.

In the *Same* condition, the balls of the relational trials were of the same color: On each cycle, one trial showed two blue balls and one trial showed two yellow balls. In the *Different* condition, the balls of the relational trials were of different colors: On each cycle, one trial showed a blue ball on the left and a yellow ball on the right (as in Figure 1, panel

*b*), and one trial showed a yellow ball on the left and a blue ball on the right. In either condition, relational trials were scheduled in one order on a random half of the cycles, and in the inverse order on the other half.

Each test trial presented an open box on the left and a ball inside it that was either green or red (Figure 1, panel *c*). The box on the right was closed, and a prompt under it, with an arrow pointing to this box, asked "Green or red?". The subject could type his or her response in a rectangular frame 0.5 cm below the prompt. When the subject pressed the ENTER key, the screen went blank for a 2-s intertrial interval.

In either condition and on each cycle, one test trial showed a green ball and one test trial showed a red ball (as in Figure 1, panel *c*). The order of the test trials on each cycle was random. We shall call the color of the ball visible in the left box the *target color*, and the name of this color, the *target name*. The issue of interest is whether the relations of identity or difference shown on the relational trials affected responding to the target color on test trials.

## RESULTS AND DISCUSSION

No subject ever typed a response other than "green" or "red" on test trials. Figure 2 shows how many times each subject typed the target name in response to the prompt. In the *Same* condition (gray bars), the number of target names averaged 7.60 across subjects. In the *Different* condition (white bars), this number averaged 0.40. A permutation test based on 10,000 random partitions of ten subjects in two groups of five (Edgington, 1995) gave a two-tailed P-value of .008 for the observed difference of 7.20 between the average numbers of target names in the two conditions.

The data of Figure 2 imply that the subjects mostly answered "red" to red and "green" to green after being exposed to stimulus identity, but mostly answered "green" to red and "red" to green after being exposed to a relation of difference. This result must be attributed to the relational aspects of the procedure, because the *Same* and *Different* conditions were equalized in terms of the individual stimuli presented on each pair of relational trials (two blue balls, two yellow balls).

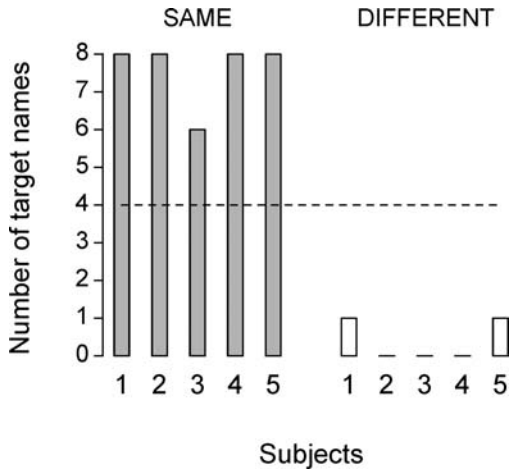


Fig. 2. Number of target names per subject in each condition of Experiment 1. Gray bars represent the data for subjects in the *Same* condition. White bars represent the data for subjects in the *Different* condition. The dashed horizontal line indicates indifference with respect to the target name.

An account of these findings can be given in terms of function transfer through stimulus correlations (see Tonneau, 2001). Consider the subjects who answered “green” to red in the *Different* condition, for example. Clearly, their behavior depended not only on the target color of the test trial (red), but also on the relation of difference present on previous trials, a result consistent with short-term memory findings in humans and nonhumans (e.g., McCarthy & White, 1987; Norman, 1966; Wickelgren, 1967). Accordingly, we assume that these subjects’ behavior was influenced by the *sequence* <different, red> (see White, 1974; Wixted, 1989). Our second assumption deals with preexperimental histories and their role in function transfer. We assume that the subjects previously had observed green and red objects in succession (which happens many times in daily life). A person sensitive to the relation of difference and shown a pair of objects, one green and one red, is actually exposed to a three-element stimulus compound (different, red, and green), in which the compound <different, red> is associated spatially and temporally with the color green. Due to this strong preexperimental correlation, in our study the behavioral effects of <green> should have transferred to <different, red>, explaining why the subjects in the *Different* condition typed “green” in the presence of red. A similar analysis applies to

the subjects’ typing “red” in the presence of green.

