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ON THE ROLE OF COVARYING FUNCTIONS IN STIMULUS CLASS FORMATION AND TRANSFER OF FUNCTION

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This experiment investigated whether directly trained covarying functions are necessary for stimulus class formation and transfer of function in humans. Initial class training was designed to establish two respondent-based stimulus classes by pairing two visual stimuli with shock and two other visual stimuli with no shock. Next, two operant discrimination functions were trained to one stimulus of each putative class. The no-shock group received the same training and testing in all phases, except no stimuli were ever paired with shock. The data indicated that skin conductance response conditioning did not occur for the shock groups or for the no-shock group. Tests showed transfer of the established discriminative functions, however, only for the shock groups, indicating the formation of two stimulus classes only for those participants who received respondent class training. The results suggest that transfer of function does not depend on first covarying the stimulus class functions.

Key words: stimulus classes, stimulus equivalence, respondent conditioning, skin conductance response, button press, adult humans

Interesting and adaptive instances of human behavior often seem to occur without having been directly trained. Behavior that apparently emerges without direct stimulus–stimulus or response–stimulus pairings includes utterance of novel sentences, fear of stimuli never paired with a fearful experience, and appropriate behavior emitted in novel situations (Gatch & Osborne, 1989). Stimulus classes and related phenomena are widely investigated by behavior analysts as potential explanations for how such novel behavior emerges in the absence of direct training (e.g., Devany, Hayes, & Nelson, 1986; Dougher & Markham, 1994, 1996; Hayes, Kohlenberg, & Hayes, 1991; Saunders & Green, 1992; Sidman, 1990, 1994; Sidman & Tailby, 1982). Stimulus classes also may have far-reaching implications for a variety of psychological phenomena investigated outside behavior analysis, such as the development, integration, and differentiation of sensory and perceptual capabilities in human and animal populations (Lickliter & Bahrick, 2000).

In general, a stimulus class can be defined as a set of stimuli that exert the same functional control over behavior (e.g., evoking the same operant) whereby the application of a variable to a subset of the class members exerts similar effects on all class members (Dougher & Markham, 1996; Dube, McDonald, & McIlvane, 1991; Goldiamond, 1962, 1966). That is, a set of stimuli that control a common response is a stimulus class only if modifying the stimulus function of one class member produces similar modifications in the functions of the other class members—a phenomenon that, in accord with tradition in the experimental analysis of behavior, we shall term *transfer of function* (Dougher & Markham, 1994, 1996; cf. Sidman, 1994, 2000).

Although stimulus classes and transfer of function form the basis of several emerging theoretical explanations of behavior, the necessary and sufficient conditions for the occurrence of these phenomena remain unclear (Dougher & Markham, 1996; Hayes, 1994; Horne & Lowe, 1996; Sidman, 2000). Therefore, the extent to which these paradigms provide a comprehensive, parsimonious, general, and internally consistent account of currently unexplained psychological phenomena remains undetermined.

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Procedural similarities among many experiments investigating stimulus class formation in humans suggest that covarying the functions of a set of stimuli may be a necessary prerequisite for stimulus class formation (Dougher & Markham, 1996). When any change in the experimental contingencies applied to one stimulus in the set is applied to all stimuli in the set, such procedures thus train *covarying functions* for that set of stimuli. Both discrimination reversals and match-to-sample (MTS) training, protocols commonly used to establish stimulus classes, inherently covary the functions of putative stimulus class members as a result of their procedural arrangement.

For example, Vaughan's (1988) discrimination reversal procedure for establishing stimulus classes in pigeons covaried functions among putative stimulus class members. Vaughan taught pigeons to discriminate two sets of 20 slides of trees. Pigeons received presentations of all 40 tree slides twice daily. Initially, responses to one set of 20 slides were reinforced (S+), and responses to the remaining 20 slides were not reinforced (S−). After pigeons learned this initial discrimination, only one function was established for each stimulus. Thus, although there were different functions trained to different stimuli, the functions of stimuli in each set had not yet covaried. Vaughan then reversed the contingencies so that the 20 positive slides became negative and the 20 negative slides became positive. This is the point at which the functions of the putative stimulus class members first covaried. The functions of *all* members of one stimulus set changed from positive to negative, and vice-versa for the other set. Thus, the functions of stimuli within each set had changed, while the functional differentiation of stimuli across classes remained intact.

Similarly, analysis of MTS procedures in a typical stimulus equivalence experiment shows how the MTS training paradigm necessarily covaries the functions of putative stimulus class members. Sidman and Tailby (1982) initially taught children three three-member stimulus classes via MTS training (A1-B1-C1; A2-B2-C2; A3-B3-C3). On trials with A1 as the sample, selections of B1 or C1 were reinforced and selections of B2 or C2 were not reinforced. In these trials, B1 and C1 functioned as discriminative stimuli and B2 and C2 each functioned as S−. In trials in which A2 was the sample, the functions of the B and C stimuli were reversed. That is, selections of B2 or C2 were reinforced, and selections of B1 and C1 were not reinforced. In such trials, B1 and C1 each functioned as S− and B2 and C2 each functioned as S+. It is in this manner that MTS procedures often covary stimulus functions among putative class members.

The present report focuses on a discrepancy in the literature that questions the necessity of directly trained covarying functions as a prerequisite to stimulus class formation. Dougher, Augustson, Markham, Greenway, and Wulfert (1994, Experiment 2) exposed human participants in a control condition to quasirandom presentations of six stimuli in two sets (B1-C1-D1, Set 1; and B2-C2-D2, Set 2). All Set 1 stimuli were paired with shock, and all Set 2 stimuli were paired with no shock. Skin conductance response (SCR) elicitation by B1, C1, and D1 indicated that all three stimuli had acquired respondent elicitation functions. Subsequent extinction of SCR responding to B1 did not transfer to C1 and D1, indicating that establishing the same respondent function for B1, C1, and D1 was not sufficient to establish stimulus classes. Dougher et al. suggested that class formation and transfer of function failed to occur because the functions of the stimuli in each set were not covaried. These results apparently support the notion that covarying functions among a set of stimuli is a necessary condition for stimulus class formation.

This account is challenged, however, by the findings of Honey and Hall (1989), who demonstrated class-like responding in rats without first covarying the functions among putative stimulus class members. They exposed two groups of rats to two auditory stimuli. Both stimuli were paired with food for Group 1, and only one of the stimuli was paired with food for Group 2. Next, both groups were exposed to aversive respondent training in which only one stimulus was paired with shock. Following this respondent conditioning, conditioned suppression of previously reinforced magazine flap pushing transferred to the other stimulus only for rats in Group 1, for which both stimuli previously had signaled food. These results suggested the formation of a two-member stimulus class and resulting transfer of function in Group 1 rats, despite the absence of covarying functions.

