TOPOGRAPHY OF RESPONSES IN CONDITIONAL DISCRIMINATION INFLUENCES FORMATION OF EQUIVALENCE CLASSES

Olivia M. Kato

Universidade Federal do Pará, Brazil

Júlio C. de Rose and Pedro B. Faleiros

Universidade Federal de São Carlos, Brazil

The effects of response topography on stimulus class formation were studied in two experiments. In Experiment 1, 32 college students were assigned to 2 response topographies and 2 stimulus sets, in a 2 × 2 design. Students selected stimuli by either moving a mouse to place an arrow-shaped cursor on the stimulus or pressing a key corresponding to stimulus location. After they learned conditional discriminations EF, DE, CD, BC, and AB and a simple simultaneous discrimination, tests for class formation were conducted. The number of students showing class formation was larger for the group using the mouse. Stimulus set had no effect. Experiment 2 included probes for controlling relations in the baseline and showed that the response topography using the mouse increases the probability of sample-S+ relations, thus increasing the probability of class formation.

Olivia M. Kato, Faculdade de Psicologia, Universidade Federal do Pará, Brasil. Julio C. de Rose and Pedro B. Faleiros (now a doctoral student at Instituto de Psicologia, Universidade de São Paulo), Departamento de Psicologia, Universidade Federal de São Carlos, Brasil.

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Reprint requests and correspondence concerning this article should be addressed to Julio C. de Rose; Departamento de Psicologia; Universidade Federal de São Carlos, Caixa Postal 676; 13565-905 São Carlos, SP; Brazil. E-mail: djcc@power.ufscar.br.

Arbitrary matching-to-sample trials display a sample (A_1 , A_2 , or A_n) and two or more comparison stimuli (B_1 , B_2 , . . . B_n). A reinforcer follows selections of a comparison stimulus conditionally on the sample stimulus: in the presence of sample A_1 , reinforcement follows selections of B_1 and not of other comparisons; in the presence of A_2 , reinforcement follows selections of B_2 ; and so forth. Such conditional discrimination, or conditional relation, between the A and B stimuli is designated as AB.

Sidman and his colleagues (see Sidman, 1994) showed that, for humans, the matching-to-sample procedure may generate equivalence relations, defined by the mathematical properties of *reflexivity*, *symmetry*, and *transitivity*. Reflexivity requires that the conditional relation hold for each stimulus and an identical one, in the absence of direct training. Symmetry is demonstrated when training a conditional relation, such as AB, results in the emergence of a conditional relation with reversed sample and comparison functions, such as BA. Transitivity is documented by an emergent relation between two sets of stimuli related to a third one: after training AB and BC, conditional relation AC then emerges. The relation symmetrical to this one, CA, requires, logically, the properties of both reflexivity and transitivity and is sometimes considered as an abbreviated test for equivalence (Bush, Sidman, & de Rose, 1989; Fields & Verhave, 1987).

After demonstration of stimulus equivalence, one may say that the related stimuli are members of equivalence classes. In the above example, there will be a class composed of A_1 , B_1 , and C_1 ; another composed of A_2 , B_2 , and C_2 ; and, if the relations involved more samples and comparison stimuli, classes composed of stimuli A_n , B_n , and C_n . Training a conditional relation between a new set of stimuli and one of the sets of class members, like CD (or DC), may add D_1 , D_2 , . . . D_n , respectively, to each class.

Fields, Verhave, and Fath (1984) showed that to form n -members equivalence classes, it is necessary to teach at least $n - 1$ conditional discriminations. Different training designs may accomplish this, and the number of possible training designs increases with the number of prospective class members. A training design is a set of conditional discriminations that relate each set of stimuli to at least one other set, so that all prospective class members are related, directly or indirectly.

Saunders and Green (1999) analyzed three categories of training design. For example, to establish three-member classes, it is necessary to train subjects in two conditional discriminations. The one-to-many (or sample-as-node) design is used to train subjects in conditional discriminations AB and AC, so that the A samples will constitute a node. The many-to-one (or comparison-as-node) design will train conditional discriminations BA and CA, so that the nodes will be comparisons. The linear design will train conditional discriminations BA and AC, so that the nodal stimuli A will be comparisons in one conditional discrimination and samples in another one. Saunders and Green restrict their discussion to conditional discriminations with two samples and two comparisons, thus forming two equivalence classes. Equivalence probes will test emergent conditional discriminations BC and CB in all three designs. Saunders and Green argue that component simple discriminations are prerequisites for these emergent conditional discriminations. To perform a conditional discrimination, participants need to make a simultaneous simple discrimination between the comparison stimuli and a successive simple discrimination between the samples. Saunders and Green compared

the simple discriminations required for successful performance in the probes with those established in the baselines and argued that the many-to-one design establishes all the required prerequisites, whereas the other designs do not necessarily establish these prerequisites in the baseline. For instance, the BC/CB emergent conditional discriminations require successive simple discrimination between the B and C stimuli. The many-to-one design is the only one that establishes all these successive discriminations in the baseline, since both B and C stimuli appear as samples in the baseline. In the one-to-many design, neither B nor C stimuli appear as samples, so that participants do not necessarily learn to make successive discriminations between these stimuli, and in the linear design the C stimuli do not appear as samples. Saunders and Green review the studies in which training designs are compared and reveal that most of them support this view, showing the many-to-one design to be more effective than both the one-to-many design and the linear design.