By contrast, the data in the *Same* condition are ambiguous. The subjects who answered “green” to green, for example, might have reacted to the sequence <same, green>, in which case their results involved the transfer of the response “green” from <green> to <same, green> due to the regular pairing of these components in any group of green objects. Alternatively, these subjects might not have been reacting to <same, green> at all and no function transfer was involved; rather, the subjects might just be naming the current color. Because Pavlovian conditioning of <green> to <same, green> and direct control by the test color lead to the same performance (typing “green” in the presence of green), the data in this condition cannot discriminate relational from nonrelational accounts. The data from the *Different* condition, however, in which the responses to the test colors were inverted (see Figure 2), clearly reveal a role for relational variables (such as <different, green>) and their correlation with other stimuli.

## EXPERIMENT 2

Experiment 1 documented a new finding (the modification of behavior through response-independent exposure to stimulus relations) but did not demonstrate function transformation. No stimulus A was shown to have acquired a behavioral function by association to a stimulus B and a contextual cue X formerly paired with a relation R. Experiment 2 provides this demonstration. We used a cue, X, that we thought would be especially salient: relative position on the screen. A stimulus was paired with a color in a position previously paired with identity, whereas another stimulus was paired with the same color in a position previously paired with difference. If this pairing arrangement produces function transformation, then the responses to the two stimuli should differ.

## METHOD

### *Subjects*

Eight students (age range: 17 to 32 years) recruited in the same introductory course participated as subjects.

*Apparatus and Setting*

Same as in Experiment 1.

*Procedure*

The instructions were identical to those of Experiment 1. The experimental session comprised six cycles. Each cycle started with a single relational trial, followed by a single pairing trial, followed by two test trials.

Each relational trial started with two columns of two boxes at the center of the screen (Figure 3, panel *a*). The two boxes on the left were open, showing two balls of the same color, either blue or yellow; the two boxes on the right were closed. After 2 s, the boxes on the right opened, each revealing one ball (Figure 3, panel *b*). The color of one of the balls on the left, whereas the color of the other ball (call it the *odd ball*) differed. The row of the odd ball (either the upper or the lower row) will be referred to as the *DIFFERENT* row; the other row will be referred to as the *SAME* row. In Figure 3, panel *b*, for example, the odd ball is yellow, the *DIFFERENT* row is the upper row, and the *SAME* row is the bottom row. The four boxes and their balls remained visible for 7 s, after which the screen went blank for a 2-s intertrial interval.

On each pairing trial, the computer showed two columns of two boxes (Figure 3, panel *c*). The two boxes on the left were open, each with a ball inside it. These two balls always were of the same color (either green or red); their color will be referred to as the *target color*. The two boxes on the right were closed. One of them bore a diagonal line on its door; the other bore an asterisk. The two open boxes on the left, the two balls on the left, and the two closed boxes on the right remained visible for 9 s, after which the screen went blank for a 2-s intertrial interval.

On each test trial, the computer presented a closed box, either with the diagonal line or with the asterisk on its door, alone at the center of the screen. Thus, the box was removed from its previous pairing location, and testing always took place in the center of the screen. As in Experiment 1, a prompt below the box asked "Green or red?". The subject wrote his or her guess in the frame below the prompt and pressed the ENTER key,

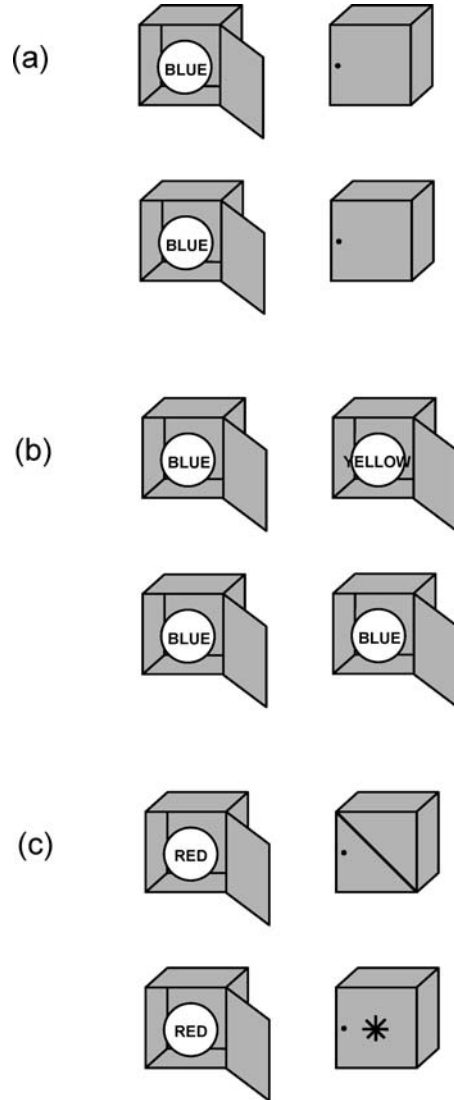


Fig. 3. Panels (a) and (b): Example of relational trial from Experiment 2. Panel (c): Example of pairing trial from Experiment 2. Same conventions as in Figure 1.

after which the screen went blank for a 2-s intertrial interval.

