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Equivalence relations and the contextual control of multiple derived stimulus functions

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Contextual control is a key aspect in equivalence research to support the claim that stimuli may have multiple functions or symbols may have multiple meanings. The present study investigated the contextual control of multiple derived stimulus functions in two experiments. In Experiment 1, equivalence classes were formed and one stimulus set from each class was used to establish two different functions: one via positive reinforcement (key-pressing) and another via negative reinforcement (button clicking), both under contextual control of two different background colors. Later, other stimuli from the equivalence class were presented on those background colors and contextual control of multiple derived stimulus functions was assessed. Experiment 2 added a third background in which no programmed response was reinforced, that is, responses were extinguished. Transfer-of-function tests revealed contextual control of three different functions, including derived extinction. Implications for equivalence relations as a behavior-analytical model of symbolic functioning are discussed.

Key words: stimulus equivalence, contextual control, multiple derived stimulus functions, transfer of function, Cfunc, humans

After mastering a small number of conditional discriminations (e.g. relations AB, BC), human participants are often able to exhibit new relations that emerge or derive from the relations taught directly. Emergent relations may show that taught relations had the properties of reflexivity (e.g., AA, BB, CC), symmetry (e.g., BA, CB) and transitivity (e.g., AC)—properties that together define *equivalence relations* (Sidman, 1994; Sidman & Tailby, 1982).

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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. The Human Research Ethics Committee previously approved (protocol CAAE 56575216.7.0000.5196) all procedures performed in the present research.

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Sidman's analysis of emergent behavior in terms of derived relations positioned behavior analysts to account for many aspects of symbolic behavior. For instance, the bidirectional property of symmetry is functionally similar to referential meaning, suggesting that "The word is a symbol for the referent and the referent is the meaning of the word because both are members of the same equivalence class. In this sense, stimulus equivalence transforms nonlinguistic conditional discriminations into semantic process (Sidman, 1986)" (Wulfert & Hayes, 1988, p. 126; see also de Rose & Bortoloti, 2007).

Beyond the typical dependent measures used in equivalence research, studies revealed that equivalence preparations produce results similar to those obtained with typical measures used in research on symbolic functioning, such as the semantic differential (Bortoloti & de Rose, 2009; Perez et al., 2019, 2020), the semantic priming task (Barnes-Holmes et al., 2005; Bortoloti & de Rose, 2011), the semantic false memories task (Guinther & Dougher, 2010, 2014) and the N400 neuroactivity measured using electroencephalography (e.g., Bortoloti et al., 2014; Haimson et al., 2009; Silveira et al., 2018).

Many aspects of equivalence relations as a model for symbolic functioning were addressed in Sidman's research (see Sidman, 1994 for a review). One aspect was that words may have different meanings. For instance, the word "cancer" spoken at a hospital may yield behavioral outcomes that differ as compared to the word "cancer" spoken in a conversation about astrology. Sidman (1986, 1992, 1994; see also Bush et al., 1989) suggested that the reorganization of equivalence classes by a contextual stimulus (e.g., Bush et al., 1989; Kennedy & Laitinen, 1988; Kohlenberg et al., 1991; Lazar & Kotlarchyk, 1986; Wulfert & Hayes, 1988) would functionally parallel words having multiple "meanings" (or functions; see Bortoloti & de Rose, 2011). Using five-term contingencies of reinforcement, the conditional discriminations that comprise equivalence classes might be rearranged depending on another stimulus. For instance, in Context 1, responses consistent with the classes A1B1C1 and A2B2C2 are reinforced whereas in Context 2, the classes are changed to A1B2C2 and A2B1C1. In the former case, suppose the word "cancer" (A1) would be in an equivalence class with "diagnose" (B1) and "illness" (C1), for instance; in the latter, the word "cancer" (A1) would be in an equivalence class with "signs" (B2) or "personality traits" (C2). In these cases, the contexts of being in a conversation with a doctor (Context 1) or with an astrologer (Context 2) would "reorganize" the equivalence classes to support effective action with a particular audience.

Describing the general case, Sidman wrote "Common experience informs us about contextual control. Everyday observation tells us that things, events, and symbols can be classified in more than one way, depending on what the situation calls for" (Sidman, 1994, p. 476). Aligned with Sidman's (1994) analysis, other researchers have suggested that the contextual control of stimulus functions is a key feature for a behavioral account of language (Dougher et al., 2002; Hayes et al., 2001; Hayes et al., 1991; Hayes & Hayes, 1989, 1992; Perez, Fidalgo, et al., 2015; Perez et al., 2017; Perkins et al., 2007; Wulfert & Hayes, 1988).

Other studies have addressed the contextual control of "meaning" using transfer of function preparations. These studies (e.g., Barnes et al., 1995; Perez, Fidalgo et al., 2015) established multiple functions under contextual control for a stimulus belonging to a particular equivalence class. Later, other stimuli from the same class were presented in the contexts in which the stimulus functions were first established and potentially derived transfer of functions was assessed. Barnes et al. (1995) investigated the transfer of discriminative functions for stimuli related through equivalence in 6-year-old children. In the early phases of their experiment, two 3-member equivalence relations were established (A1B1C1 and A2B2C2). After children were taught to clap their hands given B1 and to wave given B2, C1 and C2 stimuli were presented on no-feedback probe trials, and the occurrence of clapping and waving was measured. Evidence for transfer of function was obtained when discriminative functions trained for B1 and B2 (B1 → clap and B2 → wave) also occurred given the presence of their equivalent stimuli, C1 and C2 (C1 → clap and C2 → wave), respectively. Subsequently, colors provided contextual cues for responding. When a yellow contextual cue was present, the children had to respond B1 → clap and B2 → wave; when the cue was blue, the contingencies were reversed. Evidence for the transfer of function was obtained when C1 and C2 evoked the same responses as B1 and B2, respectively, given the presence of the yellow and blue contextual stimuli.