Several studies (e.g., Fields, Adams, Verhave, & Newman, 1990, 1993) also show that stimulus equivalence may be less likely to emerge and may require more testing trials to emerge as the number of nodes (stimuli conditionally related to two or more stimuli) increases. A stimulus function acquired by a class member transfers to the other class members in the absence of direct training (e.g., Boelens & Smeets, 1990; de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988a; Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Hayes, Kohlenberg, & Hayes, 1991). Studies showed that transfer decreases with the number of nodes between the stimulus tested and the stimulus that directly acquired a particular function (Fields et al., 1993; Fields, Landon-Jimenez, Buffington, and Adams, 1995). On the basis of these findings, these authors claim that the degree of "relatedness" of stimuli in an equivalence class is inversely proportional to the number of nodes intervening between them in training.

Previous studies in our laboratory, however, showed indications that the effects of training design and number of nodes may depend on other procedural variables. De Rose, Ribeiro, Reis, & Kledaras (1992) reported two studies with conflicting results. The first investigated the formation of two six-member equivalence classes and transfer of discriminative functions along these classes. Designs with one node trained conditional discriminations AB, AC, AD, AE, and AF (one-to-many design) or BA, CA, DA, EA, and FA (many-to-one design). A linear design with four nodes trained conditional discriminations AB, BC, CD, DE, and EF. All participants showed equivalence class formation and transfer of functions with the one-node designs. No participant exposed to the linear four-node design showed either equivalence class formation or transfer of functions. However, in a second study that attempted to replicate these data, all participants exposed either to the one-node or the four-node design showed the formation of equivalence classes and transfer of functions.

De Rose and colleagues (de Rose, 1996; de Rose, Kato, Thé, & Kledaras, 1997) suggested that these conflicting results were due to the use of different response topographies. They presented additional data showing that with a four-node linear design, when participants selected stimuli pressing keys on a computer keyboard (as in the first experiment reported by de Rose et al., 1992), few of them showed the formation of equivalence classes and transfer of functions. On the other hand, when participants selected

stimuli by using the computer's mouse to move an arrow-shaped cursor on the screen and to position it on the stimulus (as in the second experiment reported by de Rose et al., 1992), most of them showed the formation of equivalence classes and transfer of functions. These studies had, however, a potential confound. Response topographies covaried with the stimulus set. It is therefore impossible to attribute differences in class formation to the differences in response topography, since they could also be due to the differences in the sets of stimuli used (cf. Saunders, Saunders, Williams, & Spradlin, 1993).

Nevertheless, the studies by de Rose and colleagues demonstrated that under some conditions, a linear design with four nodes can be as effective as a design with only one node. On the one hand, this finding raises questions about the effects of training design and number of nodes. As Sidman (1994) suggested, these effects may be at least partly attributed to other procedural variables. On the other hand, it is relevant to determine clearly the procedural variables that interact with the number of nodes and the training design. The present report shows results of two experiments conducted to clarify these issues. With Experiment 1, we attempted to isolate effects of response topography and stimulus set, using two stimulus sets and two response topographies, in a 2×2 design. In Experiment 2, we investigated whether effects of response topography could be due to differences in stimulus control relations engendered by different response topographies.

Experiment 1

Method

Participants

Participants were 32 college students, enrolled in programs of biological sciences or humanities (excluding psychology), 8 males and 24 females, with ages ranging from 17 to 30 years. They were recruited through personal contacts, in which experimenters attempted to exclude classmates or roommates in order to decrease any influences due to personal contacts among participants. Twelve additional students participated but failed to achieve the baseline requirements.

Setting and Equipment

Experimental sessions were conducted in a sound-attenuated laboratory room. A microcomputer (Apple Macintosh Performa 630) was used to present stimuli, record responses, and provide differential consequences. Experimental tasks were programmed through MTS software (Dube, 1991). Visual stimuli (abstract pictures) were presented on five "windows" (5.6×5.6 cm) located on five positions of the computer's screen (center, upper left, upper right, lower left, and lower right). The windows were white on a gray background, and the pictures were drawn with black lines. Figure 1 presents the two different sets of visual stimuli used in this study.

Figure 1. Stimuli used in the two experiments.

Sixteen participants selected stimuli by moving the computer's mouse to displace an arrow-shaped cursor on the screen, positioning it within the stimulus window and then pressing the mouse button. The remaining 16 students pressed a key on the numeric keypad, at the right of the keyboard, whose location corresponded to the location of the window. Presses on keys 5 (center of the keypad), 7 (upper left), 9 (upper right), 3 (lower right), and 1 (lower left) selected stimuli on the windows in the corresponding positions on the screen. White adhesive labels covered these keys. The labels on the upper keys had arrows pointing up, and the labels on the lower keys had arrows pointing down. Labels did not cover the other keys and pressings on them had no scheduled consequences.

Procedure

The experiment involved use of a 2×2 group design, with response topography and stimulus set as the experimental variables. Sixteen students made selections by moving the mouse, and 16 students made selections by means of the keyboard. In each of these groups, Stimulus Set 1 was used with 8 students and Stimulus Set 2 was used with the remaining 8.

The experiment was scheduled for two sessions. Session 1 established a baseline of five conditional discriminations and a simple discrimination. Session 2 conducted probes for transfer of discriminative functions and stimulus equivalence. If a session was not completed within 600 trials, the computer halted the session and another appointment was scheduled to complete it. Students could make two sessions or continue a halted session after a break of at least 10 minutes. They could also continue on another day, but intervals could be no longer than 3 days.

Sessions comprised blocks of simple and conditional discrimination trials. Trials within each block were randomized for the sequence of samples and positions of correct and incorrect comparisons (or positions of S+ and S- for simple discrimination trials).