During the experiment and for each subject, one random half of the six cycles involved a relational trial with three blue balls and one yellow ball (as in Figure 3, panel *b*); the other random half of the cycles involved a relational trial with three yellow balls and one blue ball. For any given subject, the odd ball was either in the upper or in the lower row, the box with the diagonal line was either in the upper or in the

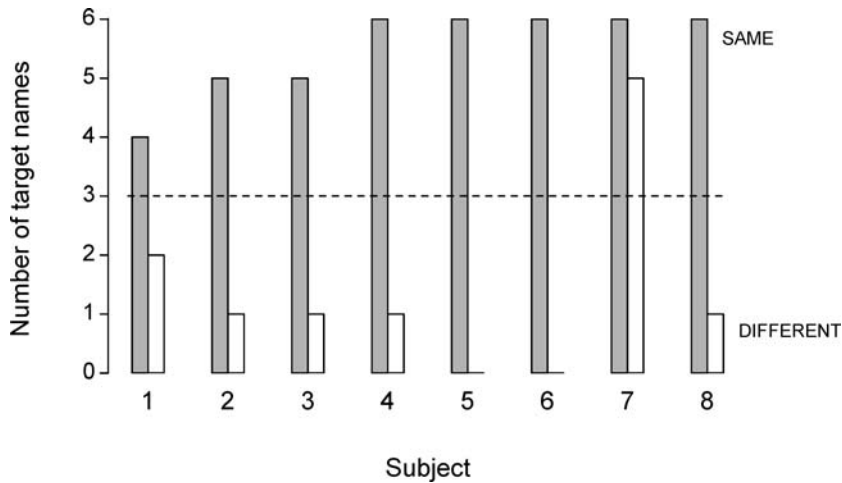


Fig. 4. Number of target names per subject and stimulus in Experiment 2. Gray bars represent the responses to the stimulus paired with the target color in the SAME row. White bars represent the responses to the stimulus paired with the target color in the DIFFERENT row. The dashed line indicates indifference with respect to the target name.

lower row, and the target color was either green or red. Combining these three variables (row of the odd ball, row of the diagonal line, and target color) factorially gave eight versions of the experiment; each version (1, 2, 3, 4, 5, 6, 7, 8) was randomly assigned to one of the 8 subjects.

The order of the test trials on each cycle was fixed: first the diagonal line, then the asterisk. The issue addressed in this experiment was whether the correlation of the upper and lower rows with identity or difference altered, within these rows, the effect of pairing the test stimuli with the target color. We expected the name of the target color to be given more frequently in response to a stimulus paired with this color in the SAME row than in response to a stimulus paired with this color in the DIFFERENT row.

#### RESULTS AND DISCUSSION

No subject ever typed a response other than “green” or “red” during testing. Figure 4 shows how many times each subject typed the target name in response to the stimuli that were paired with the target color in the SAME or in the DIFFERENT row. All subjects named the target color more often when stimulus pairing took place in the SAME row (gray bars) than when stimulus pairing took place in the DIFFERENT row (white bars). The probability of obtaining data as extreme by chance is about .008 (two-tailed binomial test across subjects with  $p = .50$  and  $N = 8$ ).

Also, all subjects typed the target name more than three times in response to the stimulus from the SAME row, with a number of target names that averaged 5.5. By contrast, 7 subjects out of 8 typed the target name *less* than three times in response to the stimulus from the DIFFERENT row, with an average number of target names (1.375) significantly lower than 3,  $t(7) = 2.876$ ,  $P = .024$  (two-tailed). Thus, the results for the stimulus paired with the DIFFERENT row cannot plausibly be explained by assuming that this stimulus failed to acquire any function, and that the subjects responded to it randomly. Rather, the subjects tended *not* to type the target name in response to this stimulus.