Species and stimulus-set size differences could explain the discrepant findings of Dougher et al. (1994) and Honey and Hall (1989). Specifically, Honey and Hall trained two two-member classes in rats, whereas Dougher et al. trained two putative three-member classes in human control-condition participants. The source of the discrepancy could also reside in the experimental preparation used by Dougher et al. For control participants, all Set 1 stimuli were paired with shock and all Set 2 stimuli were paired with the absence of shock. Next, SCR elicitation by B1 was extinguished by presenting B1 alone, without shock. Transfer of the extinction function from B1 to C1 and D1 did not occur. Although Dougher et al. suggested that lack of covarying functions might have prevented stimulus class formation, alternative interpretations are possible. Specifically, the conditioning procedures may indeed have created two classes (B1, C1, D1 and B2, C2, D2). These classes, however, may have gone undetected because the subsequent extinction of elicitation by B1 caused it to ''break away'' from Class 1. Alternatively, the experimenters' use of the absence of shock to extinguish excitatory responding to B1 could have created respondent inhibition by B1. If B2, C2, and D2 also had acquired inhibitory functions during the initial respondent training, B1 may thereby have become a member of Class 2 (see Rescorla, 1968, 1969, for more information on respondent inhibition).

Control-condition outcomes in the study by Dougher et al. (1994) are subject to multiple interpretations because a single type of response function, elicitation of SCR, was integral to both establishing classes initially and testing for subsequent transfer of function. A direct test of Dougher et al.'s suggestion that covarying functions may be necessary for stimulus class formation should therefore require the use of topographically and functionally distinct stimulus functions to establish classes and test for transfer. In the present experiment, we used an operant stimulus function for transfer tests that was distinct from the respondent stimulus functions used to establish classes, thereby reducing the possibility that the experimental contingencies applied in the transfer tests would interfere or disrupt the stimulus classes. In particular, negative outcomes during transfer tests could not be interpreted as resulting from disruptions in class membership during the tests for transfer.

To test the necessity of directly trained covarying functions as a prerequisite to stimulus class formation, we exposed college students to procedures designed to establish respondent-based stimulus classes without covarying the functions of stimuli in the putative classes, then tested for transfer of discriminative functions across those classes. Hereafter, *respondent-based stimulus class* will refer to two or more initially neutral stimuli that (a) have been repeatedly paired with the same unconditioned stimulus and (b) subsequently elicit the same behavior as the unconditioned stimulus, thereby becoming conditioned stimuli through the process of respondent conditioning. Thus, this study was a systematic replication of Honey and Hall's (1989) study with humans. If participants in the present study showed evidence of class formation without exposure to covarying functions among stimulus class members, such results would suggest that (a) training covarying functions in a set of stimuli is not necessary for class formation and transfer of function, (b) class formation in humans results from respondent contingencies as well as operant contingencies, and (c) species differences do not account for the discrepancy between the findings of Honey and Hall and Dougher et al. (1994). Conversely, lack of evidence for both respondent-based stimulus class formation and transfer of function in the present experiment would support Dougher et al.'s proposal that covarying functions are necessary for stimulus class formation in humans.

In the present experiment, we encountered an unexpected additional possibility. During training of putative respondent-based stimulus classes, participants showed no evidence of respondent conditioning. Subsequent tests for transfer of function across the experimenter-designated respondent-based stimulus classes were positive, however, suggesting that the respondent conditioning procedures had, in fact, resulted in class formation. Such findings support the conclusion that covarying functions are not necessary for stimulus class formation in humans. Further, such results bear directly on the interpretation of human studies using respondent-based or respondent-type stimulus class training without verification of resulting conditioned respondent elicitation (Leader, Barnes, & Smeets, 1996; Leader, Barnes-Holmes, & Smeets, 2000; Smeets, Leader, & Barnes, 1997).

METHOD

The present experiment was conducted and analyzed as a group-comparison design because (a) the experiment was a systematic replication of Honey and Hall (1989), who used a similar group-comparison approach, and (b) electrodermal responding is highly variable across individuals, and representative nonclinical samples usually include a number of nonresponsive individuals (e.g., Levis & Smith, 1987; O'Gorman, 1990). In the latter case, there is general agreement that analysis of electrodermal data in representative nonclinical samples often requires aggregating data across individuals (see Markham, Branscum, Finlay, & Roark, 1996).

Participants

Thirty-six undergraduates from introductory psychology courses at Florida International University volunteered to participate in the experiment through in-class announcements and posted sign-up sheets. Participants were exposed to the experimental procedures individually, and were assigned to one of three groups: shock-earn group, shock-lose group, or no-shock group. Data were first collected for the shock-earn group, then for the no-shock group, and finally for the shock-lose group. Participants were assigned to groups based on which condition was being conducted at the time they volunteered. Gender was not a consideration in assigning participants to conditions. (See the Appendix for a breakdown of gender by condition.) Participants received course credit and monetary compensation (described under Phase 2, below) for their participation in the experiment. They were debriefed after completing the experiment.

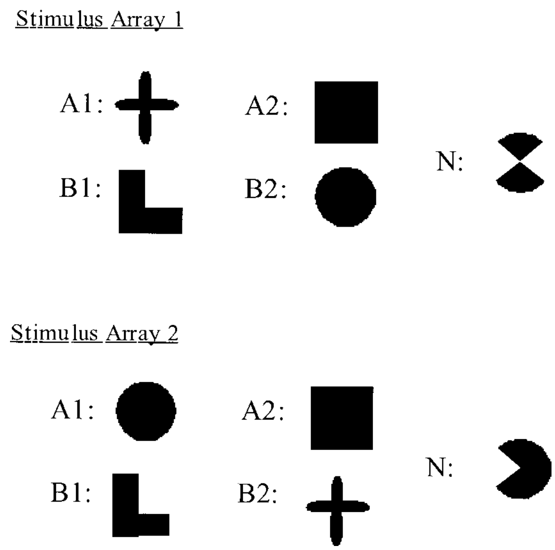

Fig. 1. Visual stimuli used in the experiment.