Perez, Fidalgo et al. (2015) replicated Barnes et al. (1995) with adults. Initially, two 5-member equivalence classes were established: A1B1C1D1E1 and A2B2C2D2E2. Participants then learned different key-pressing responses in the presence of the B stimuli depending on the background color (Blue/B1 → press X, Blue/B2 → press Z, Yellow/B1 → press M, Yellow/B2 → press N). In a transfer-of-function test C, D and E stimuli were presented on the different colored backgrounds. Results suggested that the colored backgrounds contextually controlled participants' key-pressing responses in the presence of any stimulus from the five-member equivalence class (e.g., Blue/C1 → press X, Blue/C2 → press Z, Yellow/C1 → press M, Yellow/C2 → press N).

In both studies (Barnes et al., 1995; Perez, Fidalgo et al., 2015), the change in the context (background) modulated the response occasioned by the stimuli from a particular equivalence class. Both studies, however, established two discriminative functions by programming positive reinforcement contingencies. Thus, the argument that the background colors contextually controlled multiple derived stimulus functions applied only to the situation in which similar response topographies were shaped by similar contingencies of reinforcement. The present study aimed to extend previous findings from Barnes et al. (1995) and Perez, Fidalgo et al. (2015) by establishing two different stimulus functions for B stimuli under control of the background colors: a key-pressing response established by positive reinforcement (Yellow/B1 → press Z, Blue/B2 → press Z) and a mouse-click response established by negative reinforcement (Blue/B1 → button click, Yellow/B2 → button click). Later, other stimuli from the same equivalence class were presented in the colored backgrounds to assess the contextual control of multiple derived stimulus functions (Yellow/D1 → press Z, Blue/D2 → press Z, Blue/D1 → button click, Yellow/D2 → button click).

Experiment 1

Method

Participants

Four adults (M = 3 and F = 1) ranging in age from 24 to 32 (M = 26.75; SD = 7.39) served. None had had previous experience with research in psychology. Participants read a term of consent approved by the ethics committee (protocol CAAE 56575216.7.0000.5196) before the experiment began. In this term, participants were also informed that they could discontinue participation at any time. Data collection occurred in a single session. Afterwards, all participants were fully debriefed on the study goals and how its procedures helped answer its research questions.

Setting, Equipment and Stimuli

Data collection took place in quiet room equipped with a chair, a table and a notebook model HP g42 215. Custom-written software in VB 6.0 (Delayed MTS 1.0: Perez, 2013; MultipleFunctions 2.0: Perez, 2014) controlled stimulus presentation and recorded participants' responses. Stimuli were the same used in Perez, Fidalgo et al. (2015) and were nonsense figures (Wingdings, Black, font size 14).

During matching-to-sample training (Phase 1), programmed consequences for correct responding were the successive presentation of the word "CORRECT" and of a sequence of ascending notes (Windows®, chimes.wav); incorrect responses were followed by the word "INCORRECT" and by the presentation of a dissonant chord (Windows®, chord.wav). During key-pressing training (Phase 2 and Phase 3), correct response were followed by the positive consequence sound and 10 points accumulated in a counter in the upper-center portion of the screen. Incorrect responses were followed only by the dissonant sound and no added points.

Procedure

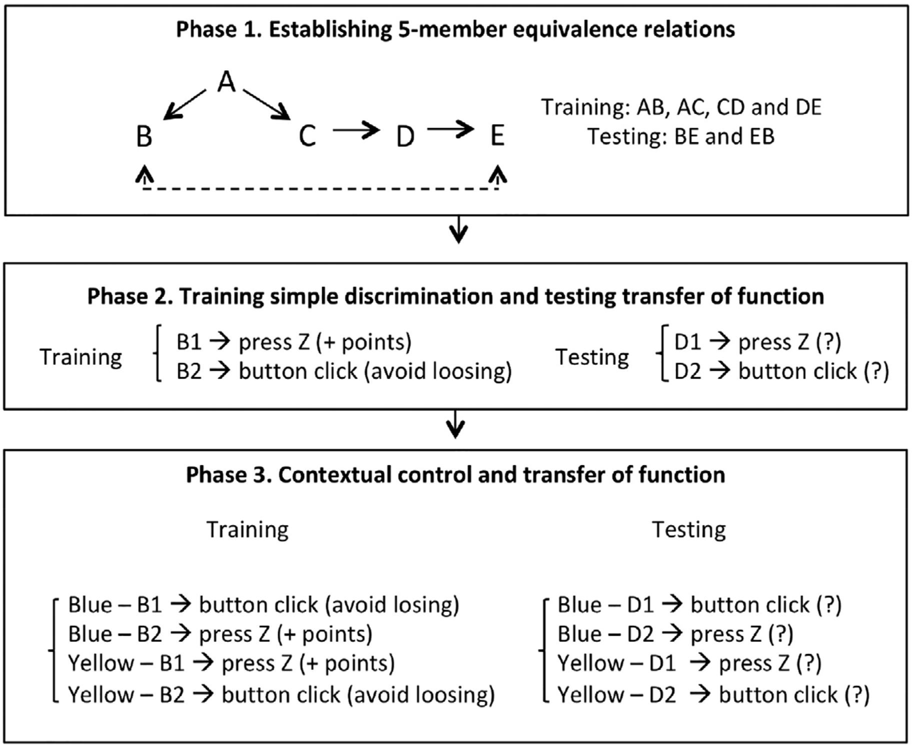
Figure 1 outlines the experimental phases. Phase 1 aimed to establish two 5-member equivalence classes (A1B1C1D1E1 and A2B2C2D2E2). Phase 2 trained a particular response for one member of each class (B1 → press Z, B2 → button click) and tested the transfer of function (D1 → press Z? and D2 → button click?). Phase 3 established contextual control by a colored background over two different functions (e.g., Blue-B1 → press Z, Yellow-B1 → button click) and tested the contextual control over the transfer of function presenting other stimuli from equivalence classes on the colored backgrounds (e.g., Blue-D1 → press Z?, Yellow-D1 → button click?).

