Psychol Rec (2016) 66:165–175
DOI 10.1007/s40732-015-0161-0

ORIGINAL ARTICLE

Effects of Successive and Simultaneous Stimulus Presentations on Absolute and Relational Stimulus Control in Adult Humans

Adam Derenne[1] · **Anthony M. Garnett**[1]

Published online: 4 January 2016

Abstract Human participants can readily learn to demonstrate absolute or relational stimulus control, but little is known about human's tendencies toward one form of control or another in situations that allow either form of control to be expressed. To examine these tendencies, we combined elements of the procedures used to study peak shift and stimulus transposition. In Experiment 1, half of the 40 participants received successive discrimination training and the other half received simultaneous discrimination training with line-length stimuli. All participants then received both a generalization test and a transposition test. Absolute stimulus control predominated except under the combination of simultaneous discrimination training and a transposition test. In Experiment 2, 40 additional participants were trained with 2 pairs of training stimuli instead of 1 in what was otherwise an identical procedure. The results suggested a shift toward relational control. A novel form of relational control was observed in some participants (chiefly those who received successive discrimination training) that involved selective stimulus transposition. Specifically, participants selected the stimulus that matched the relation of S+ to S-, but only when both test lines were similar to the S+s.

Keywords Stimulus control · Generalization · Transposition · Peak shift

✉ Adam Derenne
adam.derenne@email.und.edu

[1] Psychology Department, University of North Dakota, P.O. Box 8380, Grand Forks, ND 58202-8380, USA

Stimuli have multiple properties, and responding has the potential to be controlled by one or more properties of a stimulus but not others. One well-known distinction in how stimulus control is expressed is that of absolute stimulus control versus relational stimulus control. Absolute control is when responding depends on some intrinsic characteristic of a stimulus. For example, if the stimulus of interest is a line of particular length, absolute control would be evinced by a pattern of responding to lines of a matching length (or similar lengths due to stimulus generalization). Relational control is when responding is controlled by a relative characteristic of a stimulus. For example, in the case of line lengths, responding might occur in the presence of all relatively long lines.

Research on absolute and relational stimulus control spans decades, and within this literature much of the concern has been with the factors affecting the acquisition of a particular form of control (e.g., Hauf, Prior, & Sarris, 2008; Lazareva, 2012; Moll & Nieder, 2014; Reese, 1968; Riley, 1968; Wills & Mackintosh, 1999). A subject that has been little explored, especially with normally functioning adult humans, concerns which form of control will prevail in situations that allow either form of control to be expressed, and the reasons why one form of control should take precedence over another in those situations. Consider the typical methods used to study peak shift and stimulus transposition. In both cases, participants first receive discrimination training with one stimulus paired with reinforcement (S+) and a second stimulus paired with the absence of reinforcement (S-). For example, S+ might be a 10-cm-long line, and S- a 7-cm-long line. Participants may perceive that S+ has both absolute characteristics (it is 10 cm in length) and relational features (it is relatively long), but the procedure does not allow them to determine which feature makes S+ the line that should be selected. The methods used to study peak shift and stimulus transposition both include a test of stimulus control that encompasses a wider variety of stimuli (in the example, the test would include a wider variety of line lengths). At times, the test forces participants to express only one form of control. That is, participants might respond whenever a line is shown that appears to match S+ in length (thus evincing absolute control), or they might respond to all line lengths that match the relative difference between the stimuli (thus evincing relational control), but they cannot consistently do both. Participants do not receive feedback after making a response. Therefore, the tasks can be viewed as a vehicle for exploring participants' tendency toward absolute and relational stimulus control in what is (from the participant's perspective) a somewhat ambiguous situation (cf. Johnson & Zara, 1960).

A key procedural detail that has been omitted so far concerns how the stimuli are presented. In the case of research on peak shift, it is customary to present a single stimulus on each training and testing trial, while in the case of research on stimulus transposition, it is customary to present two stimuli on each trial. Although participants might perceive that S+ has absolute and relative features under either method, the stimulus presentation mode nevertheless appears to be important. Studies of peak shift characteristically produce absolute stimulus control, and studies of transposition characteristically produce relational stimulus control. Possibly the manner in which stimuli are presented to participants is the single most important factor determining which form of stimulus control is expressed (more on this below).

Evidence for absolute control in research on peak shift comes from the distribution of responses emitted during the test. Typically, this distribution takes the form of a generalization gradient with a peak (or modal response) centered on one test stimulus (see Fig. 1, left panel). One might expect the peak to align with S+, but often the peak of the gradient, and/or the area under the gradient, is displaced somewhat away from S+ and toward stimuli even more dissimilar to S- (hence, respectively, the terms "peak shift" and "area shift"; for recent examples, see Bizo & McMahon, 2007; Derenne, Loshek, & Bohrer, 2015; Dunsmoor & LaBar, 2013; Miller, Reed, & Critchfield, 2015; Verbeek, Spetch, Cheng, & Clifford, 2006; Wisniewski, Church, & Mercado, 2009).

Single stimulus presentations prohibit a direct comparison between the stimuli and therefore limit the potential for relational control. However, indirect comparisons can still be made. For example, participants could base responses on whether line lengths are relatively short or long in reference to some criterion that is not overtly present. Rather than a peaked gradient, the distribution of responses would resemble an elevated plateau on one end of the stimulus set (see Fig. 1, right panel). There is evidence for this kind of relational responding in the literature (for examples and discussion, see Capehart, Tempone, & Hebert, 1969; Galizio, 1980; Howard, 1979; Livesey & McLaren, 2009; Reichert & Kelly, 2012; Spetch & Cheng, 1998). Sometimes this control is likened to a decision rule (Livesey & McLaren, 2009), and at other times it has been described in terms of categorical decision making (Spetch & Cheng, 1998). On the whole, however, this is a phenomenon that has been little discussed in relation to peak shift and about which little is known.