Conditional discrimination trials began with the presentation of the sample on the center window. Selection of the sample was required as an

observing response. Presentation of two comparison stimuli followed, in two of the four outer windows; the sample remained present. Selection of a comparison stimulus ended the trial, removing the pictures, producing the consequences programmed for correct or incorrect responses, and initiating an intertrial interval of 1 s. Simple discrimination trials began with the presentation of two stimuli in two of the outer windows. Selection of one of the stimuli ended the trial, producing the scheduled consequences and intertrial interval.

A brief sequence of ascending tones and an animated display of colored stars of varying sizes and positions followed correct responses. The consequence for incorrect responses was a 3-s timeout. Probe blocks, as well as final baseline blocks, omitted differential consequences. A message on the screen informed participants that the computer would no longer signal whether their choices were correct or incorrect.

Session 1: Training conditional and simple discriminations. Each participant received and signed a written form presenting the objectives of the study and specifying the obligations of experimenters and participant (see the appendix). The first session then began, with a message printed on the computer's screen. The English translation of the message for the keyboard group was the following:

Read the following instructions; if necessary, read them again. Your task will be to choose between the pictures that will appear on the computer's screen. You will have to find out the correct choices. A picture will appear on the center of the screen and you will have to [press the key at the center of the numeric keypad (on the right-hand side of the keyboard), corresponding to the central position of the screen. Then, two different pictures will appear in two of the four outer positions on the screen, and you will have to choose one of these pictures. You can do that pressing one of the four keys with arrows, in the numeric keypad, corresponding to the four outer positions on the screen. To select a particular picture, press the arrow corresponding to its position. For instance, when your choice is the picture at the upper left of the screen, press the key located at the upper left of the numeric keypad.] The presentation of stars and a sound will indicate that you made the correct choice. The darkening of the screen will indicate that you made an incorrect choice. On some occasions, the picture on the central window will not appear; in that case, choose one of the two outer pictures. These instructions contain all necessary information and the experimenter cannot answer any question.

Thank you for your attention, and good luck.

For the students assigned to the mouse condition, the following passage was substituted for the bracketed text above:

... bring the mouse's arrow onto the central picture and press the mouse's button. Then two different pictures will appear in two of the four outer positions on the screen, and you will have to choose one of these pictures. To do this, bring the mouse's arrow onto the selected picture and press the button.

Training of conditional discriminations EF, DE, CD, BC, and AB then ensued, in that order. In the eight initial teaching trials of each conditional discrimination, the observing response to the sample produced the comparison stimuli and displayed the Portuguese equivalents of the written phrases “when this is here” and “press here” below the sample and the correct comparison, respectively. If the student did not make correct selections in all trials of this block, another block with four trials, with onscreen prompts, followed and was repeated until the student responded correctly in all four trials.

The next block presented 16 trials, without prompts, of the same conditional discrimination and was repeated until the student made 100% correct selections. (However, if the student made more than two errors, the four-trial block with prompts was presented again.) The next block consisted of a random mix of trials of all conditional discriminations taught up to that point, comprising a cumulative baseline.

The simple discrimination training was conducted after the participant attained criterion in the cumulative baseline with all conditional discriminations. Then a block with 16 trials presented stimuli A1 and A2 on two outer windows, in randomized positions. This block was repeated to criterion. The next block then added simple discrimination trials to the cumulative baseline, comprising a total of 60 trials, 10 of each discrimination taught (five conditional discriminations and the simple discrimination). After participants attained criterion in this block, the cumulative baseline was reviewed without differential consequences. Session 1 ended when students attained criterion in this block.

Session 2: Probes. The probe session began with a review of the cumulative baseline. After criterion, differential consequences were withdrawn and the baseline was reviewed again. The next block verified transfer of S+ and S– functions, from A1 and A2, respectively, to stimulus pairs B1/B2, C1/C2, D1/D2, E1/E2, and F1/F2. This block had 60 simple discrimination trials, presenting stimulus pairs A1/A2, B1/B2, C1/C2, D1/D2, E1/E2, and F1/F2 (10 trials of each pair in a randomized order).

Subsequent probe blocks verified emergent relations FA, EA, DA, CA, and again FA, in that order. Each of these probe blocks was preceded by a baseline review, without differential consequences, composed of a block mixing trials of all relations that were logically required for emergence of the probed relation. For instance, a baseline block mixing trials of conditional relations AB, BC, CD, and DE preceded the EA probe. Conditional relation EF was not presented, because it was not a logical prerequisite for the emergence of EA.

Figure 2 presents the sequence of conditions, as well as number of trials and learning criteria in each condition.

Results and Discussion

Effects of Response Topography

Transfer of functions could be inferred from consistent selections of B1, C1, D1, E1, and F1. Stimulus equivalence could be inferred from consistent selections of comparison A1 in the presence of samples F1, E1, D1, and C1. Although responses in probes could not be strictly considered as either correct or incorrect, selections consistent with inferences of equivalence and transfer were arbitrarily designated as correct, whereas other selections were designated as incorrect.

Figure 2. Sequence of probe blocks in Experiment 1. Boxes show the trial types and, within parenthesis, the total number of trials in the block and the learning criterion. When only one total is presented, there were an equal number of trials of each type. For blocks with probes, totals are presented for baseline trials and probe trials (the latter in italics). There was no learning criterion for blocks with probes. For blocks with baseline trials only, when no learning criterion is shown, criterion was 100% correct. Blocks without differential consequences for correct or incorrect responses have boxes with dotted lines.