Apparatus

Each participant sat in a reclining chair positioned in the corner of a room (2 m by 2.4 m). The chair had one response button that was positioned on the armrest of the participant's dominant hand. The response button was used to record button-press rates during certain phases. White noise (60 dB) was delivered through headphones to mask extraneous noise, and participant movement was monitored using a custom-constructed motion sensor attached to the chair. The participant faced a computer monitor placed on a desk 1.5 m in front of the chair. Throughout the experiment, a computer and recording equipment located in an adjacent room controlled stimulus presentation and recorded physiological and behavioral responses.

Visual stimuli consisted of four white geometric figures (3 cm by 4 cm) presented on a black background on the computer monitor. Stimuli were assigned to two experimenter-defined two-member classes. Alphanumeric designations (e.g., A1-B1, A2-B2) were assigned to facilitate description of class membership. Assignment of stimuli to putative classes was counterbalanced within conditions. In a given experimental condition, the first 6 participants received exposures to Stimulus Array 1, and the second 6 received exposure to Stimulus Array 2 (see Figure 1).

Presentations of visual stimuli were quasi-random, with the constraints that all stimuli be presented the same number of times within a phase and a stimulus could not appear in more than two successive trials. In Phase

1, participants received five deliveries of four stimuli for 20 total stimulus presentations. In Phase 2, participants received 10 deliveries of the two A stimuli for 20 total stimulus presentations. In Phase 3, participants received three presentations of four stimuli for 12 total stimulus presentations. In Phase 4, participants received three presentations of the two B stimuli and a novel stimulus for nine total stimulus presentations. In all phases, stimulus duration varied randomly between 15 and 25 s, and intertrial intervals (ITIs) varied randomly between 25 and 40 s (parameters adapted from Augustson & Dougher, 1997). Variation of both stimulus duration and ITI was truly random with a resolution of 1 s.

Skin conductance responses were recorded with silver–silver chloride sensors filled with 0.5% NaCl paste on the medial phalanges of the index and ring fingers on the nondominant hand (Lykken & Venables, 1971). Perforated Velcro® strips were wrapped around the sensor on each finger to keep the sensors in full contact with the skin at all times. Skin conductance responses were amplified and recorded using a Coulbourn Instruments skin conductance coupler (Model S71-22).

Shocks were delivered using a World Precision Instruments variable-amperage isolated shock generator (Model A320R-E) via disposable ConMed Diagnostic silver–silver chloride electrodes (Part 1750-001). The self-adhesive electrodes were fastened 1 cm apart to the exterior hypothenar eminence of the participant's nondominant hand. Experimenter-designated shock levels initially ranged from 1.0 mA to 3.0 mA, although 2 participants requested 4.0 mA of shock.

The institutional review board required that all participants select a level of shock that they deemed as uncomfortable but tolerable. In the shock level selection process, participants were read the following instructions before receiving the first test shock:

> This is an experiment investigating the nature of learning. There is nothing in the experiment that is designed to trick or fool you in any way. Here's the good news: Depending on your responses, you will have the opportunity to earn money during certain phases in the experiment. Here's the not-so-good news: You are going to receive several electrical stimulations throughout this experiment. Specifically, you will receive more than 10 shocks during the experiment, but you will receive less than 40 shocks during the experiment. When the shock is presented, it will last for only 200 ms, and you will not experience any residual pain after the shock turns off. For this experiment to have scientific value, it is important that the stimulation you feel is relatively uncomfortable; however, we do not want you to experience any severe pain. Therefore, I am going to expose you to the shock now. If you find it unbearable, please tell me and we will adjust the strength of the shock until it is still uncomfortable but not severely painful. I will deliver the test shock from the other room, and I will say ''Ready?'' before I deliver the shock. When you indicate you are ready, I will deliver the shock.

Once the test shock was delivered, participants were read the following:

> In selecting your shock level, it is important for you to note that the level you select will be the strongest level of shock you experience, however, not all the shocks you experience will be this strong. Can you tolerate this level of shock throughout the experiment?

If participants agreed to receive the delivered level of shock throughout the experiment, the experiment proceeded.

If the participant indicated discomfort and an unwillingness to receive further shocks as strong as the initial test shock, further test shocks were delivered, each with a 0.5-mA decrement in shock magnitude, until the participant agreed to receive shocks at that level. The experimenter then read the following instructions to the participant: ''Again, please remember that not all the shocks you experience will be this strong. Can you tolerate this level of shock throughout the experiment?'' Once participants agreed to a specific level of shock, the experimenter calculated two thirds of the accepted shock selection and set the shock generator at two thirds the strength of the shock to which the participant agreed. As a hedge against habituation, all shocks delivered to all participants in Phase 1 were two thirds the strength of the participant-selected shock level, and all shocks delivered to all participants in Phase 3 were the full strength of the participant-selected shock level. Studies using similar conditioning procedures suggest that human participants often show rapid habituation to mild shock (Augustson & Dougher, 1997; Augustson, Dougher, & Markham, 2000; Dougher et al., 1994; Markham, Augustson, & Dougher, in press).

Procedure

Figure 2 presents the sequence of experimental phases. Phase 1 was designed to train two respondent-based stimulus classes for the shock groups (A1-B1 and A2-B2), and the no-shock group was exposed to the same stimulus presentations without establishing stimulus classes. In Phase 2 an operant discriminative function was established for A1 and A2. Participants were taught to press a response key rapidly in the presence of A1 while avoiding button pressing in the presence of A2. Phase 3 was similar to Phase 1 and was designed to prevent extinction of the previously established respondent-based stimulus classes. Phase 4 tested for transfer of the discriminative functions established for A1 and A2 to the remaining stimuli, B1 and B2, and to a novel stimulus, N. For economy of presentation, the procedurally similar Phases 1 and 3 will be described first, followed by Phases 2 and 4.

Phases 1 and 3: Respondent conditioning phases. Each participant in all groups was seated in the reclining chair in front of the computer monitor and prepared for shock delivery and SCR recording. When the participant was prepared, the experimenter read the following instructions:

> Please get as comfortable as possible now before the experiment starts. It is critical for our data collection procedures that you move as little as possible throughout the duration of the experiment. Your movement will be monitored throughout the experiment. There are four phases to this experiment. The entire experiment will last approximately 1.5 to 2 hours. Your job during this experiment is to watch the symbols and pay attention to them as they appear on the screen. A noise will be presented to you through these headphones. The noise, called ''white noise'' sounds like a radio that is not set on a station. It will be on at all times so that no noises in and around the laboratory disturb you. Also, I will speak to you through the headphones between each phase of the experiment. I am now going to put the headphones on you. Feel free to adjust them for your comfort. Before I put the headphones on you, do you have any other questions?