Evidence for relational control in research on transposition comes from the choices participants make on each test trial. Consider a case in which S- is a 7-cm line and S+ is a 10-cm line. On a test trial with an 11-cm line and a 12-cm line, absolute control would be evidenced by a response to the 11-cm line (it is the line length most similar to S+), and relational control would be evidenced by a response to the 12-cm line (it is the longer of the two lines). (Not all possible transposition test trials are so revealing; if the test lines were 8 cm and 9 cm, a selection of the 9-cm line would be consistent with both absolute and relational control). Relational control is inferred if the frequency of responses that match the relationship of S+ to S- exceeds the level predicted by chance (for recent examples, see Henderson, Hurly, & Healy, 2006; Lazareva, Miner, Wasserman, & Young, 2008; Leighty, Grand, Pittman Courte, Maloney, & Bettinger, 2013; Manabe, Murata, Kawashima, Asahina, & Okutsu, 2009; Wiegmann, Wiegmann, Macneal, & Gafford, 2000; Yamazaki, Saiki, Inada, Iriki, & Watanabe, 2014). Absolute control can be inferred from an absence of relational control, but it can also be directly evidenced by the distribution of responses. Unless participants are forced to choose one of the two test stimuli on each trial, the distribution of responses should resemble the generalization gradients found in studies of peak shift.

Several authors have suggested (Mackintosh, 1983; Mazur, 2006; Riley, 1968; Zeiler, 1964) that the absolute characteristics of S+ become most salient when S+ and S- are presented at different times (as commonly occurs in studies in peak shift), and the relative characteristics of S+ become most salient when S+ and S- are presented at the same time (as commonly occurs in studies of transposition). This hypothesis about the effects of stimulus saliency might provide a simple answer to the question of how human participants choose which form of stimulus control to express, namely, whichever characteristic of S+ is most salient during discrimination training will determine which form of control is expressed during the test.

However, it is an open question how adequate stimulus saliency is as an explanation for behavior. With nonhumans, findings have been inconsistent. In the case of research on peak shift, for example, there are cases of pigeons being given simultaneous discrimination training prior to receiving a standard (single stimulus per trial) generalization test (Winton, 1975; Winton & Beale, 1971). Although the saliency hypothesis predicts that the relative difference between S+ and S- was most salient during training, research has not shown this alteration in the method to produce a diminishment in absolute control (however, the alteration may be impactful in other

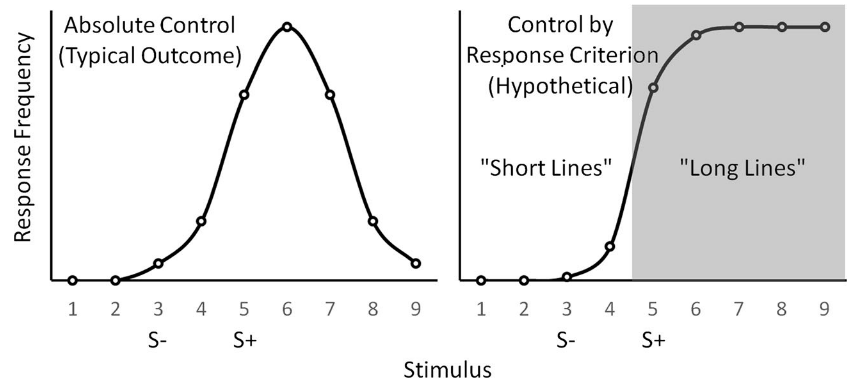

Fig. 1 Possible distributions of responses accompanying absolute stimulus control (left) and relational stimulus control (right) on a single-stimulus generalization test

ways; see, for example, Zentall & Clement, 2001). In the case of research on transposition, there are cases of pigeons being given successive discrimination training prior to receiving a standard (two stimuli per trial) transposition test. Here the stimulus presentation mode does seem to matter, but results have been inconsistent. For example, Baker and Lawrence (1951) found that rats trained on a simultaneous basis made few errors when transposing the relation between two circles to a second pair of exemplars, while rats trained on a successive basis displayed a weak form of absolute control. However, Riley, Ring, and Thomas (1960) found that rats can learn to transpose with lights of varying brightness, regardless of how the stimuli are presented, although transposition occurred more frequently when simultaneous training was used.

Perhaps the most complete test of stimulus saliency effects with these methods is a study by Honig (1962), in which different groups of pigeons received successive or simultaneous discrimination training using lights of different hues, and then all subjects received a test that included a mixture of single-stimulus and double-stimulus presentations. Unexpectedly, absolute stimulus control was the sole result, possibly because exposure to single-stimulus test trials interfered with the expression of relational control (Riley, 1968).

To explore how humans' tendency toward expressing absolute or relational stimulus control is affected by the manner in which stimuli are presented, we conducted two experiments based on Honig's procedure. In Experiment 1, different groups of participants received either successive or simultaneous discrimination training, and all participants received single and double test trials (in other words, both a generalization test and a transposition test were administered). However, the method was altered from Honig's experiment to explore the possibility that exposure to single-stimulus test trials would interfere with the expression of relational control on double-stimulus test trials. Specifically, the generalization test and transposition test occurred at different times in a sequence that was counterbalanced within each training condition, thus allowing for interference when the single-stimulus generalization test preceded the double-stimulus transposition test, but not when the reverse sequence was used. Experiment 2 was similar, except that two S+s and two S-s were used during discrimination training, allowing two different pairs of stimuli to be presented to participants. Within the stimulus transposition literature, the use of multiple training pairs is an effective means of enhancing relational control (cf. Lazareva, 2012). We sought to determine whether the additional stimuli would enhance relational control when the task included both single- and double-stimulus presentation methods.

Experiment 1

Method

Participants

The participants were 40 undergraduate students recruited from lower level courses in psychology (an additional 11 participants were replaced for failing to meet an a priori retention criterion of eight consecutive correct responses during discrimination training). Participants were compensated with extra course credit.

Apparatus

Data were collected with three Dell 425 s/L microcomputers with 13-in. UltraScan monitors. The computers, placed on tables in a small room, were separated from each other by large dividers.

Procedure

Stimuli The stimuli were horizontal lines that varied in length, a dimension that has been used repeatedly to study discrimination training, gradient shift, and stimulus transposition (e.g., Derenne, 2006; Malott, Malott, & Pokrzywinski, 1967; Manabe et al., 2009; Moll & Nieder, 2014). The lines in this case were white and the background was black. The length was defined by the number of consecutive ASCII characters of which the lines were composed (specifically, ASCII character 220). Nine different line lengths were used, composed of 5, 7, 9, 12, 16, 21, 27, 35, and 46 ASCII characters, a selection that approximated a logarithmic progression and that is in keeping with common practice in research on peak shift (Thomas, 1993) and stimulus transposition (Lazareva, 2012). As viewed on the monitors, these lines ranged from 1.6 cm to 15.0 cm in length. The position of the lines on the screen varied randomly with each presentation; however, the lines were always at least 2.5 cm from the edge of the screen.