The test data of Figure 4 are analogous to the function-transformation effects observed in some RFT studies (e.g., Whelan & Barnes-Holmes, 2004, Experiment 1). In this experiment, an arbitrary stimulus paired with the target color on the SAME row (a contextual cue correlated with identity) acquired the behavioral functions of the target color, whereas an arbitrary stimulus paired with the target color on the DIFFERENT row (a contextual cue correlated with difference) acquired a *different* function.

As in Experiment 1, a Pavlovian account of these results is possible (Tonneau, 2001). Assume, for example, that the diagonal line was paired with the target color red on the DIFFERENT row. Presumably, this row and the

relation of difference were functionally equivalent with respect to later conditioning (e.g., Dwyer, 2000; Dwyer *et al.*, 1998; Hall, 1996), due to their spatial and temporal association on the relational trials. Therefore, pairing the diagonal line with <DIFFERENT row, red> should have had the same behavioral effect as pairing the diagonal line with <different, red>; and, we know from Experiment 1 that <different, red> and <green> are functionally equivalent (see Figure 2). Therefore, typing “green” should have transferred to the diagonal line (Tonneau, 2001, pp. 121–123), as was observed. A similar account applies to the other stimulus combinations tested in this experiment.

As in Experiment 1, the results for the DIFFERENT row (in which the responses observed in testing *differed* from those predicted by a direct pairing account) are crucial for uncovering the role of relational variables. The results for the SAME row might just as well be attributed to function transfer from a non-relational stimulus, namely, the target color present on the pairing trial (e.g., Tonneau & González, 2004).

### EXPERIMENT 3

Although the data of Experiment 2 are consistent with function transformation, one issue should be addressed. That the subjects avoided the target name in response to the test stimulus from the DIFFERENT row might have been due in part to a process of exclusion. In studies of exclusion (e.g., Wilkinson, Dube, & McIlvane, 1998), subjects tend to choose a novel comparison in the presence of a novel sample, provided that the alternative comparisons have been associated previously with alternative samples (e.g., Clement & Zentall, 2003). A similar phenomenon might have operated in Experiment 2; a subject who typed the target name in response to a test stimulus might have excluded this option when responding to the other test stimulus. Why the former stimulus should always have been the stimulus from the SAME row (see Figure 4) is unclear on this account, but the issue seemed worth checking.

Accordingly, in Experiment 3 all subjects were tested with only one stimulus (the asterisk), so that exclusion could not operate during testing. The procedure was otherwise identical to that of Experiment 2, and the

relational and pairing trials still involved the asterisk and the diagonal line. For half of the subjects (corresponding to the odd-numbered versions of the experiment), the asterisk was paired with the target color on the SAME row, whereas for the other half (versions 2, 4, 6, 8), the asterisk was paired with the target color on the DIFFERENT row. We expected responding to the asterisk to differ among these two groups of subjects.

The instruction from the previous experiments was adjusted slightly because computing the proportion of errors across subjects and as a function of cycle number showed that this proportion increased (Figure 5, top panel, dotted line: Experiment 1) or oscillated (Figure 5, top panel, solid line with triangles: Experiment 2) near the end of the session. Also, one subject from Experiment 2 commented that he was probably “doing something wrong” because “the computer kept asking the same questions.” That the test trials of Experiment 3 had only one stimulus instead of two might have further increased the subjects’ tendency to alter their behavior as the test trials recurred without feedback. Hence, we inserted a few words of warning (“The computer will always ask you the same question. Don’t worry, this is okay.”) in the instruction, right after “You’ll need to guess.”

### METHOD

#### *Subjects*

Eight students (age range: 18 to 26 years) recruited in the same introductory course participated as subjects.

#### *Apparatus and Setting*

Same as in Experiment 2.

#### *Procedure*

With the exception of the additional line in the instruction (see above) and the fact that each cycle involved only one test trial (with the asterisk as a test stimulus), the procedure was identical to that of Experiment 2.