If the participant asked any questions, the questions were answered without divulging any additional information regarding the nature of the experiment. Then, the experimenter put the headphones over the participant's ears, left the room, and closed the door. All other instructions were read to the participant through the headphones via a microphone. These remaining instructions were read to the participant before the experimenter began the computer-automated experiment program:

> There are four phases to this experiment, and I am about to start the first phase. It is important you pay attention during all phases, because what you learn in each phase may have an impact on what happens in other phases. The experiment has begun. Please remember to remain as still as possible.

During Phase 1, a delayed respondent conditioning procedure was used to establish two two-member respondent-based stimulus classes for the shock groups. The computer screen quasirandomly presented four visual stimuli (i.e., A1, B1, A2, and B2), alone. For both shock groups, two of the visual stimuli were always followed by shock, and the two remaining visual stimuli were never followed by shock. For the shock-earn group, presentations of A1 and B1 were always followed by shock, whereas presentations of A2 and B2 were never followed by shock. For the shock-lose group, the reverse was true. The phase consisted of five presentations of each stimulus (20 total stimulus presentations). When shock was delivered, it coincided with the last 200 ms of stimulus presentation. Skin conductance was recorded during stimulus presentations and continued for 5 s after stimulus offset.

Procedures for the no-shock group during Phase 1 were identical to those for the shock groups, except the no-shock group did not receive shock. Therefore, during Phase 1, no-shock participants were exposed only to the visual stimuli presented on the computer screen.

Phase 3 procedures were identical to those of Phase 1, except that each stimulus was presented only three times (12 trials total). Institutional review board protocol limited the number of 200-ms shock deliveries to 20, including test shocks. Therefore, a maximum

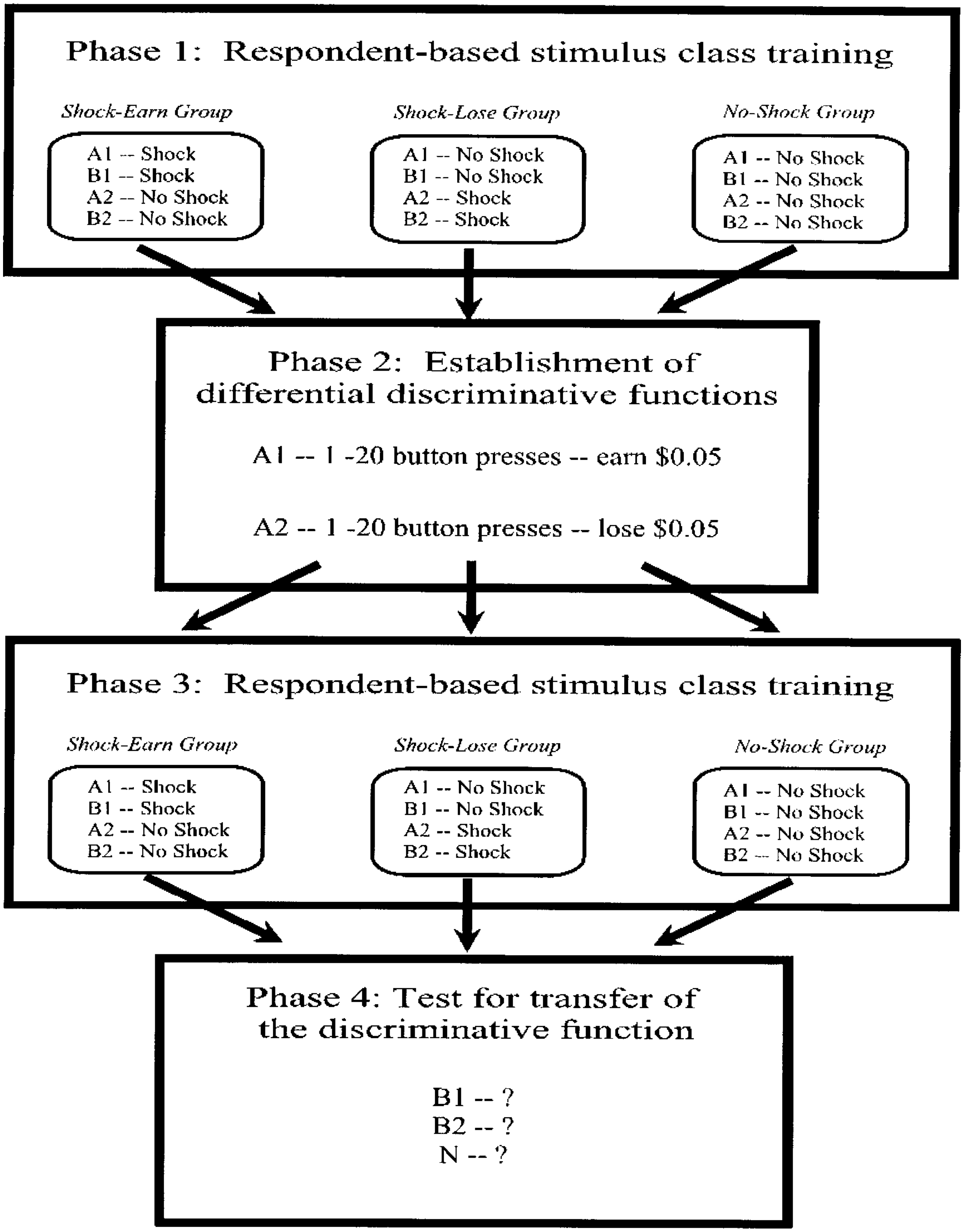

Fig. 2. Schematic outline of procedural phases.

of 16 shocks for respondent conditioning trials was allowed. The experimenter read the following before beginning the computer program for Phase 3:

> This is the third phase of the experiment. During this phase, you will see symbols appear on the screen. You may receive electrical stimulation during this phase. Are you ready to begin Phase 3 of the experiment?

Phase 3 began immediately after these instructions were given.

Phase 2: Discriminative function training. Following the first phase of respondent-based stimulus class training, participants in all conditions were taught different discriminative functions in the presence of A1 and A2. Phase 2 procedures were identical for all groups. Before beginning Phase 2, participants received minimal instructions indicating that earning or losing money was possible as a result of button pressing. Participants were read the following:

> We are now entering the second phase of the experiment. Under no circumstances will you receive any shock during this phase of the experiment. During this phase, you will be exposed to different stimuli on the screen. It is your job to pay attention to these stimuli. Also during this phase, you will have the opportunity to win money. You will start out with one dollar, which we are giving to you. Sometimes, pressing the button on the box attached to the right armrest on the chair will allow you to earn money, and sometimes, pressing the same button will cause you to lose money. Go ahead and try out the button now. The amount of money you have will remain on the screen at all times throughout this phase, so you will know whether pushing the button is allowing you to earn or lose money at a given point in time. It is important for you to know that just pressing the button once will not necessarily allow you to earn money. This does not mean the button is not working. Actually, the more you press the button, the faster you will earn or lose money. You can choose to press or not press the button whenever you want throughout this phase. You will actually receive the money you have earned at the end of this experiment. You can start pressing the button as soon as the phase begins. Ready?