Design Half of the participants were assigned to a successive discrimination training condition in which a single stimulus (S+ or S-) was presented on each trial; the other half were assigned to a simultaneous discrimination training condition in which both S+ and S- were presented on each trial. All participants received the single and double-stimulus tests; the test order was counterbalanced so that within each training condition half of the participants received the one-stimulus test before the two-stimulus test, and the other half received the two-stimulus test before the one-stimulus test. Ten participants were randomly assigned to each of the four possible combinations of discrimination training condition and test order.

General Experimental sessions lasted approximately 30 min. At the beginning of the session, participants were told that they could earn the equivalent of 1 hr of extra course credit by responding accurately to the stimuli (cf. Critchfield, Schlund, & Ecott, 2000); however, they were not told how to identify S+. Instead, participants were told they would need to determine which characteristics defined S+ through their responses. Participants were also instructed to refrain from responding if they did not see the “correct” stimulus.

Training Phase For all participants, S+ was a line of 16 ASCII characters. As an internal check on the validity of the results, the relative position of S- was counterbalanced within each of the four groups so that in half the cases S- was relatively short (Line 12), and in the other half S- was relatively long (Line 21). Variations in S- commonly produce variations in the gradient. Finding such a well-known effect, in conjunction with research on variables whose effects are not well known, can be used to help determine whether participants were properly sensitive to the experimental procedure.

The response during training and testing varied for trials with one and two stimuli. When one stimulus was shown, participants were instructed to press the spacebar if they believed the stimulus was correct and to make no response if they believed the stimulus was incorrect. When two stimuli were shown, one line appeared in the upper half of the screen and the other in the lower half. Participants were instructed to press keys labeled “top” or “bottom” (these were relabeled keys on a numeric keypad) to indicate which stimulus was correct or to again make no response if neither stimulus was correct.

Training ended when participants made the correct choice on eight consecutive trials (this included making no response if only S- was shown). Participants who failed to meet this criterion within 30 trials were advanced to the test phase and allowed to complete the experiment, but their data were later replaced.

Testing Phase The single-stimulus and double-stimulus tests were organized into cycles of trials. A cycle of single-stimulus test trials included one presentation of each of the nine different line lengths included in the stimulus set (e.g., Lines 5, 7, 9, 12). A cycle of double-stimulus test trials included one presentation of each of the eight pairs of adjacent line lengths in the stimulus set (e.g., Lines 5 and 7, Lines 7 and 9, Lines 9 and 12). The different trials within each cycle were presented to participants in a random order. Participants first received six cycles of trials in one presentation mode (either the single-stimulus or double-stimulus format) and then an additional three cycles of trials in the other presentation mode. The first test included more cycles because performances at the beginning of a generalization test have been found to sometimes differ from performances later in the test (e.g., Thomas, Svinicki, & Vogt, 1973). We were prepared to omit the initial cycles from the analysis for this reason, but close examination of the data showed no systematic differences between cycles, and therefore all of the data are reported below.

Across all trials, participants had 4 s to respond; during the first 2 s the stimuli were visible and during the last 2 s the screen was blank. During training, a message followed each trial indicating whether the response (or absence of one) was “Correct” or “Incorrect.” During test trials, all responses produced the message “Response Registered”; no message was displayed in the absence of a response. The intertrial interval was 10 s; during this interval, a message was displayed indicating that the program was resetting.

Results and Discussion

The data were analyzed in two steps. First, a statistical analysis was conducted that followed typical practices in the peak shift and stimulus transposition literatures. Second, a graphical analysis of individual performances was conducted to determine the frequency of absolute and relational control.

Statistical analysis of the single-stimulus test data was based on the means of the individual response distributions (i.e., generalization gradients). The mean was calculated as follows: each response during the test was assigned a numerical value equivalent to the line length that was shown (e.g., 16 for each response to S+); the sum of these values was divided by the total number of responses. ANOVA indicated that, as expected, the position of S- relative to S+ (the manipulation check) caused differences in the means of the gradients ($M = 20.21 \pm 1.03$ when S- was relatively short, $M = 16.07 \pm 1.03$ when S- was relatively long), $F(1, 32) = 8.04$, $p = .008$. As for the variables of central interest, the means did not differ depending on how stimuli were presented during training ($p = .505$) or on the order in which the tests occurred ($p = .962$). The interactions were also nonsignificant.

Statistical analysis of the double-stimulus test data was based on the percentage of responses that matched the relation of S+ to S-. When responding is controlled by chance, about 50 % of responses should be consistent with the S+ to S- relation. (Trials without responses were excluded from the analysis because the absence of a response on a given trial was potentially consistent with absolute stimulus control, relational control by a decision rule, or a slow reaction by the participant). ANOVA indicated that a higher percentage of responses matched the relation when the training stimuli were presented simultaneously ($M = 80.0 \pm 3.8$ % of responses were relational) than when the training stimuli were presented successively ($M = 57.9 \pm 3.8$ % relational responses), $F(1, 32) = 16.51$, $p < .001$. There was also a tendency for more responses to match the relation when S- was shorter than S+ ($M = 74.9 \pm 3.8$ %) than when S- was longer than S+ ($M = 63.08 \pm 3.8$ %), $F(1, 32) = 4.77$, $p = .036$. Performances did not vary as a function of test order ($p = .805$), and the interactions were nonsignificant.

Figure 2 shows the results from the single-stimulus test (top) and the double-stimulus test (bottom). The large panels within the figure show performances following successive training (left side) and simultaneous training (right side). The large panels combine data from the different test orders (which statistically had no effect on performance) and the relative position of S-. For the single-stimulus test, the labels on the *x*-axis indicate the relation of each stimulus to S+ and S- rather than absolute line length. Because S- appears on the left side of each panel, a shift in the gradient would be expected to occur toward the right (specifically, the stimuli labeled +1, +2, +3, and +4). The double-stimulus test data are organized in a similar fashion. Pair 1 (P1) is the pair of line lengths on the far end of the S- side of the dimension (the pair consisting of Line 5 and Line 7 when S- was relatively short and the pair consisting of Line 35 and 46 when S- was relatively long). Pair (P7) is the pair of line lengths furthest removed from S-, and the direction in which gradient shift would occur. The black line shows the distribution of responses, and the underlying gray bars show what proportion of those responses matched the relation of S+ to S-.