### RESULTS AND DISCUSSION

No subject ever typed a response other than “green” or “red” during testing. The bottom panel of Figure 5 (solid line with squares)

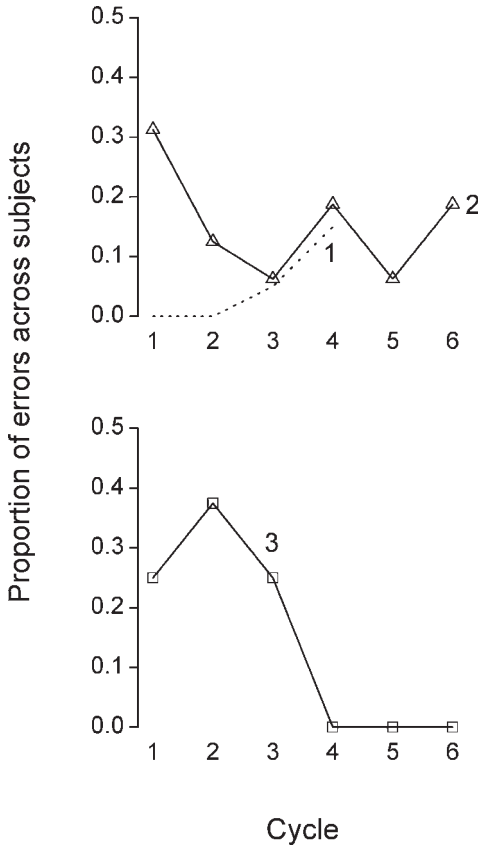


Fig. 5. Proportion of errors pooled across subjects in each cycle of Experiment 1 (top panel, dotted line), Experiment 2 (top panel, solid lines with triangles), and Experiment 3 (bottom panel, solid lines with squares).

shows the proportion of errors across subjects and as a function of cycle number. After reaching its maximum on cycle 2, the proportion of errors decreased and no error occurred on cycles 4 to 6, consistent with what we expected from the adjusted instruction.

Figure 6 shows how many times each subject wrote the target name in response to the asterisk when paired with the target color in the SAME row (subjects 1, 3, 5, 7) or when paired with the target color in the DIFFERENT row (subjects 2, 4, 6, 8). In the former condition (gray bars), the number of target names averaged 5.50 across subjects. In the latter condition (white bars), this number averaged 1.25. A permutation test based on 10,000 random partitions of 8 subjects in two groups of 4 gave a two-tailed *P*-value of .03 for the observed difference of 4.25 between the

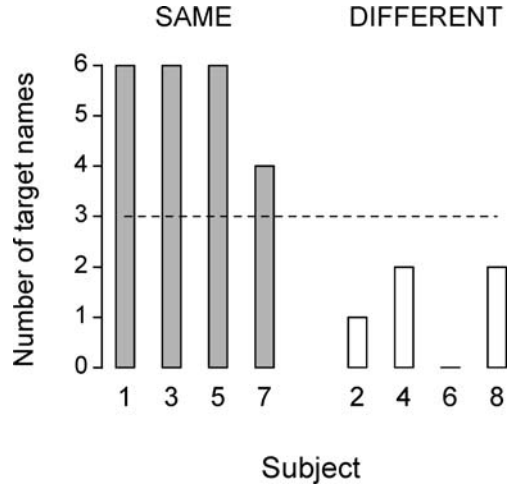


Fig. 6. Number of target names per subject in Experiment 3. Gray bars represent the data for the subjects in the odd-numbered versions of the experiment, for whom the test stimulus came from the SAME row. White bars represent the data for the subjects in the even-numbered versions of the experiment, for whom the test stimulus came from the DIFFERENT row. The dashed line indicates indifference with respect to the target name.

average numbers of target names in the two conditions. Thus, as in Experiment 2, the relation of sameness or difference modulated the effect of stimulus pairing on test performance.

To confirm that the target name was actually selected or avoided, depending on whether stimulus pairing occurred in the SAME or in the DIFFERENT row, Experiment 3 was replicated with 8 additional subjects (age range: 18 to 31). In this replication, the subjects in the odd-numbered versions of the experiment (corresponding to pairing in the SAME row) typed the target name 6, 6, 4, and 2 times, whereas the subjects in the even-numbered versions (corresponding to pairing in the DIFFERENT row) typed the target name 1, 1, 2, and 3 times. Pooling the data across the initial experiment and its replication, 7 subjects out of 8 typed the target name *more* than 3 times when the asterisk came from the SAME row, and the average number of target names (5) in this condition was significantly higher than 3,  $t(7) = 3.742, P = .007$  (two-tailed). By contrast, when the asterisk came from the DIFFERENT row, 7 subjects out of 8 typed the target name *less* than 3 times, and the average number of target names (1.5) in this condition

was significantly lower than 3,  $t(7) = 4.583$ ,  $P = .002$  (two-tailed).