After the instructions were read, 10 trials each of A1 and A2 (20 trials total) were presented on the computer screen in quasirandom order, with the restriction that the same stimulus could not be presented on more than two consecutive trials. Visual stimulus duration and ITI were as in Phase 1. A monetary counter was displayed 2 cm above the visual stimulus on the computer screen. In accordance with the verbal instructions, the monetary counter displayed $1.00 at the beginning of Phase 2. The monetary counter was displayed only during visual stimulus presentations. When A1 was present, a button response increased the amount on the monetary counter by $0.05. When A2 was present, a button response decreased the amount on the monetary counter by $0.05. Increments in value on the monetary counter were accompanied by a 500-ms high tone (3000 Hz) delivered through the headphones, and decrements in value on the monetary counter were accompanied by a 500-ms low tone (500 Hz) delivered through the headphones.

At the start of the procedure, a participant's first button press resulted in the gain or loss of money. Thereafter, the number of button presses required for gain or loss of money increased by two until the button-press requirement reached 20, where it remained for the rest of the procedure. Throughout the phase, button presses had an effect on monetary gain or loss only while a visual stimulus was on the screen, and the program did not count button presses between trials. Participants who did not reach the 20-press criterion in the presence of the stimulus for which button presses earned money before the end of Phase 2 were rerun through Phase 2 until they reached this criterion.

Phase 4: Test for transfer of discriminative functions. Following respondent class maintenance training in Phase 3, a test for transfer of the Phase 2 discriminative function was conducted. Participants in all groups were exposed to identical conditions in Phase 4. The experimenter read the following instructions to each participant through the headphones before beginning the computer program for Phase 4:

> This is the last phase of this experiment. During this phase, you will see symbols appear on the screen. Under no circumstances will you receive shock during this phase. This phase is similar to the second phase in the experiment in that button presses will either allow you to earn or cause you to lose money during the

phase. However, this phase is different from the second phase in that, although you will be earning or losing money by pressing the button, you will not be able to see how much you have, or whether you are earning or losing money. This phase is also different from the second phase in that you will not hear the high "beep" or the low "buzz" indicating whether you are earning or losing money. During this phase, it is your job to try to earn and retain as much money as possible by pressing or not pressing the button. Good luck!

Phase 4 was similar to Phase 2 except that different stimuli were presented, and participants did not receive auditory or visual feedback indicating gain or loss of money. In this phase, quasirandom stimulus presentations included B1, B2, and N (a novel stimulus). The monetary counter was still displayed concurrently with visual stimulus presentations, but asterisks replaced the digits in the counter, thus preventing the participant from detecting whether he or she was earning or losing money. In addition, although the participant was earning or losing money by pressing the button, tones were not presented with consequence delivery. Button-press rates were recorded as in Phase 2.

The experiment ended at the completion of Phase 4. At the end of Phase 4, all electrodes were removed from the participant's hand. Participants were then fully debriefed, and they were paid the amount of money they had earned by the end of the experiment.

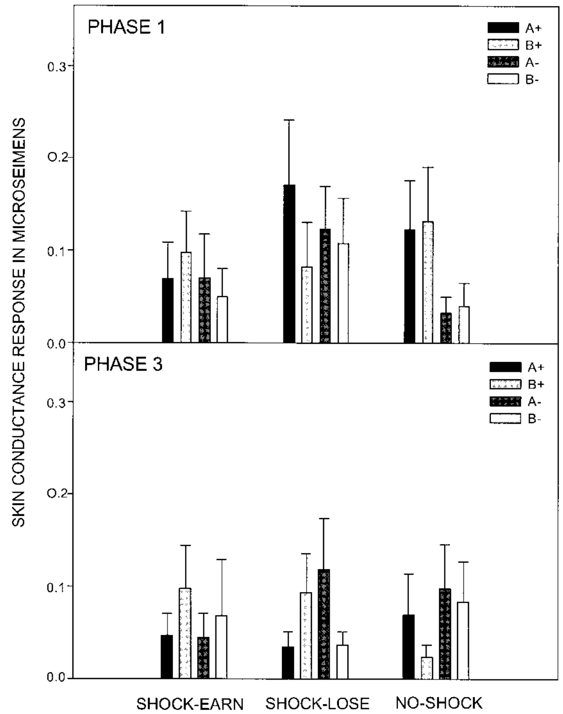

Fig. 3. Mean peak SCR for the last presentation of each stimulus in Phase 1 for the shock-earn group, shock-lose group, and no-shock group (error bars show *SEM*).

RESULTS AND DISCUSSION

Phases 1 and 3

Peak SCR (in microsiemens) was assessed during the first 10 s of each stimulus presentation. An SCR was defined as any phasic deviation from the tonic skin conductance during the assessment interval and was measured as the magnitude of that deviation at its maximum. When more than one SCR occurred within an assessment interval, the peak SCR was the response of greatest magnitude. This manner of quantifying SCR is consistent with empirical definitions of SCR as a response elicited by external events (Venables & Christie, 1980) and with previous studies investigating interactions of stimulus classes and respondent conditioning (Augustson & Dougher, 1997; Augustson et al., 2000; Dougher et al., 1994; Markham et al., in press).

Figure 3 shows mean peak SCR for the last presentation of each stimulus for each group in Phases 1 and 3. We expected that A1 and B1 would elicit significantly higher peak SCR than A2 and B2 for the shock-earn group, whereas the opposite would occur for the shock-lose group, and no differences would be seen for the no-shock group. As seen in Figure 3, however, and confirmed by two 4×3 analyses of variance (ANOVA) for each phase (Stimulus × Group), there were no significant differences in peak SCR among the stimuli for all groups in Phase 1, all Fs < 1.5, all ps $> .20$, or in Phase 3, all Fs < 1.5, all ps $> .35$.