The two small panels to the right of each large panel show how performances within the large panel were affected by the relative position of S-. The position of the label "S-" within each panel indicates whether S- was shorter (left side) or longer (right side) than S+. The *x*-axis depicts, from left to right, increasingly long lines or line pairs. If S- appears on the left side of the panel, any gradient shift would be expected to occur toward the right, and if S- appears on the right side of the panel, any gradient shift would be expected to occur toward the left.

Each distribution of responses, in both the large and small panels, includes a peak either at or near S+, indicating that a measure of absolute control was present, regardless of how participants were trained. None of the conditions produced a dramatic gradient shift. Although absolute control predominated, evidence for transposition was found under the combination of simultaneous discrimination training and a double-stimulus test (the set of panels at lower right). In this case, the majority of responses made in the presence of each line pair matched the relation of S+ to S-. Relational responses in the presence of P1, P2, and P3 are consistent with both absolute and relational control. However, relational responses in the presence of P6, P7, and P8 are instances when participants selected the member of the line pair that matched the relation rather than the member that was most similar to S+ in length.

A more subtle difference among the panels is that a greater degree of stimulus generalization was observed in participants trained on a simultaneous basis than those trained on a successive basis. There are at least a couple of reasons why simultaneous training may have led to a greater degree of generalization. Possibly the enhanced generalization reflects a disruption in stimulus control stemming from the transition participants made from a double-stimulus training format to a single-stimulus testing format. Alternatively, the greater degree of generalization might be reflective of the response contingency that was present during training. Participants trained on a simultaneous basis always had to make a response to obtain positive feedback, whereas participants trained on a successive basis obtained positive feedback from not responding in the presence of S-.

The following criteria were used in the graphical analysis of individual performances. Stimulus transposition was inferred if at least 80 % of participants' responses during the double-stimulus test matched the relation of S+ to S- (a somewhat arbitrary value, but a level of performance seemingly well within the capabilities of adult human participants in view of past studies of transposition; cf. Reese, 1968). Relational control by a decision criterion was inferred if the distribution of responses approximated the pattern shown in Fig. 1 (right panel). Specific requirements included that (1) the gradient of responses included a single slope, (2) no responding occurred at the extreme S- end of the stimulus dimension, and (3) maximal responding occurred at the extreme S+ end of the stimulus dimension. Absolute control was inferred in part from the absence of evidence for relational control. In addition, responding was required to decrease on either side of the modal response.

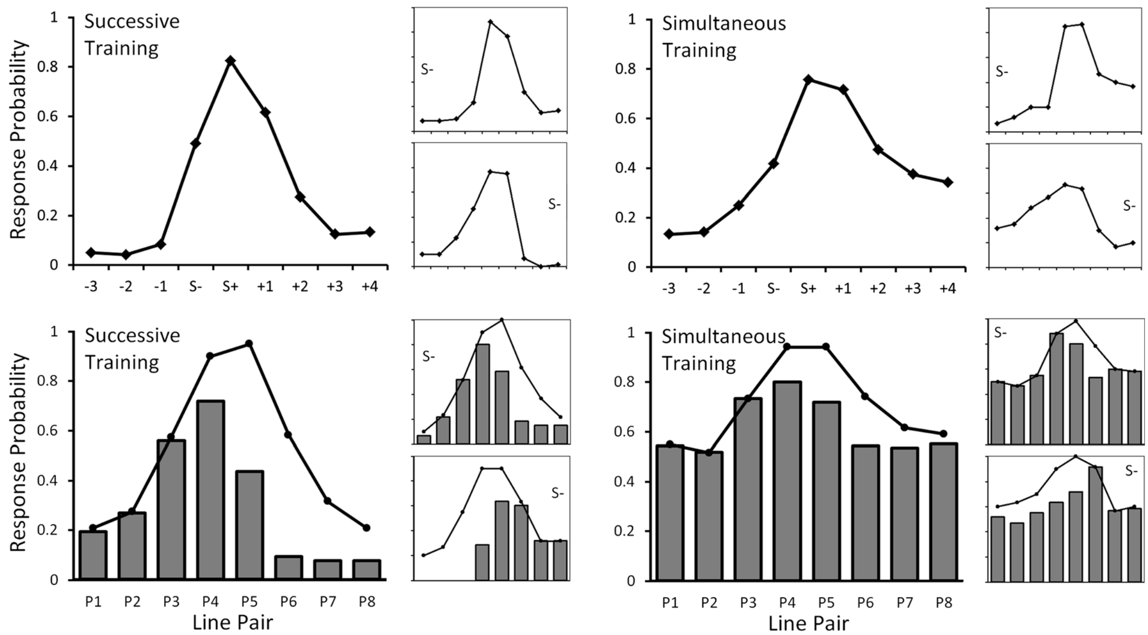

Fig. 2 Top row: Generalization gradients in Experiment 1 following successive and simultaneous discrimination training. Bottom row: Distributions of responses (black line) and frequency of relational responses (gray bars) during the transposition test in Experiment 1. Small panels show how performances varied with the position of S-. Aggregated performances are shown in the large panels. For the single-stimulus test, -1, -2, -3 show stimuli increasingly removed from S- on the S- side of the dimension; +1, +2, +3, +4 show stimuli increasingly removed from S+ and S- on the opposite side of the dimension. For the double-stimulus test, P1–P8 = the eight pairs of test stimuli, with P1 designating the pair at the extreme end of the S- side of the dimension. S- was a line length in both P3 and P4; S+ was a line length in both P4 and P5

Figure 3 shows some of the diversity of individual performances during the single-stimulus test. The first two gradients appear to show absolute stimulus control (a modest gradient shift is evident in the second). The third gradient is consistent with relational control via a decision criterion (cf. Fig. 1). The fourth is an example of a gradient that did not match any of the classification criteria. Unexpectedly, one of the double-stimulus test performances met the criteria for both stimulus transposition and relational control by a decision rule; in this case, the participant refrained from making any response during the double-stimulus test if both line lengths were relatively short (similar to S- in this case), but when both line lengths were relatively long, the participant always responded and the response always matched the relation of S+ to S-.