Tables 1 and 2 show probe scores of students who made selections with the mouse and with the keyboard, respectively. Logically, emergence of the FA relation would demonstrate transitivity and symmetry of all trained conditional relations (cf. Bush et al., 1989; Fields & Verhave, 1987). However, consistent selections of comparison A1 in the presence of sample F1 and of comparison A2 in the presence of sample F2 could also arise from sources other than equivalence. Saunders et al. (1993) showed that persons with a history of conditional discrimination would show generalized conditional responding to new stimuli, arbitrarily assigning each comparison to a particular sample. If stimulus equivalence had not emerged for a particular student, he or she could still show generalized conditional responding, arbitrarily assigning each A comparison to one of the F samples. There would be, then, a 50% probability of consistent selections of A1 in the presence of F1 and of A2 in the presence of F2. Since there is a high probability of spurious positive results due to generalized conditionality in any particular test, it is not possible to make conclusions about the emergence of any particular conditional relation. However, the probability of arbitrarily assigning A1 to all the samples in Class 1 and A2 to all the samples in Class 2 would be only about 0.16. The probability that students did such arbitrary assignment and also selected Class 1 stimuli in all probes for transfer of functions would be

even lower. Therefore, results for the probes were taken as a whole, and only students who achieved criterion of 90% of responses consistent with class formation in all probe blocks were considered to show class formation.

Table 1
Percentage Correct in Probe Trials for Students Making Selections with the Mouse

Students	Probes					
	TF	FA	EA	DA	CA	FA
Stimulus Set 1						
BIA	100	95	100	100	100	100
LEO	100	90	100	100	100	95
ELI	98	100	100	100	95	95
DAN	100	100	100	100	95	100
ALC	100	100	100	100	100	100
ERI	100	100	100	100	100	100
FLA	100	100	100	100	100	100
ERH	48	45	15	95	95	5
Stimulus Set 2						
AND	100	95	100	100	100	100
MIC	100	95	100	100	100	100
ANL	100	100	100	100	95	100
GMO	100	100	100	100	100	100
PIE	100	95	100	100	100	100
VAL	100	100	100	100	100	100
CAS	100	100	100	100	100	100
LUZ	26	5	0	5*		
	42	0	0	5	5	0

Note. Probe blocks were transfer of functions (TF), with 50 probe trials, and emergent conditional discriminations FA, EA, DA, CA, and again FA, with 20 probe trials each.

*Baseline deteriorated after this point. Probes were repeated after baseline recovery and are presented in the following line.

According to this criterion, 14 students who made selections with the mouse and 6 who made selections with the keyboard showed class formation. The Pearson χ^2 test showed a significant effect of response topography on the number of participants who showed immediate emergence both of transfer of functions and of stimulus equivalence ($\chi^2 = 8.533$, $p = 0.003$).

There was no noticeable difference between the two groups for the acquisition of the baseline. In considering the total number of trial blocks necessary for each participant to complete the baseline phase, the Pearson χ^2 test shows no significant difference between the two groups. Also, there was no significant difference between the groups for the number of trial blocks to attain criterion in the acquisition of each conditional discrimination and in the simple discrimination.

Performance of Students Who Did Not Attain Criterion in All Probe Blocks

Results among students who did not attain criterion in all probe blocks are often difficult to interpret, because some scores of 100% correct (or close to 100% correct) may be due to generalized conditional responding. However, if that was the basis of responding, some scores of 0% correct (or close to

it) may be also expected. Therefore, an apparently random distribution of scores close to 100% and 0% suggests responding on the basis of generalized conditionality, in the absence of equivalence. This is the case of SAM and DEB, in the keyboard group.

Table 2
Percentage Correct in Probe Trials for Students Making Selections With the Keyboard

Students	Probes					
	TF	FA	EA	DA	CA	FA
Stimulus Set 1						
GUST	92	100	95	100	100	100
REG	100	100	100	100	100	100
MCL	100	100	100	100	100	100
LUC	100	100	100	100	100	100
RAQ	50	45	50	50	100	90
GUSA	76	100	100	100	100	100
VIV	22*	100	100	100	100	100
SAM	100	100	60	0	100	100
Stimulus Set 2						
PAUL	100	100	100	100	100	100
MAR	100	100	100	100	100	—
MARI	44*	75	85	100	100	95
GAB	100	100	40	60	95	0
NEL	100	0	50	50	10	0
TAG	10	100	100	100	100	100
DEB	40	10	50	0	100	15
CRI	84	95	75	100	95	100

Note. Probe blocks were transfer of functions (TF), emergent conditional discriminations FA, EA, DA, CA, and again FA (conducted in this order). Scores are presented as ratios of correct responses by total number of probe trials.

*Accuracy in baseline probes fell below criterion of 90% correct during probe block.

The literature often reports initially imperfect scores in equivalence probes, with increasing scores as tests are repeated (e.g., Spradlin, Cotter, & Baxley, 1973; Devany, Hayes, & Nelson, 1986; Sidman, Kirk, & Wilson-Morris, 1985). This delayed emergence of equivalence is often found when probes proceed from high-node to low-node classes and back to high-node classes. Since the formation of classes with a lower number of nodes is a logical prerequisite for the formation of classes with a higher number of nodes, Sidman et al. (1985) suggested that failure to show high-node classes may be due to imperfect emergence of low-node prerequisites. They also argued that tests might provide an occasion for classes to form. Therefore, low-node classes may emerge during tests and may also give rise to the classes with a higher number of nodes. This seemed to happen with RAQ, MARI, and CRI, in the keyboard group. They showed imperfect scores in initial equivalence probes, attained criterion for lower-node classes, and then attained criterion in the second FA probe.