A mixed one-to-many (AB, AC) + linear (CD, DE) training structure was implemented (e.g., Bortoloti & de Rose, 2009; Perez et al., 2019, 2020; Perez, Fidalgo, et al., 2015) to increase experimental control regarding two aspects (see Dymond & Rehfeldt, 2000 for further discussion): To document genuine transfer of function (1) the stimulus set used during transfer-of-function tests should not be used in equivalence tests and (2) equivalence tests with all stimulus sets should be avoided so that apparent transfer-of-function effects could not be attributed to any second-order respondent type or stimulus compounding process (Barnes & Keenan, 1993; Rehfeldt & Hayes, 1998; Wulfert et al., 1991).

In our study, the mixed training structure allowed (1) using a separate stimulus set (i.e., D) exclusively for transfer-of-function tests and (2) conducting a subsequent equivalence test (BD/DB) that would assess indirectly the properties of reflexivity, symmetry and transitivity in all other relations of the experimentally defined classes (cf. Sidman, 1994, p. 224).

Establishing Five-member Equivalence Classes. A matching-to-sample (MTS) task was implemented to establish two 5-member equivalence classes. Before starting this phase, the participants read the following instructions on the screen (in Portuguese):

Figure 1
Experiment 1: Summary of the Experimental Phases



> *Some figures will be presented on the monitor screen. Each trial will begin with a figure presented in the center. After you click on it, three other figures will appear in the corners and only one must be chosen. To choose a given figure, just click on it. Correct choices will be followed by a soft sound and the word CORRECT; incorrect choices will be followed by a dissonant sound and the word INCORRECT. As you progress in this task, there will be a moment when the computer will no longer give you any feedback. However, it will keep recording your responses, evaluating your hits and errors.*
> *Have a good game!*

The training started establishing AB relations (A1B1 and A2B2). On each trial onset a stimulus from set A (A1 or A2) was presented in the center of the screen as a sample stimulus. A mouse click on the sample stimulus immediately produced three comparison stimuli (B1, B2 and B3) in the lower portion of the screen aligned side-by-side. Clicking the class-consistent comparison stimulus (e.g., B1 given A1) was the correct response, and clicking any others was incorrect (e.g., B2 or B3 given A1); visual/auditory consequences were provided accordingly. A 2-s intertrial interval (ITI) separated the delivery of consequences from the next trial onset. Note that the third comparison stimuli (e.g., B3) were never correct options and did not belong to any particular class. Three comparison stimuli were used to discourage the establishment of reject control (e.g., Perez, Tomanari et al., 2015; Sidman & Tailby, 1982).

Sample stimuli were presented in a quasirandom order with the constraint that the same stimulus could not be presented more than five times consecutively. Across trials, comparison stimuli were quasirandomly presented in each location with the constraint that the same stimulus could not be presented more than five times consecutively in the same position. Training continued until participants met the mastery criterion of 36 consecutive correct responses. This mastery criterion was used throughout the training MTS phase.

After the participant met the mastery criterion during AB training, AC (A1C1 and A2C2) training started immediately following the same parameters, followed by CD (C1D1 and C2D2) and DE (D1E1 and D2E2) relational training. After mastering each particular set of relations separately, mixed AB+AC+CD+DE training took place. Achieving the mastery criterion immediately initiated a 16-trial block (two trials for each AB, AC, CD and DE relations) with no feedback. Equivalence tests started if the participant maintained 100% of correct responses. If accuracy was below criterion, then the mixed training and the no-feedback training block were repeated.

Equivalence tests involved testing for BE (B1E1 and B2E2) and EB (E1B1 and E2B2) derived relations in a single test block composed of 24 trials (six for each relation) with no feedback. BE and EB trials were randomly presented following the same criterion used during training. The criterion for passing the testing block was 85% of class-consistent correct responses. If the participant did not meet the criterion, then the mixed training was reviewed and the test block was repeated once more. If the participant again failed to meet criterion, s/he was thanked and debriefed and did not progress further.

Establishing a Simple Discrimination and Testing for Transfer of Function. This phase aimed to establish two different functions for B1 and B2, respectively. Each trial onset began with B1 or B2 on the center of the screen along with two images presented, one in each lower corner of the screen: an image of the key Z on the keyboard and an image of a red button. The stimuli presentation initiated a 5-s interval in which the participant had to emit one of two responses: to press the key Z or to mouse-click the red button. Whenever B1 was presented, pressing Z was followed by 10 points added to a counter at the end of the interval; any other response or no response produced no programmed consequences. Whenever B2 was presented, a single mouse-click on the red button avoided losing 5 points at the end of the interval; any other response was followed by losing 5 points. The delivery of consequences occurred after the 5-s training trial elapsed. Consequence presentation occurred during a 2-s interval in which all stimuli were withdrawn from the screen and a counter was presented in the central upper portion. Points added to the counter occurred along with the message "+10 points" below it and the simultaneous presentation of the ascendant sequence of notes; point subtraction occurred with the message "-5 points" below the counter and simultaneous presentation of the dissonant sound. If no points were added or subtracted, only the counter and the number of points accumulated were presented during the 2-s interval. A 1-s ITI immediately followed the delivery of consequences. Another 5-s training trial followed the ITI.