The complete results of the graphical assessment are listed in Table 1. Two-tailed binomial tests were conducted to determine whether the frequency of absolute and relational control under with each combination of training and testing formats differed from that predicted by chance. As indicated in the table, participants trained on a successive basis demonstrated absolute control under both the single-stimulus and double-stimulus tests. This result is consistent with the saliency hypothesis, which suggests that successive discrimination training makes the absolute characteristics of S+ most salient and therefore leads to absolute control. However, the saliency hypothesis also predicts that participants trained on a simultaneous basis should show relational control, and this did not occur. Instead, these participants demonstrated absolute control during the single-stimulus test and a mixture of absolute and relational control during the double-stimulus test.

Taken as a whole, the results are similar to Honig's (1962) finding of absolute control with all groups under a similar procedure. However, the explanation given for Honig's failure to find relational control does not pertain to our data. In Honig's case, exposure to single-stimulus test trials appears to have interfered with relational control on double-stimulus trials (Riley, 1968). We separated the two types of test trials,

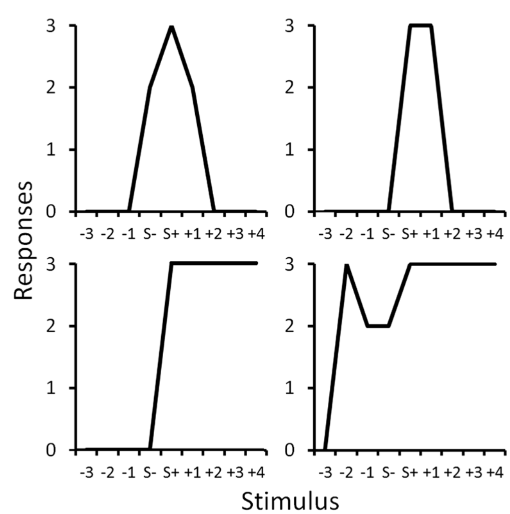

Fig. 3 Examples of individual generalization gradients in Experiment 1

Table 1 Number of individual performances evincing absolute and relational stimulus control in Experiment 1

Training	Test	Abs. Control	Relat. Control	Unclear
Successive	Single	18**	1**	1
	Double	19**	1**	0
Simultaneous	Single	15*	2*	3
	Double	7	13	0

*$p < .01$. **$p < .001$

and half of the participants received the double-stimulus test immediately after simultaneous discrimination training (thus, no interference could have occurred), and test order did not have a significant effect on relational control. Possibly, the lack of relational control is related to the instructions participants received at the beginning of the study. The instructions were written in a manner that could apply to either stimulus presentation method and to either absolute or relational control. However, telling participants to not respond if they did not see the correct line (instructions appropriate to the times when a single-stimulus presentation mode was used) might have inadvertently influenced participants to show absolute control instead of stimulus transposition on double-stimulus trials.

Experiment 2

Absolute stimulus control generally predominated in Experiment 1. In the stimulus transposition literature, one method of enhancing relational control is to give subjects training with multiple pairs of positive and negative stimuli (e.g., Lazareva et al., 2008; Lazareva, Wasserman, & Young, 2005). The effect can be understood in terms of a saliency effect, with the relative characteristic of S+ being more pronounced when it appears across multiple training pairs than when it is present within a single pair. We sought to determine whether the use of multiple S + s and S-s during discrimination training would similarly enhance relational control under the combinations of stimulus presentation modes used in Experiment 1.

Method

Participants and Apparatus

The participants were 40 undergraduate students (an additional 13 participants were replaced for failing to meet the training criterion). Participant characteristics and the apparatus used in data collection were unchanged from Experiment 1.

Procedure

The procedure repeated that used in Experiment 1 except that four lines (Lines 5, 12, 21, and 46) were used during training instead of two. The line lengths selected for training were intended to provide participants with two distinctly different positive stimuli (e.g., Line 21 and Line 46) and two distinctly different negative stimuli (e.g., Line 5 and Line 12). The intention was to help ensure that participants did not mistakenly perceive either the two positive stimuli or the two negative stimuli as being a single line length.

For half of the participants, S+ was Line 5 and 12 and S- was Line 21 and 46; for the other half, the selection was reversed (S+ was Line 21 and 46, S- was Line 5 and 12). For participants who received simultaneous training, Line 5 was always paired with Line 21, and Line 12 was always paired with Line 46. For participants who received successive training, the four lines alternated across trials in a semirandom manner.

Results and Discussion

The data were analyzed in the manner adopted for Experiment 1. In brief, first ANOVAs were performed to assess the effects of stimulus presentation mode during training, the order of the single and double-stimulus test, and the position of the negative stimuli relative to the positive stimuli. Then, a graphical analysis was conducted of the stimulus control expressed in the individual performances.

For the single-stimulus test, ANOVA was based on the mean point of each individual generalization gradient. As was the case in Experiment 1, the gradients differed depending on the placement of S-, $F(1, 32) = 225.04$, $p < .001$. When the negative stimuli were relatively short (Line 5 and Line 12), participants responded, as expected, primarily to relatively long lines ($M = 28.00 \pm .79$); likewise, when the negative stimuli were relatively long (Line 21 and Line 46), participants responded primarily to relatively short lines ($M = 11.34 \pm .79$). As for the chief variables of interest, performances did not differ depending on how stimuli were presented during training ($p = .693$) or on the order in which the tests occurred ($p = .299$). The interactions were also nonsignificant.

For the double-stimulus test, ANOVA was based on the percentage of relational responses (i.e., responses consistent with the relationship of S+ to S-). The percentage of relational responses was higher when the training stimuli were presented simultaneously ($M = 96.1 \pm 3.7$ %) than when they were presented successively ($M = 82.6 \pm 3.7$ %), $F(1, 32) = 6.82$, $p = .014$. Performances did not vary as a function of test order ($p = .357$) or the relative placement of S- ($p = .487$). The interactions were nonsignificant.