To examine these results at the level of individual participants, we calculated an index of conditioning for each participant by subtracting the sum of his or her peak SCR to the stimuli paired with the absence of shock from the sum of his or her peak SCR to the

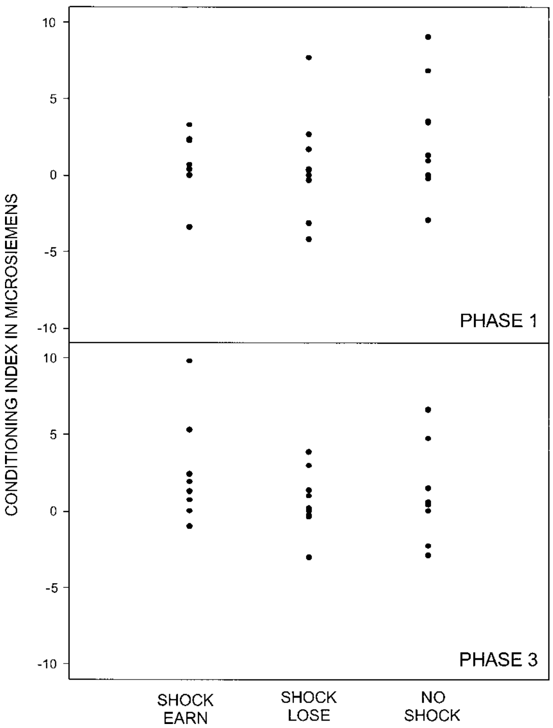

Fig. 4. Conditioning index scores for participants in each experimental group in Phase 1 (top panel) and Phase 3 (bottom panel).

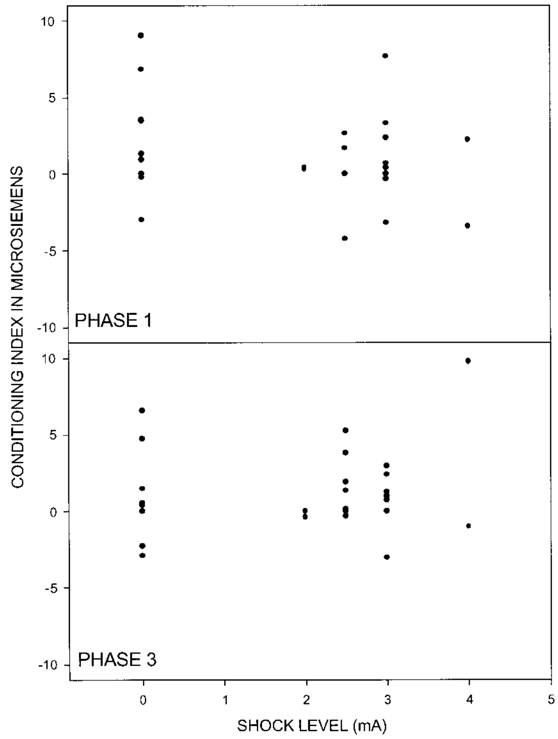

Fig. 5. Relation between individual conditioning index and shock level.

stimuli paired with shock. Thus, larger positive values of the conditioning index reflect respondent conditioning. Figure 4 shows individual conditioning index scores for participants in Phase 1 (top panel) and Phase 3 (lower panel). Most participants' conditioning index scores were near zero, and there were no systematic between-group differences in the pattern of individual scores. Figure 5 suggests that between-subject variance in conditioning was not a straightforward function of using different shock levels with different participants. Each participant's conditioning index as a function of his or her self-selected shock level in Phases 1 and 3 is shown. Self-selected shock level was not systematically related to participants' degree of respondent conditioning in either phase.

Although the procedures in Phases 1 and 3 were modeled after the successful conditioning procedures of Dougher et al. (1994), several procedural differences may account for why differential SCR conditioning did not occur in the present experiment. First, Phase 1 of the present study presented fewer conditioning trials than did Dougher et al., and this may have not been sufficient to establish differential conditioning. Combined, Phases 1 and 3 of the current study incorporated more conditioning trials than in some portions of Dougher et al., but the intervening procedures of Phase 2 may have somehow interfered with conditioning.

Second, the shocks in the current study may not have been aversive enough to establish reliable SCR conditioning. Although shock intensities were relatively high in the present study, shock aversiveness ratings can vary on dimensions other than current, such as duration, wavelength, pulse width, and duty cycle (e.g., Girvin et al., 1982). Therefore, differences in shock parameters other than current may have caused the shocks in the present study to be less painful than shocks of equal or lower amplitude delivered in other studies.

Third, low-magnitude unconditioned stimuli exhibit earlier habituation effects (Dougher et al., 1994). Previous results obtained in Dougher's laboratory indicated that 12 trials were sufficient for differential respondent conditioning, and more than 12 conditioning trials could cause habituation to either or both the unconditional stimulus (US) and the conditional stimuli (CSs) (Augustson, Markham, & Dougher, 1994). The present study assessed SCR data during Trials 9 and 10 in Phase 1 and during Trials 5 and 6 in Phase 3 (arguably Trials 15 and 16 of respondent conditioning). It is possible therefore that conditioning could have occurred earlier in Phase 1, and responding to the US and CS may have habituated by Trials 9 and 10 of Phase 1.

Finally, it is possible that, contrary to the instructions, participants did not always attend to the stimuli presented on screen. Dougher et al. (1994) employed an operant task to maintain participants' attending to the computer screen on which the visual stimuli were presented. The present study did not employ such an operant task; therefore, lack of attending during the CS–US pairing may provide an additional explanation for why respondent conditioning did not occur in the present study. Regardless of why it occurred, the apparent failure of respondent conditioning during Phases 1 and 3 holds important implications for the interpretation of the Phase 4 outcomes and will be discussed below in the General Discussion.

Phase 2

Button presses during the last three presentations of each stimulus were summed for A1 and A2. Total button presses were square-root transformed due to skewness in the distribution of raw button presses (Howell, 1992, p. 314). Figure 6A shows mean square-root button presses to A1 and A2 for all groups.

A Greenhouse-Geisser adjusted 2 × 3 ANOVA (Stimulus × Group) revealed a main effect for stimulus, $F(1, 33) = 276.086$, $p < .0001$. Conservative post hoc comparisons for the effect of stimulus within each group were conducted using Tukey's wholly significant difference (WSD; Maxwell & Delaney, 1990, p. 185). These tests revealed that participants in the shock-earn group made more button presses in the presence of A1 than in the presence of A2, $F(1, 33) = 97.843$, $p < .01$. Likewise, participants in the shock-lose group made more button presses to A1 than to A2, $F(1, 33) = 87.901$, $p < .01$. Finally, participants in the no-shock group also made more button presses to A1 than to A2, $F(1, 33) = 90.480$, $p < .01$.