Before starting Phase 2, the participant read the following instruction on the screen:

> *The computer will show you one of two figures in the center of the screen. Learn what you have to do in the presence of each of them. For one of them you must press Z to earn points in a counter; for the other, you must click on the red button to avoid losing points. Your goal is to earn as many points as you can, by learning what to do in the presence of each figure. Later, in this task, the computer will no longer give you any feedback. That is, the counter will be withdrawn. In this case, the computer will keep recording your points. Then, keep responding considering what you have learned in the previous phases.*

During training, B1 and B2 trials were randomly displayed. However, the same stimulus would not be presented on more than three consecutive trials. Training ended once the participant met the mastery criterion of 36 consecutive correct responses (B1 → pressing Z, B2 → button clicking). After that, a 36-trial block with no feedback started. During this block, and also during tests, only the ITI followed the 5-s training interval (i.e., no counter was presented). If the performance was maintained (100% of correct responses), the transfer of function tests began. If not, the participant was re-exposed to the training followed by the block without feedback until s/he met mastery criterion. The transfer-of-function test block presented D1 and D2 five

Table 1

Experiment 1: Participants' Results During Phase 1

Experimental phase			Participants			
			S1	S2	S3	S4
1	Training (# trials until mastery criterion)	AB	38	46	39	40
		AC	38	47	38	42
		CD	49	38	37	36
		DE	58	38	39	83
		AB+AC + CD + DE	70	36	37	36
		AB+AC + CD + DE (no feedback)	15/16	16/16	16/16	16/16
	Test (correct responses/test trials)	BE+EB	24/24	19/24	24/24	24/24

times each. The criterion to advance to the next phase was 80% correct responses during test. If the participant did not pass the test, s/he were exposed to the training and testing once more. Not passing the second test ended her/his participation in the experiment.

Contextual Control and Transfer of Function Test. During this phase, responses to B1 and B2 stimuli were established under contextual control of two background colors in which the stimulus was presented: Blue and Yellow. When the background color was Blue, correct responses were: Blue-B1 → button click, Blue-B2 → press Z; when the background color was Yellow, correct responses were: Yellow-B1 → press Z, Yellow-B2 → button click. Each trial onset presented B stimuli in one of the two possible background colors in a quasirandom order with no combination presented more than three times consecutively. Before initiating Phase 3, the participant read the following instruction on the screen:

> *In this phase you will use the two response options that you have learned: 1) press Z to earn points or 2) click on the red button to avoid losing points. Now, pay close attention to the background color in which the figure is presented. That will determine which of the two response options is correct in the presence of each figure. As you progress, the computer will no longer give you any feedback. That is, the counter will be withdrawn. In this case, the computer will keep recording your points. Then, keep responding considering what you have learned in the previous phases.*

The parameters for training trials and the mastery criterion were the same as in the previous phase. Once the participants met mastery criterion, a no-feedback training trials block began. If the participant's performance was maintained, transfer of function tests began. The transfer-of-function test presented D1 and D2 stimuli five times each on each background within a single 20-trial test block. Contextual control was documented if participants performed in accordance with the following

Table 2

Experiment 1: Participants' Results During Phase 2 and Phase 3

	Task		Participants			
Exp. Phase	Press Z/button click	Set	S1	S2	S3	S4
2	Training (# trials until mastery criterion)	B	42	40	79	50
		B (ext.)	36	36	35	36
	Test (correct responses/test trials)	D	8/10	9/10	10/10	9/10
3	Training (# trials until mastery criterion)	B	50	78	179	61
		B (ext.)	36	36	36	36
	Test (correct responses/test trials)	D	18/20	19/20	19/20	19/20

class-consistent responses: Blue-D1 → button click, Blue-D2 → press Z, Yellow-D1 → press Z, and Yellow-D2 → button click.

Results

Table 1 presents results from the equivalence training and testing (Phase 1). All participants mastered the conditional relations and most scored high during tests. The only exception was S2, who scored 79% during equivalence testing, but whose inaccurate responses occurred at the beginning of the test block and were accurate for the rest of the block. Thus, we allowed S2 to progress to the next phase without test repetition.

Table 2 present results from Phase 2 and Phase 3. All participants reached criterion during the simple discriminative training with B stimuli and showed transfer of function during tests with D stimuli. The same happened during the contextual control training with the background colors and during transfer-of-function tests presenting D stimuli on the two different backgrounds.

Discussion

Studies have separately documented the transfer of many stimulus functions such as discriminative (e.g., de Rose et al., 1988), respondent (e.g., Dougher et al., 1994; Luciano et al., 2014), avoidance (e.g., Augustson & Dougher, 1997; Luciano et al., 2014), consequential (e.g., Hayes et al., 1991), and contextual functions (e.g., Gatch & Osborne, 1989; Perez, Fidalgo et al., 2015; Perez et al., 2017). Few studies, however, have explored the contextual control of multiple derived stimulus functions. One example was Hayes et al. (1991) that investigated the transfer of two consequential functions (derived reinforcer or derived punisher) using contextually controlled equivalence classes. The present study assessed the contextual control of derived responses originally established via positive and negative reinforcement contingencies. These results expand the generality of the contextual control of derived functions shown in the laboratory (e.g., Barnes et al., 1995; Perez, Fidalgo et al., 2015; Hayes et al., 1991; Wulfert & Hayes, 1988). In addition, this study replicates previous studies on the contextual control of multiple derived functions using an experimental preparation that established more than one function for the same stimulus instead of establishing different functions for different stimuli and contextually reorganizing the equivalence classes (Hayes et al., 1991). It also extended the contextual control to novel functions and response topographies (Barnes et al., 1995; Dougher et al., 2002; Hayes et al., 1991; Perez, Fidalgo et al., 2015; Perkins et al., 2007; Wulfert & Hayes, 1988).