Figure 4 shows the performances of participants trained on a successive and simultaneous basis under the single-stimulus

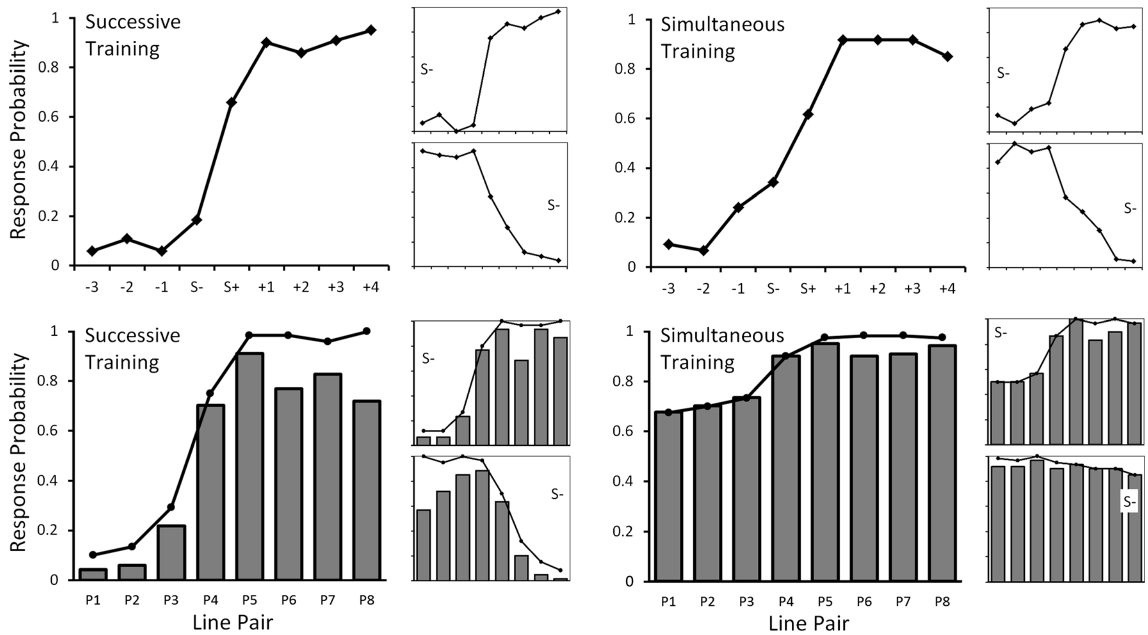

Fig. 4 Results from the generalization tests (top row) and transposition tests (bottom row) in Experiment 2. The black lines show the distributions of responses, and, for the transposition test, the gray bars show the frequency of responses that matched the relation of S+ to S-

and double-stimulus tests. This figure is organized in the same manner as Fig. 2. The single-stimulus test gradients do not contain two distinct peaks, as might be expected to result from discrimination training with two relatively distinct S+s (e.g., Blough, 1969; Galizio, 1985; Galizio & Baron, 1979; LaBerge & Martin, 1964; Lazareva et al., 2008; Thomas & Williams, 1963). Instead, the gradients approximate those hypothesized to accompany control by a decision criterion (see Fig. 1). However, this correspondence should be interpreted cautiously. Summation of generalization can accompany training with multiple S+s, and the resulting gradient can include a single wide peak (cf. Blough, 1969) that is also consistent with the pattern in the figure.

The double-stimulus tests provide clearer evidence for relational control. Under the double-stimulus test, participants trained on a simultaneous basis generally responded in a manner consistent with stimulus transposition (a response was made on most trials and that response usually matched the relation of S+ to S-). However, participants trained on a successive basis displayed a form of stimulus control that appears to combine stimulus transposition with relational control involving a decision rule. When a test pair was shown that included line lengths similar to the S+s, participants usually responded to the line that matched the relation of the S+s to the S-s. When a test pair was shown that included line lengths that resembled the S-s, participants seldom responded to either line. This tendency was less clear in the aggregate than it was in individual cases (discussed below) due to some individual participants expressing other forms of stimulus control.

Individual performances were assessed using the criteria developed for Experiment 1, with the exception that absolute control was assessed if the distribution of responses contained either one peak or two. The results of this assessment are shown in Table 2. Two-tailed binomial tests were performed to determine whether the frequency of absolute and relational control under the several combinations of stimulus presentation methods significantly differed from the level of chance.

Table 2 shows a reversal from the predominance of absolute control found in Experiment 1. In this case, a majority of performances met the criteria for relational control under every combination of stimulus presentation methods. However, this finding should be interpreted cautiously in the case of the single-stimulus test data. We selected two relatively different line lengths to serve as S+ so that absolute control might take the form of a generalization gradient with two distinct peaks, but this outcome occurred in only a few individual cases. More often, absolute control was inferred because a response decrement was observed on either side of a single peak. It's possible that at least some of the performances that met the criteria for relational control by a decision rule actually involved absolute control, but the range of line lengths selected

Table 2 Number of individual performances evincing absolute and relational stimulus control in Experiment 2

Training	Test	Abs. Control	Relat. Control	Unclear
Successive	Single	4*	14*	2
	Double	8	11	1
Simultaneous	Single	5	12	3
	Double	1**	18**	1

*$p < .05$. **$p < .001$

for the test permitted observation of only one of the two slopes of the gradient.

The results from the double-stimulus tests are comparatively clear. Participants who trained on a successive basis showed relational control in 11 of 19 cases. In each of these 11 cases, stimulus transposition was combined with apparent control by a decision rule. This pattern was observed in a single participant in Experiment 1 and apparently was made commonplace by the inclusion of additional stimuli during discrimination training. Participants trained on a simultaneous basis almost always showed relational control. A majority of these instances (13 of 19) involved simple stimulus transposition with every test pair; the remainder involved the apparent combination of stimulus transposition with a decision rule noted above. Together these data show that successive discrimination training has the potential to produce relational stimulus control, and that different ways of presenting stimuli to participants can lead to different forms of relational control.

General Discussion

Human participants are sensitive to the absolute and relational characteristics of simple, unidimensional stimuli, and they can be made to demonstrate absolute or relational control through the procedures used to study peak shift and stimulus transposition. We combined elements of these methods to explore how situational factors (in this case, the manner in which stimuli are presented to participants) affects people's tendency to express one form of control instead of another. The method was inspired by suggestions that the development of stimulus transposition in nonhumans depends on how stimuli are presented during training. Specifically, simultaneous discrimination training is thought to promote control by the relative difference between S+ and S- while successive training is thought to promote control by the absolute physical characteristics of S+ (Mackintosh, 1983; Mazur, 2006; Riley, 1968; Zeiler, 1964).