Students GUSA, VIV, and TAG, in the keyboard group, showed imperfect scores only in the initial probe, for transfer of functions. This finding may

also be considered as delayed emergence of equivalence. If classes had formed completely, all Class 1 stimuli would be equivalent to A1 and all Class 2 stimuli would be equivalent to A2. Participants would, therefore, be expected to select Class 1 stimuli in these probes, an outcome that has been usually found (e.g., de Rose et al., 1988a; Smeets, 1994). Therefore, for these participants also, class formation was not demonstrated at the initial exposure to the probe context; some additional exposure to the probes was required for classes to emerge.

Other students attained criterion in the lower node probes but did not achieve criterion both in the first and in the second FA probe. This result suggests that lower-node classes may have formed but the complete four-node class did not emerge, at least with the amount of testing provided. This happened with ERH in the mouse group and with DEB in the keyboard group. DEB's results, however, could also be due to generalized conditionality, so the controlling factors over her performance are not clear.

Students SAM, GAB, and NEL performed perfectly on the probes for transfer of functions and then performed poorly on some equivalence probes. This is a puzzling outcome, since perfect performance on tests for transfer of functions suggests formation of two distinct classes. A few earlier studies reported such dissociation between "functional classes," documented by means of transfer of functions, and "equivalence classes," documented by means of transitivity, symmetry, and reflexivity (e.g., de Rose, McIlvane, Dube & Stoddard, 1988b; Sidman, Wynne, Maguire & Barnes, 1989). Sidman (1994), however, argued strongly that functional and equivalence classes imply one another and dissociations between them are likely to be artifacts. It is unlikely that students would perform perfectly on probes for transfer of functions by chance or by arbitrary assignment. It is possible, however, that some kind of interference deteriorated performance on equivalence probes. Possible interfering variables could be extinction along repeated probes without differential reinforcement or competing stimulus control relations in conditional discrimination probes (see McIlvane, Serna, Dube, & Stromer, 2000; McIlvane & Dube, 2003).

Effects of Stimulus Set

A total of 11 students exposed to Stimulus Set 1 showed class formation, whereas 9 students exposed to Set 2 showed class formation. The Pearson χ^2 test showed that this difference is not significant. However, if comparison between the two response topographies is made separately for students assigned to each stimulus set, the difference between mouse and keyboard seems larger for students trained with Set 2. The numbers, in this case, are not very large for a meaningful statistical comparison. It seems almost obvious that the nature of stimuli should affect the formation of stimulus classes, but this should interact with many other variables, so that the actual experimental demonstration of such effects is not very easy.

The present experiment was not devised to explore effects of stimulus set. Two sets were used in an attempt to show that earlier results could be attributed to topography and not to stimulus set. It is probable, however, that if different stimulus sets were used, with the difference between them increasing gradually, a point would be found where the stimulus set would have an effect on class formation.

Experiment 2

Differences in equivalence outcomes are often explained in terms of differences in acquired baseline relations or differences in other repertoires of the participants, such as verbal skills (cf. Fields & Verhave, 1987; Horne & Lowe, 1996). According to these views, different response topographies in baseline conditional discriminations should not produce differences in outcome tests, since participants were verbally competent and learned the same baseline relations.

Carrigan and Sidman (1992) argued, however, that responding controlled by different types of relations between sample and comparison stimuli may meet the reinforcement contingencies of conditional discriminations. Such different controlling relations usually are not distinguishable in the observable conditional discrimination performance. They can be detected only when special tests are conducted.

In a sample-S+ controlling relation, the sample conveys S+ functions to the comparison stimulus designated as correct. Therefore, the controlling relation is also called a "select" relation, because the sample controls selection of the S+. If the controlling relation is exclusively sample-S+, the S- does not exert control over the selection response. In a sample-S- controlling relation, on the other hand, the sample conveys S- functions to the comparison stimulus designated as incorrect. The controlling relation is also called a "reject" relation, because the sample controls rejection of the S-. If the controlling relation is exclusively sample-S-, participants may not even notice the distinctive features of the S+: although they emit the designated response to the S+, this response is controlled only by rejection of the S-.

Such controlling relations may be detected on the basis of probes that remove one of the baseline comparisons. A novel stimulus may be substituted for it (e.g., Stromer & Osborne, 1982), or only one comparison may remain. In the latter case, participants learn to select either the single comparison or a "neutral" alternative (e.g., McIlvane, Kledaras, Munson, King, de Rose, & Stoddard, 1987). In probe trials that remove the S- and present only the former S+, sample-S+ relations are the only possible basis for accurate responding. If sample-S+ control has not been firmly established, participants cannot respond accurately. Errors in these probes, therefore, indicate imperfect sample-S+ control. The reverse is expected in probe trials that remove the S+ and present only the S-. In these trials, participants cannot respond accurately if sample-S- control has not been firmly established. Therefore, errors in these probes indicate imperfect sample-S- control.

The purpose of Experiment 2 was to search for differences in stimulus control relations acquired when students made selections using the mouse or the keyboard, and to verify whether different controlling relations in the baseline were related to different outcomes in equivalence tests. Controlling relations were verified through probes that substituted novel stimuli for either the S+ or the S-.

Method

Participants

Participants were 16 college students, 10 female and 6 male, with ages ranging from 18 to 25 years. They were recruited through personal contact, with the same restrictions as in Experiment 1. Five other students participated but did not complete the experiment, and their data are not presented.

Setting and Equipment

Setting and equipment were the same as in Experiment 1. The study used only Stimulus Set 1, from Experiment 1.

Procedure

Eight students made selections with the mouse, and 8 with the keyboard. Figure 3 shows, for each experimental session, the sequence of trial blocks, the total number of baseline and probe trials in each block, and the learning criteria.

Session 1: Baseline training. The sequence of training blocks was the same as in Experiment 1, with changes in the number of trials in some blocks (see Figure 3).