Although S2 had an imperfect score during equivalence tests, that did not affect performance during transfer-of-function tests. The transfer of multiple functions under contextual control was showed immediately for all participants, and neither training nor test repetition was needed. As equivalence relations increase in complexity (e.g., Bush et al., 1989), so too would the transfer of function tests. We might expect more participants to fail under such circumstances. This did not happen in the present study or in Perez, Fidalgo et al. (2015), thus suggesting that the contextual control of derived functions is a robust and replicable phenomenon.

A limitation of Experiment 1 was that programmed contingencies for each background color determining a specific stimulus function were fixed for all participants. Although specific color influence on particular functions seems unlikely, this limitation was addressed in Experiment 2.

Experiment 2

Another important aspect of symbolic function regards contexts in which some of the multiple derived stimulus functions are under extinction. As suggested by Sidman (1992):

> (…) the words 'Route 128' on the map, and the road on which we are driving are equivalent when we are trying to find our way to an unfamiliar place, but we do not try to drive our car onto the words, or to illuminate the road with a reading light. We do not try to eat the word 'bread', or to swat the word, 'fly.' (…) We really would, for example, eat the word 'bread,' did we not learn through experience or through rules that words, even when equivalent to foods, are not eatable. (Sidman, 1992 p. 22)

As noted above, contextual control is also important to prevent the occurrence of particular derived responses. Few experiments have explored this issue (Dougher et al. 2002; Perkins et al. 2007). Dougher et al. (2002) established one context in which responses in accordance with transfer of functions were reinforced and another in which responses in accordance with transfer of functions were punished. Adult participants were exposed to a MTS task that aimed to establish three 5-member equivalence classes, A1B1C1D1E1, A2B2C2D2E2 and A3B3C3D3E3. Next, specific stimulus functions were established for stimuli B1, B2 and B3. After that, equivalent stimuli (e.g., C1, C2, C3) were presented on a red or a blue background. When the background color was red, class-consistent derived responses (transfer of function) were reinforced (i.e., respond to C1 as trained for B1; respond to C2 as trained for B2, etc.); when the background was blue, however, responses in accordance with transfer of function were punished. As multiple-exemplar training with different types of responses (e.g., sequencing, key-choice, color sorting) progressed, transfer of function occurred in the presence of the red background but not in the presence of the blue background. Perkins et al. (2007) systematically replicated that study, finding also that transfer of function may be reinforced and punished for specific stimuli of a given class (for instance, transfer to B stimuli but not for D stimulus set). A possible limitation of these studies was that only discriminative functions established by positive reinforcement were programmed throughout the experimental phases.

Experiment 2 examined an experimental analogue to the phenomenon described by Sidman (1992) in the 'Route 128' example. It systematically replicated Experiment 1 by adding a context in which responses were under extinction to those established by positive and negative reinforcement contingencies. First, we established three different stimulus functions for B stimuli under control of the background colors: a key-pressing response established by positive reinforcement (e.g., Blue/B1 → press Z), a mouse-click response established by negative reinforcement (e.g., Yellow/B1 → button click), and a third context in which no response had any programmed consequence, namely extinction (e.g., Purple/B1 → extinction). Later, stimuli from the other members of the equivalence class were presented in the colored backgrounds to assess the contextual control of multiple derived stimulus functions (e.g., Blue/D1 → press Z, Yellow/D1 → button click, Purple/D1 → extinction).

Method

Participants

Three adults (M = 1 and F = 2) served. They ranged in age from 24 to 28 (M = 26; SD = 2). None had previous experience with research in psychology. Ethical standards and debriefing were as described in Experiment 1.

Setting, Equipment and Stimuli

These were the same as described in Experiment 1.