A further examination of these data is shown in Figure 6B, which displays total button presses in the presence of the two stimuli for each participant in each experimental group. Of the 36 individuals who participated in the experiment, only 1 participant from the no-shock group showed higher button pressing in the presence of A1 compared to A2. The Appendix shows raw button-press rates for each participant.

Phase 4

As in Phase 2 analyses, button-press rates in the presence of the last three presentations of each stimulus were summed for each stimulus (i.e., B1, B2, and N). Button presses in the presence of N were not different among groups. Accordingly, Figure 6C shows only the mean square root of total button presses to B1 and B2 for participants in all groups. A Greenhouse-Geisser adjusted 3 × 3 ANOVA (Stimulus × Group) revealed a significant interaction for Stimulus × Condition, $F(3.12, 52.75) = 3.285$, $p < .05$. As conservative follow-up tests of the significant interaction, nine pairwise comparisons were conducted using Tukey's WSD to control for experiment-wise Type I error (Maxwell & Delaney, 1990). Specifically, square-root button presses were compared between Stimuli B1 and B2, B1 and N, and N and B2, within each condition. For the shock-earn group, button presses for B1 were greater than those for B2, $F(1, 53) = 7.518$, $p < .01$. Likewise, button presses were higher for B1 than for B2 in the shock-lose group, $F(1, 53) = 4.995$, $p < .05$. No other pairwise comparisons were statistically significant. Thus, button-press rates were higher to B1 than to B2 only in the two shock groups.

Figure 6D shows total button presses to B1 and B2 for individual participants in each group. Button-press rates to B1 were higher than button-press rates to B2 for 18 of the 24 participants in the shock groups; specifically, 9 of the 12 participants in each shock group pressed to B1 more than B2. In the no-shock group, 4 of the 12 participants pressed to B1 more than to B2.

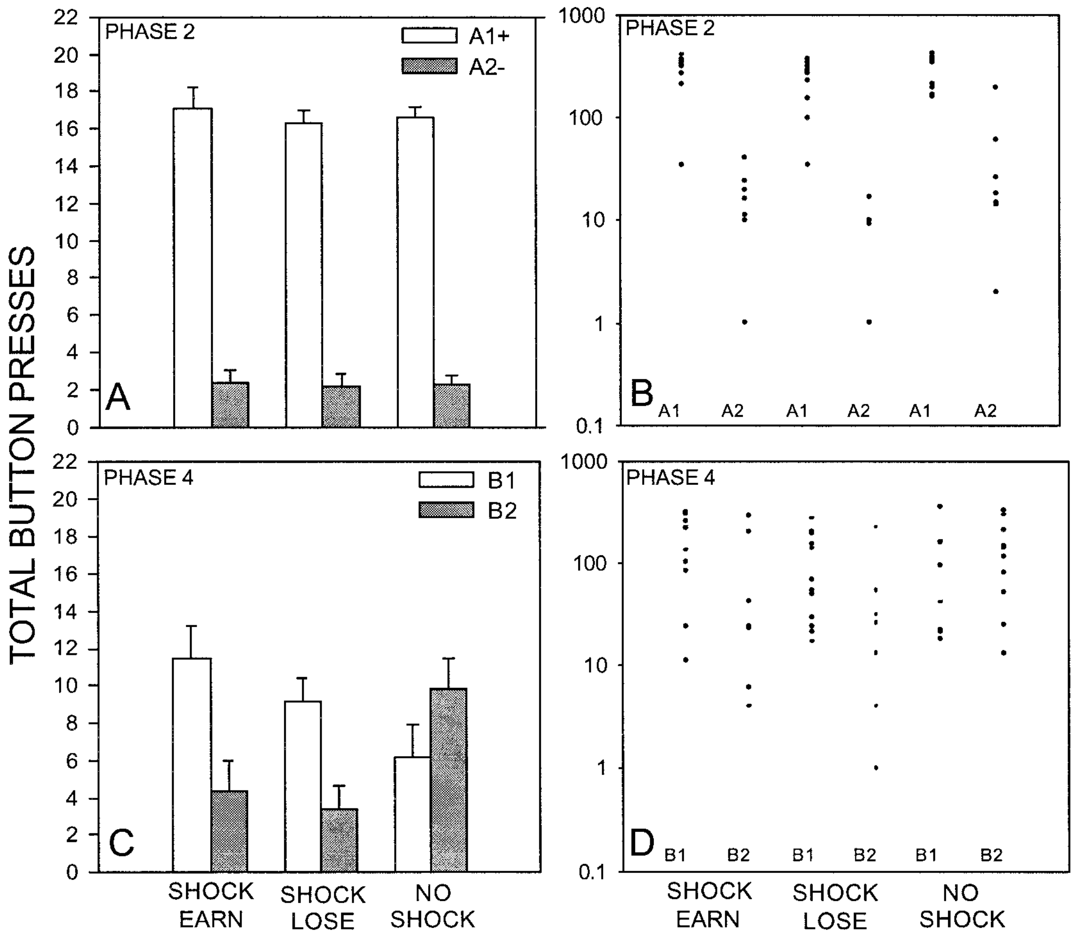

Fig. 6. (A) Mean square-root transformed total button presses in the presence of A1 and A2 during Phase 2 discrimination training, grouped by condition. Button presses were summed across the last three presentations of each stimulus and square-root transformed. Error bars indicate *SEM.* (B) Raw (untransformed) total button-press scores to A1 and A2 during Phase 2 for all participants in all conditions. (C) Mean square-root transformed total button presses in the presence of B1 and B2 during Phase 4 discrimination training, grouped by condition. Button presses were summed across the last three presentations of each stimulus and square-root transformed. Error bars indicate *SEM.* (D) Raw (untransformed) total button-press scores to B1 and B2 during Phase 2 for all participants in all conditions.

GENERAL DISCUSSION

This study investigated whether covarying functions were necessary for stimulus class formation and transfer of function to occur in humans. In Phases 1 and 3, two stimuli (e.g., A1 and B1) were paired with shock, and two other stimuli (e.g., A2 and B2) were not paired with shock. Phase 2 trained two discriminative functions: high-rate button pressing in the presence of A1 and low-rate button pressing in the presence of A2. Phase 4 tested whether B1 and B2 had acquired the functions of A1 and A2, respectively. Successful transfer of the functions established for A1 and A2 to B1 and B2 should indicate that two respondent-based stimulus classes were established in Phases 1 and 3 (i.e., A1, B1 and A2, B2).