Session 2: Stimulus control probes. This session began with a review of the conditional discrimination baseline. The probe block followed. Just before the block began, the Portuguese equivalent of the following message appeared on the screen: "From this moment on, if you consider that there is no picture to choose among those displayed, you may choose a window with no picture."

Probes for S+ control presented the sample, the S+, and a novel stimulus. Any selection of the novel stimulus or a blank window indicated that the current sample did not exert perfect control of S+ selections. Probes for S- control presented the sample, the S-, and a new stimulus. The probe block included both probes for S+ and S- control, with all baseline samples. These probes were interspersed within baseline trials, in a randomized sequence. Selections of windows with or without stimuli ended the trials.

There were 20 probes for S+ control and 20 for S- control. Probes used 26 novel stimuli. Therefore, 6 of them were used only in one probe for S+ control and one for S- control, and 14 were used in two probes for S+ control and two for S- control, always in trials probing different conditional discriminations.

Since probes could potentially change controlling relations in the baseline, Session 2 was conducted with only four participants in each group. The other participants advanced directly from Session 1 to Session 3.

Session 3: Probes for transfer of discriminative functions and stimulus equivalence. After a review of the cumulative baseline, probe blocks verified transfer of discriminative functions and emergent relations FA, EA, DA, and CA, as in Experiment 1. From then on, the sequence differed from Experiment 1 and continued with probes for emergent relations FB, EB, and DB (see Figure 3 for details).

Session 4: Transitivity probes. Session 4 conducted probes for emergent relations AF, AE, AD, AC, BF, BE, and BD. The probe blocks and the sequence of blocks were similar to those verifying equivalence relations. The only difference was the reversion of sample and comparison functions in the probes: AF instead of FA, AE instead of EA, and so forth.

Figure 3. Sequence of probe blocks in Experiment 2. Boxes show the trial types and, within parentheses, the total number of trials in the block and the learning criterion. When only one total is presented, there were an equal number of trials of each type. For blocks with probes, totals are presented for baseline trials and probe trials (the latter in italics). There was no learning criterion for blocks with probes. For blocks with baseline-trials only, when no learning criterion is shown, criterion was 100% correct. Blocks without differential consequences for correct or incorrect responses have boxes with dotted lines.

Session 5: Reflexivity probes. The session began with a review of the conditional discrimination baseline. Six blocks of reflexivity probes followed. The first was composed of trials with A1 and A2 as comparison stimuli, with either A1 or A2 as samples, in a randomized order. Subsequent probe blocks presented similar trials for the B, C, D, E, and F stimuli.

Session 6: Stimulus control probes. Session 6 repeated Session 2 and was conducted with all participants.

Results and Discussion

Response Topography and Class Formation

Both groups showed similar acquisition of the baseline. Table 3 shows probe performances of students in both groups. Columns at the left-hand side show performance in probes for transfer of functions, equivalence, transitivity, and reflexivity. For brevity, scores are presented as percentage

Table 3
Performance in Probes of Participants of Experiment 2

Students	Class Formation (% correct)				Class	Control	
	TF	Equiv.	Trans.	Reflex.		S+	S-
Mouse							
HEN	100	99	100	100	AF (4)	5 / 5	5 / 5
ROD	100	99	100	100	AF (4)	5 / 5	5 / 5
PAT	100	95	99	100	AE (3)	5 / 5	5 / 5
AND	40	13	29	60	—	3 / 3	3 / 3
FER	93	100	100	75	AF (4)	5	5
PRI	100	100	100	100	AF (4)	5	5
WIL	100	100	100	100	AF (4)	5	5
VAL	53	24	35	100	—	5	5
Keyboard							
SOR	100	97	97	100	AF (4)	5 / 5	4 / 5
VAN	37	41	31	52	—	4 / 4	4 / 4
OTA	83	84	86	100	AD (2)	5 / 4	5 / 5
FLA	20	96	95	100	AF (4)	5 / 5	4 / 5
ADR	100	99	100	100	AF (4)	4	5
APS	80	100	99	100	AF (4)	4	4
REN	57	45	56	100	—	3	4
LUCI	60	38	61	100	—	5	5

Note. Percentage correct in probes for class formation: transfer of functions (TF), with 42 probe trials; equivalence probes (Equiv.), showing percentage of correct probe trials for relations FA, EA, DA, CA, FB, EB, and DB (totaling 100 probe trials); transitivity probes (Trans.) showing percentage of correct probe trials for relations AF, AE, AD, AC, BF, BE, and BD, totaling 100 probe trials; and the total of 48 reflexivity probes (Reflex.); classes inferred from probe performance; and number of baseline conditional discriminations in which participants showed complete sample-S+ control and sample-S- control (first test/second test).

correct for each of these categories. The following column, labeled "class," presents the equivalence classes that may be inferred from performance in equivalence and transitivity probes. For instance, students HEN and ROD (first two lines) made only one incorrect response each and thus attained

criterion in all probes. This indicates formation of the complete classes, composed of stimuli from A to F, with four nodes (the number of nodes of the classes formed is included within parentheses). Student PAT, on the other hand, scored 95% correct in equivalence probes. Errors, however, occurred mostly in the FA probe. Therefore, she achieved criterion in all equivalence probes but FA, indicating formation of 3-node classes, composed of stimuli from A to E. The following student, AND, did not achieve criterion in any equivalence probe, indicating that classes were not formed.