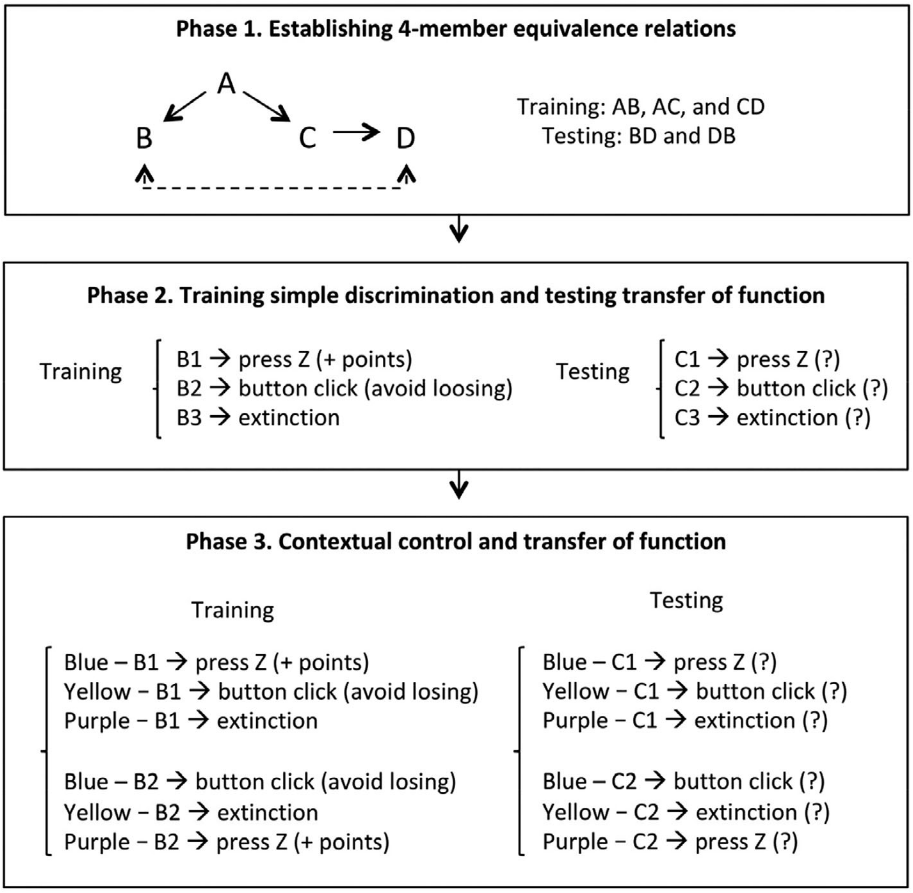
Procedure

Figure 2 presents an outline of the experimental phases. Phase 1 aimed to establish three 4-member equivalence classes (A1B1C1D1, A2B2C2D2, and A3B3C3D3). Phase 2 trained a particular response for one member of each class (B1 → press Z, B2 → button click, B3 → extinction) and tested transfer of function (C1 → press Z?, C2 → button click?, C3 → extinction?). Phase 3 established contextual control by a colored background over two different functions (e.g., Blue-B1 → press Z, Yellow-B1 → button click, Purple-B1 → extinction) and tested for contextual control of transfer of function by presenting other stimuli from equivalence classes on the colored backgrounds (e.g., Blue-C1 → press Z?, Yellow-C1 → button click?, Purple-C1 → extinction?).

Considering that Experiment 2 increased the complexity of training and tests for transfer of function, we decided to reduce the size of the stimulus sets from five members to four to reduce the time spent on the task and to avoid fatigue. Notably, studies in our laboratory (e.g., Perez et al., 2019; 2020) and by others (e.g., Bortoloti & de Rose, 2009) have shown robust effects with similar training and testing structures.

Establishing 4-member Equivalence Classes. A matching-to-sample (MTS) task was implemented to establish three 4-member equivalence classes (A1B1C1D1, A2B2C2D2, and A3B3C3D3). Instructions and most of the parameters of the training and testing trials

Figure 2
Experiment 2: Summary of the Experimental Phases



were the same as in Experiment 1. AB (A1B1, A2B2, A3B3), AC (A1C1, A2C2, A3C3) and CD (C1D1, C2D2, C3D3) relations were taught separately until participants met a mastery criterion of 16 consecutive correct responses at each training step. After that, a mixed AB+AC + CD training was presented until a mastery criterion of 36 consecutive correct responses. Mastering training relations in the mixed block immediately initiated equivalence tests. Equivalence tests involved testing for BD (B1D1, B2D2, B3D3) and DB (D1B1, D2B2, D3B3) derived relations in a single test block composed of 24 trials (four for each relation) without feedback.

Establishing a Simple Discrimination and Testing for Transfer of Function. This phase aimed to establish three different functions for B1, B2 and B3, respectively. Training and testing parameters were similar to those described in Experiment 1. Each trial began with the presentation of B1, B2 or B3. If B1 was presented, pressing Z was followed by 10 points added to a counter by the end of the interval; any other response or no response had no programmed consequences. If B2 was presented, a single mouse-click on the red button avoided losing 5 points by the end of the interval; any other response was followed by minus 5 points in the counter. If B3 was presented, no response produced any programmed consequence. Before starting Phase 2, the participant read the following instruction on the screen:

> *The computer will show you one of two figures in the center of the screen. Learn what you have to do in the presence of each of them. For one of them you must press Z to*

earn points in a counter; for the other, you must click on the red button to avoid losing points; when pressing Z does not make earning points and clicking of the red button does not avoid losing them, you must simply wait for the next trial onset. Your goal is to learn what to do in the presence of each figure: to press Z, to click on the red button or wait for the next trial.

During training, B1, B2 and B3 trials were quasirandomly presented. The same stimulus would not be presented for more than three consecutive trials. Training ended once the participant met the mastery criterion of 18 consecutive correct responses (B1 → pressing Z, B2 → button clicking, B3 → no response). After that, the transfer of function test began. Before starting the testing phase, the participants read the following instruction on the screen:

Later, in this task, the computer will no longer give you any feedback. That is, the counter will be withdrawn. In this case, the computer will keep recording your points. Then, keep responding considering what you have learned in the previous phases.

The transfer-of function test presented C1, C2 and C3 six times each in a single 18-trial test block. The criterion to advance to the next phase was 88% of correct responses. If the participant did not pass the test, they were exposed to the training and testing once more. Not passing the test in a second round ended their participation.

Contextual Control and Transfer of Function Test. During this phase, responses to B1 and B2 stimuli were established under contextual control of three background colors in which the stimulus was presented: Blue, Yellow and Purple. The particular function specified for each background was randomized across participants. As one example, if the background color was Blue, correct responses were: Blue-B1 → press Z, Blue-B2 → button click; if the background color was Yellow, correct responses were: Yellow-B1 → button click, Yellow-B2 → extinction; if the background color was Purple, correct responses were: Purple-B1 → extinction, Purple-B2 → press Z. Each trial onset presented B stimuli in one of the three possible background colors in quasirandom order, considering that the same combination was not presented more then three times consecutively. Before initiating Phase 3, the participants read the following instruction on the screen:

In this phase you will use the three response options that you have learned: 1) press Z to earn points, 2) click on the red button to avoid losing points, 3) simply wait for the next trial onset when neither pressing Z nor clicking on the button works for any purpose. Now, pay close attention to the background color in which the figure is presented: Blue, Yellow or Purple. That will determine which of the three response options is correct in the presence of each figure. As you progress, the computer will no longer give you any feedback. That is, the counter will be withdrawn. In this case, the computer will keep recording your points. Then, keep responding considering what you have learned in the previous phases.