To speak broadly about the results, absolute stimulus control predominated following discrimination training with a single S+ and a single S- (see Experiment 1). Although relational control occurred frequently under the combination of simultaneous discrimination training and a double-stimulus test (see Table 1), the aggregated distribution of responses resembled a generalization gradient because some participants expressed absolute control (see Fig. 2). The inclusion of two S+s and two S-s during discrimination training (see Experiment 2) reversed tendencies in favor of relational control (see Table 2). However, the relational control that was observed differed somewhat from expectations. It was thought that single-stimulus tests might reveal relational control by a decision rule while double-stimulus tests would reveal relational control in the form of transposition. However, a combination of these two forms of relational control occurred when successive discrimination training was combined with a double-stimulus test (see Fig. 4).

In further characterizing the results, it should be added that several features of the research limit the confidence in the interpretations suggested by the data and in the possible generality of the results. For example, the single and double-stimulus tests were of brief duration, and longer tests would have provided more data on which to base the assessments of stimulus control. Perhaps the chief difficulty concerns determining whether relational control was present under the single-stimulus test. Participants were not asked to provide self-reports; instead stimulus control was assessed solely in terms of the observed performances. The observed, plateau-like response distributions in Experiment 2 (and in several individual cases in Experiment 1; see Fig. 3) are consistent with expectations for relational control via a decision criterion but we are admittedly uncertain as to what the results would have been had the range of test stimuli been further extended. For example, would participants who responded to all relatively long lines under the present procedure also respond to even longer line lengths if they were included in the test? Perhaps, instead, a decline in responding would have been observed at such extreme values, causing a change in assessment to absolute control. Then again, how the test is designed may independently affect how stimulus control is expressed; participants who use a single decision criterion with one set of test stimuli might not also do so with a greater or lesser range of test stimulus values. In view of these uncertainties, the present data do not allow definitive statements to be made about expressions of relational control under single-stimulus test formats. We claim only that the data provide an additional indication that such control may be possible (for past discussions, see Capehart, Tempone, & Hebert, 1969; Howard, 1979; Galizio, 1980; Spetch & Cheng, 1998), and they suggest a possible scenario under which such control might occur.

The development of relational control involving comparisons of test stimuli to a single decision criterion is a subject that seems worth further exploration. Human participants may more easily learn and respond on the basis of the relational characteristics of stimuli than on the absolute characteristics (e.g., Riley, McKee, Bell, & Schwartz, 1967), and they may spontaneously adopt a relational strategy rather than an absolute strategy when the task is relatively complex (e.g., Galizio, 1980). For research on peak shift, this means a more pronounced shift in responding than is normally reported. A wide variety of naturalistic situations have been linked to peak shift-like behavior in humans (e.g., Costa & Corazza, 2006; De Block & Du Laing, 2010; Derenne, 2010; Dunsmoor, Mitroff, & LaBar, 2009; Martindale, 2006; Miller et al., 2015; Ramachandran & Hirstein, 1999). A common characteristic of these situations is that they entail a level of complexity and variety that exceeds what is commonly studied in laboratory-based experiments. If relatively complex tasks engender a greater tendency towards responding to extreme stimuli than relatively simple tasks, then it stands to reason that much of the literature on peak shift effectively understates the degree of behavioral change that accompanies peak shift in naturalistic situations.

Compliance with Ethical Standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of Interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

Baker, R. A., & Lawrence, D. H. (1951). The differential effects of simultaneous and successive stimulus presentations on transposition. *Journal of Comparative and Physiological Psychology, 59*, 118–121.

Bizo, L. A., & McMahon, C. V. (2007). Temporal generalization and peak shift in humans. *Learning & Behavior, 35*, 123–130.

Blough, D. S. (1969). Generalization gradient shape and summation in steady-state tests. *Journal of the Experimental Analysis of Behavior, 12*, 91–104.

Capehart, J., Tempone, V. J., & Hebert, J. (1969). A theory of stimulus equivalence. *Psychological Review, 76*, 405–418.

Costa, M., & Corazza, L. (2006). Aesthetic phenomena as supernormal stimuli: the case of eye, lip, and lower-face size and roundness in artistic portraits. *Perception, 35*, 229–246.

Critchfield, T. S., Schlund, M., & Ecott, C. (2000). A procedure for using bonus course credit to establish points as reinforcers for human subjects. *Experimental Analysis of Human Behavior Bulletin, 18*, 15–18.

De Block, A., & Du Laing, B. (2010). Amusing ourselves to death? Superstimuli and the evolutionary social sciences. *Philosophical Psychology, 23*, 821–843.

Derenne, A. (2006). Effects of S+ and S- separation on gradient shifts in humans. *The Journal of General Psychology, 133*, 163–173.

Derenne, A. (2010). Shifts in postdiscrimination gradients within a stimulus dimension based on bilateral facial symmetry. *Journal of the Experimental Analysis of Behavior, 93*, 485–494.

Derenne, A., Loshek, E. A., & Bohrer, B. (2015). Postdiscrimination gradients with familiar and unfamiliar faces. *The Psychological Record, 65*, 77–82.

Dunsmoor, J. E., & LaBar, K. S. (2013). Effects of discrimination training on fear generalization gradients and perceptual classification in humans. *Behavioral Neuroscience, 127*, 350–356.

Dunsmoor, J. E., Mitroff, S. R., & LaBar, K. S. (2009). Generalization of conditioned fear along a dimension of increasing fear intensity. *Learning & Memory, 16*, 460–469.

Galizio, M. (1980). Conditional gradient displacements: the effects of conditional discrimination training on human auditory frequency generalization. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 766–777.

Galizio, M. (1985). Human peak shift: analysis of the effects of three-stimulus discrimination training. *Learning and Motivation, 16*, 478–494.

Galizio, M., & Baron, A. (1979). Human postdiscrimination gradients: the effects of three-stimulus discrimination training. *Animal Learning & Behavior, 7*, 53–56.

Hauf, P., Prior, H., & Sarris, V. (2008). Generalization gradients and representation modes after absolute and relative discrimination learning in young chickens. *Behavioural Processes, 78*, 93–99.