Five students who made selections with the mouse, HEN, ROD, FER, PRI, and WIL, attained criterion in all probes for transfer of functions, equivalence, and transitivity. One of these students, FER, did not attain criterion in reflexivity probes. Previous experimental contingencies, arranging reinforcement only for selection of comparison stimuli that differed from the sample, may have provided conflicting sources of control in reflexivity probes (cf., Saunders & Green, 1992). The report of the student in the postexperimental interview confirms this hypothesis. Therefore, FER was included among students who showed class formation.

Only two students who made selections with the keyboard, SOR and ADR, attained criterion in all probes for transfer of functions, equivalence, and transitivity. These results replicate findings of Experiment 1, showing that there is a higher probability of class formation when students make selections using the mouse than when they use the keyboard.

If probes for transfer of functions are disregarded, however, there are a total of four students in the keyboard group that showed formation of the four-node classes. The difference between groups is maximal, therefore, in the probes for transfer of functions, the first to be conducted, and virtually disappears from the second probe block on.

Stimulus Control Relations

The right-hand-side columns of Table 3, labeled Control, summarize performance in stimulus control probes. With the S+ present, any response to the novel stimulus or a blank window indicated that the particular sample did not exert complete control over S+ selection. Likewise, any selection of the S-, instead of the new stimulus or a blank window, was taken as evidence that the particular sample did not control S- rejection. Therefore, results were summarized in terms of the number of baseline relations in which complete S+ control was found and the number of baseline relations for which complete S- control was found. Any number smaller than 5 indicates that S+ (or S-) control was imperfect in at least one baseline conditional discrimination. For students who received probes in both Sessions 2 and 6, both scores are presented, separated by slashes.

The scores in Table 3 confirm the hypothesis that selecting stimuli with the mouse increased the probability of sample-S+ relations. Among the 8 students who made selections with the mouse, 7 showed complete sample-S+ control in all baseline conditional discriminations. Only 2 students who made selections with the keyboard showed complete sample-S+ control in all baseline relations.

Sample-S+ control is not incompatible with sample-S- control. A response may be controlled both by S+ selection and rejection of the S-. It is interesting that students who made selections with the mouse also showed more complete

sample-S- control in baseline relations. All 7 students in the mouse group who showed complete sample-S+ control also showed complete sample-S- control. In the keyboard group, only 3 students showed complete sample-S- control in all baseline relations.

According to the logical demonstration of Carrigan and Sidman (1992), if one or more baseline performances are controlled exclusively by a sample-S- relation, the expected outcomes of equivalence tests should not be obtained. If this analysis is correct, accurate performance showing formation of four-node classes in this study should be expected only from students who showed complete sample-S+ control, regardless of response topography. Table 4 shows that a total of 9 students showed complete sample-S+ control (7 in the mouse group and 2 in the keyboard group). Seven of these students showed complete formation of four-node classes (5 in the mouse group and 2 in the keyboard group). Among the 7 students who did not show complete sample-S+ control, only 2 showed formation of four-node classes.

Table 4
Number of Students Who Formed Four-Node Classes as a Function of Sample-S+ Control

S+ control	Formed Class: Mouse		Formed Class: Keyboard	
	Yes	No	Yes	No
Complete	5	2	2	0
Incomplete	0	1	2	4

The results are highly consistent with the predictions based on the analysis by Carrigan and Sidman. The consistency is particularly striking, considering the limitations of the probe method. The most important of these limitations are the following. First, stimulus control may change with time, and the probes themselves may occasion changes in stimulus control relations. Therefore, it is not always certain that stimulus control relations that prevailed during equivalence probes were the same that prevailed during stimulus control probes. Second, few probes were conducted with each sample, to minimize the chances that probes themselves would induce changes in stimulus control relations. Assuming that, when a sample-S+ control relation was not perfect, the student would choose randomly between stimuli, the probability of two selections of the S+ would be 0.25, and sample-S+ control would be incorrectly inferred. The probe method entailed, therefore, a relatively high probability of false-positive results. Third, the introduction of new stimuli may have introduced new sources of control, so that probes may not have reflected exactly the controlling relations that prevailed during the baseline.

Limitations such as these are inherent in any method based on probes. In view of these limitations, the general consistency in the results lends considerable strength to the conclusions that perfect sample-S+ control was more probable when students made selections with the mouse and that formation of complex stimulus classes may be predicted on the basis of baseline stimulus control relations.

General Discussion

Current views on stimulus equivalence predict that once baseline conditional discriminations have been acquired, according to an appropriate logical design, emergent relations will be shown. Some features of the

logical design can retard class formation or decrease its probability, such as the number of nodes (e.g., Sidman et al., 1985; Fields et al., 1990) and the differences in the discriminations of test stimuli established by each training design (Saunders & Green, 1999). According to some theories, class formation does also depend on the verbal repertoire of participants and collateral verbal responses (e.g., Horne & Lowe, 1996).

Studies and theories have not given much attention to "human factors" involved in the task, such as responses and stimulus display. Responses are probably chosen for their convenience, considering the available equipment and software, as well as the ability of participants to learn them. Commonly used responses have been touching the stimulus, pressing keys or buttons corresponding to stimulus location, and moving a mouse. Other responses have been also used, such as lifting a three-dimensional object in a Wisconsin General Test Apparatus (Pilgrim & Galizio, 1990) and drawing a circle around a printed word (Kennedy, Itkonnen, & Lindquist, 1994). Results are typically compared with respect to the logical training designs or the verbal repertoire of participants, regardless of differences in the responses used.