Contextual control training began with winning-points trials: Blue-B1 and Purple-B2 stimuli were presented. Mastery criterion was 12 consecutive correct responses. After that, avoid-losing trials were presented: Blue-B2 and Yellow-B1. After mastery criterion was achieved, winning-points and avoid-losing trials were quasirandomly presented in mixed training in which the same type of trial could not be presented more the three times consecutively. Mastery criterion was 18 consecutive correct responses.

After achieving mastery criterion, winning-points, avoid-losing and extinction (Purple-B1 and Yellow-B2) trials were presented in a mixed training as in the previous phase. The mastery criterion was 36 consecutive correct responses. After training was complete, the transfer-of function test was initiated. Before that, the participant read the same instructions presented in the previous testing phase. Transfer of function test trials presented C1 and C2, six times in each background, comprising a single 36-trial test block. Contextual control was documented if the participant performed in accordance with the following class-consistent responses: Blue-C1 → press Z, Blue-C2 → button click, Yellow-C1 → button click, Yellow-C2 → extinction, Purple-C1 → extinction, and Purple-C2 → press Z.

Table 3

Experiment 2: Participants' Results During Phase 1

Experimental Phase		S1	S2	S3
Training (# trials until mastery criterion)	AB	49	19	22
	AC	18	21	20
	CD	18	31	18
	AB+AC + CD	36	57	36
Test (correct responses/test trials)	BD + DB	20/24	24/24	24/24

Results

Table 3 shows that all participants mastered the conditional relations and passed the equivalence tests in Phase 1. Table 4 present results from Phase 2 and Phase 3. All participants met criterion during the simple discriminative training with B stimuli and showed 100% correct responses during transfer of function tests with C stimuli. During the contextual control training, participants took from 157 to 198 trials to meet criterion on winning-points trials; from 16 to 39 on losing-points trials; from 22 to 51 on mixed winning-points + avoid-losing trials; and from 109 to 264 trials on the complete winning-points + avoid-losing trials + extinction trials. During the transfer of function test with the colored backgrounds, participants' scores ranged from 33 to 34 correct responses in 36 test trials.

Discussion

Experiment 2 results corroborate Experiment 1 regarding the contextual control of multiple derived functions, including also a context in which derived extinction took place. The nonoccurrence of a derived function has been shown previously using specific stimuli of a class for which transfer of function was punished in a given context (Dougher et al., 2002; Perkins et al., 2007). In the present study, derived extinction was shown by all participants, albeit by a different route, thus suggesting that the behavior described in the quote from Sidman (1992 p. 22) may be a function of multiple processes. Although derived extinction has been shown in other studies (e.g., Boldrin & Debert, 2020; Dougher et al., 1994; Roche et al., 2008; Vervoort et al., 2014), the present study adds to the literature by assessing derived extinction under contextual control.

An odd finding in the present study is the large number of trials that participants needed to meet criterion during the first step of the contextual training. A possible explanation, supported by participants' reports, is the effect of the instructional control. Whereas only one possible response was reinforced in all winning-points trials (press Z), the instruction specified three possibilities: pressing Z, button clicking and waiting for the next trial onset when nothing worked. Therefore, as participants explored the three options, any error would restart the process of counting correct trials to the mastery criterion and thus inflate the overall number of training trials. The participant needed only a few trials to mastery criterion in the avoid-losing training step as compared to the latter training step. During mixed training (winning-points + avoid-losing + extinction), the participants needed a larger number of trials. Compared to Phase 2, when the three functions were isolated for a specific stimulus, the added complexity of contextual control led to a longer learning curve—an expected finding given the results of other studies that used more complex relational training (e.g., Bush et al., 1989; see also Sidman, 1994) and transfer of function tests (e.g., Dougher et al., 2002; Perkins et al., 2007; Hayes et al., 1991).

General Discussion

The present study investigated the contextual control of multiple derived stimulus functions in two experiments. In Experiment 1, equivalence classes were formed and one stimulus set from each class was used to establish two different functions: one via positive reinforcement (key-pressing) and another via negative reinforcement contingency (button clicking), both under contextual control of two different background colors. Later, other stimuli from the equivalence class were presented in those background colors and the contextual control of multiple derived stimulus functions was assessed. Experiment 2 added a third

Table 4

Experiment 2: Participants' Results During Phase 2 and Phase 3

	Task		Participants		
Exp. Phase	Press Z/button click/extinction	Stimulus set	S1	S2	S3
2	Training (# trials until mastery criterion)	B	27	25	25
	Test (correct responses/test trials)	D	18/18	18/18	18/18
3	Training (# trials until mastery criterion)	B winning-points	157	198	193
		B avoid-losing	39	16	35
		B winning-points + avoid-losing	22	18	51
		B winning-points + avoid-losing + extinction	264	109	157
	Test (correct responses/test trials)	C	33/36	33/36	34/36

background in which no programmed response was reinforced, that is, responses were under extinction. Transfer-of-function tests revealed the contextual control of three different functions, including derived extinction.