Thus, the current data confirm what was observed in Experiment 2, while eliminating exclusion as a possible account of the findings. As in Experiment 2, the difference among conditions must be attributed to relational aspects of the stimulus-presentation schedule, because the SAME and DIFFERENT rows were equalized in terms of the colored stimuli they contained (two blue balls and two yellow balls per cycle pair).

## GENERAL DISCUSSION

*Summary of the results.* Two novel findings are documented here. The first finding (Experiment 1) is that exposure to a relation of identity or difference between two stimuli, A and B, can modify performance with respect to another stimulus, C. No selection responses were required or reinforced, and the results cannot be explained in terms of formal stimulus generalization from A or B to the test stimulus C, because all individual stimuli were equalized across conditions. Although this experiment does not document function transformation, it suggests that the effects of stimulus relations on human performance can be pervasive as well as nonobvious.

The second finding (Experiments 2 and 3) is that whereas a stimulus, A, paired with a target, B, and a cue correlated with identity acquires the functions of B; a stimulus, A, paired with B and a cue correlated with difference acquires functions that *differ* from those of B. This finding is the first reported case of function transformation (as distinct from mere function transfer) obtained without training selection responses and without programming reinforcement. Irrespective of the logical flaws with RFT accounts (see above), our results contribute to an experimental analysis of relational-frame procedures by suggesting that operant reinforcement is not necessary to the occurrence of function-transformation effects. More generally, the present results call for a detailed evaluation of the role of nonoperant variables in function transformation.

*Procedural issues.* To design our procedures, we simply replaced the matching relations of RFT experiments (e.g., Dymond & Barnes, 1995) by stimulus pairings. In Experiments 2 and 3, for example, the target and test

stimuli A and B were paired, not matched, with a contextual cue X that was itself paired, not matched, with a relation of difference or identity. Such pairing procedures may provide a valuable alternative to the complex operant arrangements of RFT. In Experiment 1 by Whelan and Barnes-Holmes (2004), for example, 2 subjects out of 5 were excluded after they failed various probes (p. 185), and sessions were at least 30-min long; the duration of relational training phases, although not reported, presumably exceeded 5 min. By contrast, our Experiments 2 and 3 produced function transformation in 7 subjects out of 8 in 5 min at most. For the few subjects who showed function transformation in only one cycle (e.g., Subject 6, Experiment 3), the effective duration of training was less than 25 s.

We suspect that the effectiveness of the current procedures derives from the use of salient and memorable contextual cues (positions on the screen). These cues could be used in more complex designs analogous to indirect matching to sample (AB, BC, etc). By showing rows of boxes with varying numbers of balls inside them, for example, the modulation of pairing effects by numerical relations (less-than, more-than, etc.) could be studied (cf. Dymond & Barnes, 1995). With increasingly complex stimulus arrays, however, operant tasks such as matching to sample may become a practical necessity. By making reinforcement dependent on controlling relations between environment and behavior, these tasks guarantee that the subjects attend to the experimenter-specified properties of stimuli, whereas Pavlovian procedures offer no such warrant.

*A nonoperant explanation of function transformation.* Experimental research with nonhuman species has long shown the relevance of Pavlovian correlations to the stimulus control of operant behavior (e.g., Rescorla & Solomon, 1967). Transfer tests with separately trained operant performance often can be used to reveal the effects of such stimulus correlations (e.g., Delamater, 1996; Rescorla, 2000). Starting from this experimental background and from the fact that stimulus pairings promote functional equivalence (Hall, 1996), it is only a small step to develop a general explanation of function transfer in terms of Pavlovian correlations.

The proposed account includes Pavlovian conditioning *stricto sensu* (Gormezano & Kehoe, 1975) as a case of function transfer in which the eliciting functions of the unconditional stimulus transfer to the conditional stimulus. Other functions susceptible to transfer through stimulus correlations, however, include operant and Pavlovian reinforcement as well as occasion setting (Tonneau, 1993). The present account is therefore a general one, in the sense that *any* behavioral function, operant or otherwise, is assumed to be sensitive to stimulus correlations. Because such correlations appear to promote function transfer independently of the operant/respondent dichotomy, from our perspective it becomes less important to classify a function as “operant” or “respondent” than to identify its environmental sources of transfer (Turkkan, 1993). Similarly, and consistent with documented cases of sensory and higher-order preconditioning (e.g., Barnett, Cole, & Miller, 1997; Pfautz, Donegan, & Wagner, 1978; Rizley & Rescorla, 1972), our account takes networks of stimulus correlations as fundamental independent variables, and does not require a response to occur in the presence of all of the stimuli involved in a network. If a response, R, is evoked by a stimulus compound, XA, for example, then R may transfer to XB through a network of indirect pairings (e.g., AC, CB) without ever being emitted in the presence of A, C, or B alone.