The literature on stimulus equivalence has tended to ascribe great relevance to data about failures to show stimulus equivalence. Data showing that participants with no language did not show class formation (Devany et al., 1986) or that stimulus equivalence was less likely to emerge when participants did not name the stimuli (Eikeseth and Smith, 1992) are the major empirical support of theories about the role of naming in stimulus equivalence (e.g., Horne & Lowe, 1996). Data showing that stimulus equivalence or transfer of functions is less likely or delayed with a larger number of nodes support the notion that "relatedness of stimuli" is an inverse function of nodal distance (Fields et al., 1995). Theoreticians accounted failures to show equivalence on the basis of the verbal repertoire of participants or the training designs. However, in the present study, an apparently irrelevant change of response topography changed the efficacy of a four-node linear design.

Experiment 2 permits the inference that the different response topographies influenced the stimulus control relations established in conditional discrimination training. Carrigan and Sidman (1992) argued that this would affect the outcomes of equivalence tests. They demonstrated that the expected equivalence performances are obtained only when baseline conditional discriminations have been acquired under homogeneous sample-S+ control. Homogeneous sample-S- control would generate other equivalence relations, also predictable but different from those arisen from sample-S+ control. Heterogeneous control, that is, some relations acquired with sample-S+ control and others acquired with sample-S- control, would lead to unpredictable results in tests for equivalence. The present results are compatible with this analysis. The probability of complete sample-S+ control was higher for students who used the mouse, and equivalence class formation was more probable given complete sample-S+ control.

However, students who used the mouse and showed complete sample-S+ control also showed complete sample-S- control. Students who used the keyboard also had a lower probability of showing complete sample-S- control. The 7 students in the mouse group that formed four-node classes showed both complete sample-S+ control and complete sample-S- control. The pattern of probe results of students in the keyboard group can be better interpreted

as a mixture of controlling relations: some samples controlled both selection of the S+ and rejection of the S-, whereas other samples controlled only selection of the S+ or rejection of the S-.

Responding with the mouse required that students observe the cursor movement on the screen and the relative locations of the cursor and the S+ comparison. This is likely to have increased visual contact with sample and comparison stimuli, so that students learned more about the relation of the sample with both the S+ and the S-.

The analysis of Carrigan and Sidman (1992) states that complete and homogeneous sample-S+ control is sufficient to engender class formation. If this analysis is true, the fact that students in the mouse group also learned about the relation between samples and S- was not necessary for class formation. The difference in the equivalence outcomes of both groups could be explained solely on the basis that complete sample-S+ control develops more reliably when students use the mouse. Moreover, equivalence outcomes could be predicted, regardless of class formation, on the basis of sample-S+ relations in baseline conditional discriminations. Participants with complete sample-S+ control would be expected to show class formation, whereas those with incomplete sample-S+ control would be expected not to show class formation. Small discrepancies in these predictions would be due to the limitations of the probes to assess baseline controlling relations.

An alternative explanation would take into account also sample-S- relations, stating that learning more about the relations between samples and both S+ and S- would increase the likelihood of class formation. Since, in the present study, participants who showed complete sample-S+ control also tended to show complete sample-S- control, it is difficult to determine whether sample-S- control was necessary or not for class formation. This could be done with a method that induced particular controlling relations (e.g., Johnson & Sidman, 1993), so that equivalence outcomes could be compared for participants who learned only sample-S+ relations and participants who learned both sample-S+ and sample-S- relations.

It is not surprising that response topography affects stimulus control relations. The topography with the mouse requires students to place the cursor on the sample, press the mouse button, producing the comparisons, then move the cursor onto the S+ and press the mouse button. The participant is required to look at the screen and follow the movement of the cursor. Responding with the keyboard, on the other hand, is made away from the stimuli. The participant can press a key while looking at the S+, the S-, or none of them. Another possible explanation, which does not exclude the first one, is that responding with the keyboard required equivalences between particular keys and particular locations. These equivalences may interfere with the equivalences between the visual forms, increasing the probability of a disruption of stimulus equivalence for participants who use the keyboard.

The present results indicate that the efficacy of training parameters for equivalence class formation cannot be evaluated regardless of human factors, like the kind of response used and particular controlling relations or other equivalence relations induced by this response. Since stimulus equivalence is at the core of many academic performances (e.g., de Rose, de Souza & Hanna, 1996; Lynch & Cuvo, 1995; Mackay & Sidman, 1984), this

should also be a factor considered in the design of computerized instruction programs. For instance, programs that use tasks similar to conditional discriminations might implement responses that explicitly require students to look at the stimuli, to increase the probability of learning about the relations between stimuli.

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Appendix:

English Translation of the Printed Sheet
Received by Participants for Informed Consent

You will participate in research on teaching methods. Our interest is in knowing about efficient ways to teach. This research is not a test: the methods used do not permit conclusions about participants' individual characteristics. At the moment, we cannot give you more information about the research. However, after you finish your participation, we will impart any information you may be interested in.

Your task will be to choose among pictures that will appear on the microcomputer's screen. When the experiment begins, you will receive additional instructions on how to do that.

The computer will automatically record your choices. At the end of each session, you will receive points, corresponding to your percentage of correct choices during the session. Therefore, you can receive up to 100 points in one session. At the end of your participation, you will know how many points you made in each session and will receive a money payment corresponding to the total of points you made. Each 100 points will be worth R\$2.50.

You can do more than one session in the same day, but a minimum interval between sessions is necessary. In such cases, you will decide when you are ready for the next session.

You will be paid for your participation only if you attend all scheduled sessions, with a maximum interval between sessions of 3 days. You are expected to let the experimenter know beforehand if you, for any reason, cannot attend a scheduled session. Please try to be on time for the sessions.

We request that you do not talk to other people, especially other college students, about your participation in this research.

I agree to participate in the research, in the conditions described above, and I agree not to talk to other people about the research.

signature