Although multiple derived stimulus functions have been widely assumed to be an important part of language in natural settings (Dougher et al., 2002; Hayes et al., 2001; Hayes et al., 1991; Hayes & Hayes, 1992; Perez, Fidalgo et al., 2015; Perez et al., 2017; Perkins et al., 2007; Sidman, 1986, 1992, 1994; Wulfert & Hayes, 1988), experimental demonstrations of this phenomenon have been few. There is a vast literature on contextual control and the reorganization of equivalence classes (e.g., Bush et al., 1989; Gatch & Osborne, 1989; Griffee & Dougher, 2002; Kennedy & Laitinen, 1988; Kohlenberg et al., 1991; Lynch & Green, 1991; Meehan & Fields, 1995; Serna & Pérez-González, 2003; Sigurðardóttir et al., 2012; Stromer et al., 1993; Wulfert et al., 1994), however, few studies have investigated multiple (or different) stimulus functions under contextual control using equivalence relations. So far, only two different functions per stimulus/context have been investigated (e.g., Hayes et al., 1991). Therefore, the present results add to the literature in support of the claim that equivalence relations are a behavioral model of symbolic functioning and that a key feature of such a phenomenon, the contextual control of different meanings, is not restricted to particular stimulus functions or experimental preparations. In addition, the external validity of experimental analogs reflect the widely held idea in the equivalence literature that stimuli have multiple functions (e.g., Bush et al., 1989; Dougher et al., 2002; Hayes et al., 2001; Hayes et al., 1991; Hayes & Hayes, 1989; 1992; Perez, Fidalgo et al., 2015; Perez et al., 2017; Perkins et al., 2007; Sidman, 1986, 1992; 1994; Wulfert & Hayes, 1988). It also reflects the idea that there are at least two relevant aspects of verbal regulation to consider: (1) transfer of multiple derived stimulus functions under contextual control (e.g., Hayes et al., 1991; Hayes & Hayes 1989), and (2) contexts in which no derived function is at play (Dougher et al., 2002; Perkins et al., 2007; Sidman, 1986; 1992; 1994).

RFT denotes "C_{func}" the contextual stimuli that are established to select specific stimulus functions on a particular occasion (see Hayes, Fox et al., 2001, p. 33). As noted by Perez, Fidalgo et al. (2015), the colored background functioned as C_{func} stimuli, modulating the functions of B and C stimuli. Over the years a robust number of experiments have accumulated in the equivalence literature that have progressively increased in complexity and sophistication (Barnes-Holmes et al., 2017). Recently, the importance of contextual variables that modulate stimulus functions has been highlighted as an issue that waits for further scrutiny considering its dynamical nature and interaction with a myriad of different relational contexts (Barnes-Holmes et al., 2020). In this sense, a caveat for the interpretation of our results is considered: Similar outcomes—presented here in terms of contextual control of multiple derived functions via equivalence relations—may also arise from other experimental preparations involving other types of relational responses beyond equivalence, as suggested by Relational Frame Theory (see Hayes, Barnes-Holmes, & Roche, 2001, for a book-length overview). Thus, the account for participants' responses here presented is one possibility among many others for similar outcomes, and is supported by tracking the artificial contingencies programmed in the context of this experiment. Other interpretations for similar behavioral patterns can be found among other sources in the behavior-analytic literature (see also Perez, Fidalgo et al., 2015).

Finally, it is worthy noticing that issues related to the contextual control were highlighted by Sidman (1994) in the later part of his book. The importance of contextual control for Sidman's account is affirmed by the fact that this was possible as the main topic of his epilogue. As suggested by Sidman:

> Contextual control is not just a laboratory phenomenon. We can see examples all around us, some relevant particularly to equivalence relations and some more general. Things and events in our environment affect us in different ways under different circumstances —in different contexts (…) With respect to equivalence relations in particular, we all recognize that varying conditions can change the meaning of words and other symbols. (…). Both lay and professional communities will justifiably be dissatisfied with, and probably distrustful of the validity of any behavioral formulation that fails to take contextual control into account. (Sidman, 1994, p. 476).

Exploring multiple stimulus functions in different contexts is also relevant in the clinical setting. Inflexible behavior extensively based on avoidance is an important diagnostic feature of anxiety-related disorders (Dymond & Roche, 2009; Hayes et al., 1996, 2012). For instance, presenting an avoidance-evoking stimulus in different contexts in which competing behaviors are reinforced is a possible strategy for addressing generalized avoidance (e.g., Bennett et al., 2020). As another example, defusion and acceptance strategies used in ACT (Acceptance and Commitment Therapy; Hayes et al., 2012) consist of presenting stimuli with aversive and/or derived aversive functions linked to problematic behaviors in novel contexts so that other relational and functional contextual cues may broaden the variables that influence the client's behavior (e.g., Luciano et al., 2014). Considering that such therapeutic tools are extensively based on the assumption that stimuli have multiple functions that can be oriented under contextual control, the current research is relevant as an initial experimental demonstration and possible setup for future translational research. In this direction, we are now developing a model for defusion ACT strategies as a way to establish contextual control over directly established and derived and stimulus functions.

Concerning possible limitations of the present study, the small sample size should be addressed in future replications. On balance, however, results were consistent across experiments and all participants showed immediate transfer of function without retraining or retesting. Many other aspects are relevant for future research such as the investigation of other functions, for instance, respondent or motivating functions. Also priorities are studies with young children and those with neurodevelomental disorders associated with delayed language development.

Future studies should also address how instructions impact training and test outcomes. It is likely that training particular responses to the different backgrounds was facilitated by our instructions. They specified the programmed contingencies, such as the response topographies and consequences. Importantly, the instructions did not specify the formation of particular equivalence classes or the transfer of a particular function for any specific stimulus (including the background colors). Therefore, the present transfer-of-function results could not be explained by instructional control. Notably, instructions have (almost always) been implemented in other studies assessing transfer of function. In a similar research context, for instance, Dymond and Barnes (1994) used instructions to facilitate performance under two complex schedules of reinforcement. Further investigation (Dymond & Barnes, 1998) suggested that instructions were not necessary to establish the particular performance on each schedule or to facilitate derived transfer of function. In addition, other studies counterbalanced class-consistent and class-inconsistent instructions during transfer-of-function test blocks and reliably observed transfer-of-function effects using a latency-based task (e.g. Perez et al., 2019). As suggested by Dymond and Rehfeldt (2000), the role of instructional control in transfer of function studies needs further investigation. Thus, it remains necessary to replicate the present study without instructions to evaluate the extent to which complex performances, such as those observed herein, are modulated by instructional control.

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