Here we extend this proposal to function-transformation effects. Although a detailed theoretical explanation of function transformation may appear challenging (Tonneau, 2001, pp. 121–123), the idea behind our explanation can be stated simply: *a stimulus paired with a relation becomes a functional substitute for this relation*, alone or in compound with other stimuli. Thus, pairing a stimulus A with X and B, where B is another stimulus and X a cue associated with <difference>, is functionally equivalent to pairing A with <different, B>, which in turn is functionally equivalent to pairing A with any stimulus associated with <different, B>, that is, *any stimulus actually different from B*. On this account, “function transformation” is not a basic behavioral process at all, but only a by-product of function transfer and compounding with relational stimuli.

*Relations as stimuli.* Most of our explanation is uncontroversial. That test responses in

Experiment 1 depended not only on the test color, but also on the stimulus relation shown on previous trials, is clear from the data themselves. That the behavior of human and nonhuman animals can be sensitive to stimulus compounds across time is supported by numerous findings about memory (see Fetterman, Stubbs, & MacEwen, 1992). That the pattern <different, red> is spatially and temporally associated with <green> in any pair of red and green objects is equally uncontroversial; the life of any normal adult may comprise thousands of such pairings. Our other assumptions about functional equivalence and stimulus compounds receive independent support from Pavlovian research (see above and Dwyer, 2000; Hall, 1996; Holland, 1990).

To accommodate the present findings, we need only one additional assumption: namely, that relations of identity and difference can serve as conditioned stimuli, in the sense that a cue, X, paired with a stimulus relation can become functionally equivalent to this relation. We are unaware of nonhuman findings that would provide unambiguous support for this hypothesis. However, results from Miller and colleagues (for reviews see Arcediano & Miller, 2002, and Savastano & Miller, 1998) suggest that *temporal* relations between stimuli can be part of the stimulus complex to which behavior is conditioned. If this interpretation is correct, then at least one case of Pavlovian conditioning to stimulus relations has been documented in nonhuman animals. The ability to display Pavlovian conditioning to other, nontemporal types of stimulus relations may be typical of *Homo sapiens*, however, and may represent a parametric difference among species. In any event, our account appeals to a particular type of conditioned stimulus, but the underlying processes are supposed to be shared with nonhuman animals.

*Implications for research on complex human behavior.* Our account predicts the data reported here, but only under the assumption that the subjects actually are sensitive to the formal stimuli and relations being manipulated. The stimuli must of course be attended to (see above), and the formal properties of the patterns presented by the experimenter must match those that actually control behavior. Currently we rely on intuition, common sense, or pilot work to guess what stimulus format

(e.g., Figure 1) is more likely to make the manipulated relations sufficiently salient. Theorists of all persuasions, however, should eventually develop noncircular principles to predict which formal stimuli also will be functional stimuli (Gibson, 1960). Pavlovian research on overshadowing and blocking (Kamin, 1968) shows that the occurrence of stimulus control cannot be predicted without taking previous stimulus correlations into account.

Aside from difficulties in identifying functional stimuli, our account could be strengthened if specific Pavlovian predictions (with respect to temporal parameters, for example) were shown to apply to function transformation. A methodological difficulty with this proposal is that in function-transformation procedures the temporal parameters of individual stimuli and stimulus relations are confounded, so that crucial tests are hard to devise. Another difficulty is that despite some encouraging results (e.g., Arcediano, Escobar, & Miller, 2003), humans and nonhumans may differ in terms of strength of sensory preconditioning and sensitivity to temporal variables.

Finally, in the case of human subjects previous verbal repertoires may interact with Pavlovian variables to influence current results. However, verbal behavior may itself involve Pavlovian components (Tonneau & Sokolowski, 1997; Turkkan, 1989; Yoon & Bennett, 2000), so the nature of the relation between the former and the latter is far from simple. Meanwhile, Pavlovian explanations of function transfer and apparent function-transformation effects provide a parsimonious theoretical baseline against which more complex hypotheses may be compared.

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Received: June 15, 2005

Final acceptance: January 3, 2006