Henderson, J., Hurly, T. A., & Healy, S. D. (2006). Spatial relational learning in rufous hummingbirds (*Selasphorus rufus*). *Animal Cognition, 9*, 201–205.

Honig, W. K. (1962). Prediction of preference, transposition, and transposition-reversal from the generalization gradient. *Journal of Experimental Psychology, 64*, 239–248.

Howard, R. W. (1979). Stimulus generalization along a dimension based on a verbal concept. *Journal of the Experimental Analysis of Behavior, 32*, 199–212.

Johnson, R. C., & Zara, R. C. (1960). Relational learning in young children. *Journal of Comparative and Physiological Psychology, 53*, 594–597.

LaBerge, D., & Martin, D. R. (1964). An analysis of summated generalization. *Journal of Experimental Psychology, 68*, 71–79.

Lazareva, O. (2012). Relational learning in a context of transposition: a review. *Journal of the Experimental Analysis of Behavior, 97*, 231–248.

Lazareva, O., Miner, M., Wasserman, E., & Young, M. (2008). Multiple-pair training enhances transposition in pigeons. *Learning & Behavior, 36*, 174–187.

Lazareva, O. F., Wasserman, E. A., & Young, M. E. (2005). Transposition in pigeons: reassessing Spence (1937) with multiple discrimination training. *Learning and Behavior, 33*, 22–46.

Leighty, K. A., Grand, A. P., Pittman Courte, V. L., Maloney, M. A., & Bettinger, T. L. (2013). Relational responding by eastern box turtles (*Terrapene carolina*) in a series of color discrimination tasks. *Journal of Comparative Psychology, 127*, 256–264.

Livesey, E. J., & McLaren, I. P. L. (2009). Discrimination and generalization along a simple dimension: peak shift and rule-governed responding. *Journal of Experimental Psychology: Animal Behavior Processes, 35*, 554–565.

Mackintosh, N. J. (1983). *Conditioning and associative learning*. New York: Oxford University Press.

Malott, R. W., Malott, M. K., & Pokrzywinski, J. (1967). The effects of outward-pointing arrowheads on the Mueller-Lyer illusion in pigeons. *Psychonomic Science, 9*, 55–56.

Manabe, K., Murata, M., Kawashima, T., Asahina, K., & Okutsu, K. (2009). Transposition of line-length discrimination in African penguins (*Spheniscus demersus*). *Japanese Psychological Research, 51*, 115–121.

Martindale, C. (2006). Peak shift, behavioral contrast, and phonological evolution with explanations of the Great English Vowel Shift and Grimm's Law. *Journal of Cultural and Evolutionary Psychology, 4*, 5–26.

Mazur, J. E. (2006). *Learning and behavior* (6th ed.). Upper Saddle River: Prentice Hall.

Miller, J. R., Reed, D. D., & Critchfield, T. S. (2015). Modeling the effects of melanoma education on visual detection: a gradient shift analysis. *The Psychological Record, 65*, 323–335.

Moll, F. W., & Nieder, A. (2014). The long and the short of it: rule-based relative length discrimination in carrion crows, *Corvus corone. Behavioural Processes, 107*, 142–149.

Ramachandran, V. S., & Hirstein, W. (1999). The science of art: a neurological theory of aesthetic experience. *Journal of Consciousness Studies, 6*, 15–51.

Reese, H. W. (1968). *The perception of stimulus relations: discrimination learning and transposition*. New York: Academic Press.

Reichert, J. F., & Kelly, D. M. (2012). Discrimination of geometric angles by adult humans. *Animal Cognition, 15*, 271–284.

Riley, D. A. (1968). *Discrimination learning*. Boston: Allyn & Bacon.

Riley, D. A., McKee, J. P., & Bell, D. B. (1967). Auditory discrimination in children: the effect of relative and absolute instructions on retention and transfer. *Journal of Experimental Psychology, 73*, 581–588.

Riley, D. A., Ring, K., & Thomas, J. (1960). The effect of stimulus comparison on discrimination learning and transposition. *Journal of Comparative and Physiological Psychology, 53*, 415–421.

Spetch, M. L., & Cheng, K. (1998). A step function in pigeons' temporal generalization in the peak shift task. *Animal Learning & Behavior, 26*, 103–118.

Thomas, D. R. (1993). A model for adaptation-level effects on stimulus generalization. *Psychological Review, 100*, 658–673.

Thomas, D. R., Svinicki, M. D., & Vogt, J. (1973). Adaptation level as a factor in human discrimination learning and stimulus generalization. *Journal of Experimental Psychology, 97*, 210–219.

Thomas, D. R., & Williams, J. L. (1963). A further study of stimulus generalization following three-stimulus discrimination training. *Journal of the Experimental Analysis of Behavior, 5*, 375–381.

Verbeek, E. L., Spetch, M. L., Cheng, K., & Clifford, C. W. G. (2006). Determinants of range effects in face recognition. *Learning & Behavior, 34*, 229–240.

Wiegmann, D., Wiegmann, D., Macneal, J., & Gafford, J. (2000). Transposition of flower height by bumble bee foragers (*Bombus impatiens*). *Animal Cognition, 3*, 85–89.

Wills, S., & Mackintosh, N. J. (1999). Relational learning in pigeons? *The Quarterly Journal of Experimental Psychology Section B: Comparative and Physiological Psychology, 52*, 31–52.

Winton, A. S. W. (1975). Peak shift following simultaneous discriminations. *Journal of the Experimental Analysis of Behavior, 24*, 303–310.

Winton, A. S. W., & Beale, I. L. (1971). Peak shift in concurrent schedules. *Journal of the Experimental Analysis of Behavior, 15*, 73–81.

Wisniewski, M. G., Church, B. A., & Mercado, E. (2009). Learning-related shifts in generalization gradients for complex sounds. *Learning & Behavior, 37*, 325–335.

Yamazaki, Y., Saiki, M., Inada, M., Iriki, A., & Watanabe, S. (2014). Transposition and its generalization in common marmosets. *Journal of Experimental Psychology: Animal Learning and Cognition, 40*, 317–326.

Zeiler, M. D. (1964). Transposition in adults with simultaneous and successive stimulus presentation. *Journal of Experimental Psychology, 68*, 103–107.

Zentall, T. R., & Clement, T. S. (2001). Simultaneous discrimination learning: stimulus interactions. *Animal Learning & Behavior, 29*, 311–325.