The Phase 4 tests for transfer of function indeed were positive, but under unexpected conditions. The predicted transfer of function occurred in Phase 4 despite the absence of evidence for differential SCR conditioning in Phases 1 and 3. Specifically, Phases 1 and 3 were designed to train two two-member respondent-based stimulus classes (A1-B1 and

A2-B2). Shock pairings with A1 and B1 and no-shock pairings with A2 and B2 were expected to lead to high peak SCR in the presence of A1 and B1 and low peak SCR in the presence of A2 and B2. But, there was no evidence of differential SCR conditioning during Phases 1 and 3.

In Phase 2, all participants acquired the discriminative functions trained for A1 and A2. That is, participants learned to button press rapidly to A1 and avoid button pressing to A2. Therefore, all participants learned the operant functions necessary to test for transfer of function in Phase 4. Despite the absence of evidence for respondent conditioning in Phases 1 and 3, results from Phase 4 indicate that transfer of function did, in fact, occur in accord with two stimulus classes (A1-B1 and A2-B2). Specifically, a high number of button presses in the presence of B1 and few or no button presses in the presence of B2 showed that discriminative functions trained to A1 and A2 had transferred to B1 and B2, respectively, for participants in both shock groups. This conclusion is further supported by the fact that participants in the no-shock group who did not receive shock in Phases 1 and 3 did not show evidence of transfer of function.

At the group level, these results suggest there was no relation between respondent conditioning (as measured by SCR) and the transfer of function observed in Phase 4. There was, however, considerable variability in SCR outcomes within groups, and it is possible that individual SCR outcomes might yet predict function transfer in Phase 4. That is, participants who showed greater evidence of conditioning in Phases 1 and 3 may also have shown greater evidence of transfer of function in Phase 4. Figure 7 examines this possibility. We used the conditioning index scores for each participant in Phases 1 and 3 (see Figure 4) as the measure of each individual's degree of conditioning in that phase. To quantify each participant's performance in Phase 4, we calculated a transfer index as total presses to B1 minus total presses to B2. Thus, higher scores indicate stronger evidence of transfer in Phase 4 tests. The top panel of Figure 7 shows the relation between Phase 1 conditioning indexes and Phase 4 transfer indexes. The bottom panel of Figure 7 shows that there was no systematic relation between Phase 3 conditioning indexes and Phase 4 transfer indexes. Linear regression analyses also revealed no systematic relation between Phase 1 conditioning and Phase 4 transfer tests, $r^2 = 0.002$, $F(1, 34) = 0.06$, *ns*, or between Phase 3 conditioning and Phase 4 transfer, $r^2 = 0.048$, $F(1, 34) = 1.72$, *ns*. These results again support the conclusion that differential SCR conditioning in Phases 1 and 3 was not the basis for the positive transfer tests observed in Phase 4.

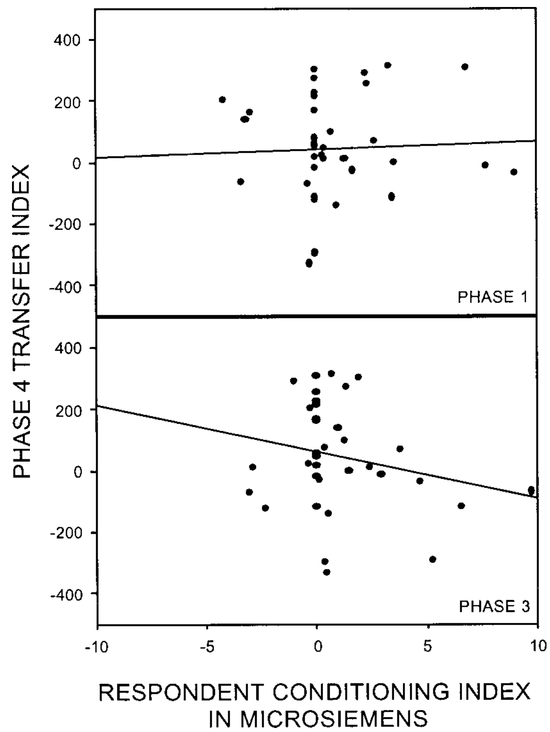

Fig. 7. Upper panel: scatter plot of Phase 4 transfer index by Phase 1 conditioning index for all participants. Lower panel: scatter plot of Phase 4 transfer index by Phase 3 conditioning index for all participants. Trend lines show least squares linear regression.

Despite lack of SCR differentiation in Phases 1 and 3, Phase 4 provides strong evidence for class formation. This study thereby systematically replicates Honey and Hall's (1989) experiment and supports the conclusion that covarying the functions of a set of stimuli is not necessary for stimulus class formation and transfer of function in humans. Further, the functions used for transfer tests in the present study were both topographically and functionally different from those designed to establish initial stimulus classes. The resulting positive tests for transfer of function suggest that participants in the control condition of Dougher et al. (1994) might have shown class formation and transfer of function had the experimenters used a function other than extinction of SCR elicitation to B1 to test for function transfer to C1 and D1.

From the perspective of the experimental analysis of behavior, an obvious limitation of the present study was the use of a group-comparison design that did not allow a precise evaluation of controlling relations at the individual level. This design was selected in part because electrodermal responding is highly variable across individuals, and some individuals, in fact, do not show electrodermal responding in experimental settings (Levis & Smith, 1987; O'Gorman, 1990). Single-case experimental analysis of electrodermal responding often relies on restrictive participant selection procedures that limit the generality of the resulting data (e.g., prescreening for electrodermally responsive individuals as per Augustson et al., 1994; or selecting only female participants as per Dougher et al., 1994).

The present results raise the important question of how stimulus classes developed in Phases 1 and 3 when the respondent SCR presumed to underlie class formation showed no differentiation among the stimuli. Several interpretations of this outcome are possible. First, as Sidman (1994) argues, stimulus classes may form during tests for transfer of function. In the present experiment, classes may have formed purely as a function of the Phase 4 tests for transfer. However, the no-shock group in the present study demonstrated that exposure to tests for transfer without initial visual stimulus–shock pairings was not sufficient for transfer of function responding.

Second, a respondent in a modality other than the one being measured may have been conditioned (Levis & Smith, 1987; Smith & Levis, 1991); therefore, respondent conditioning and respondent-based stimulus class formation may have occurred without experimental detection. For example, the conditioning procedures may have established respondent elicitation of acceleration or deceleration in heart rate rather than SCR elicitation. The present procedures cannot rule out this possibility. They were devised, however, in light of the fact that SCR is arguably the most reliable measure of human respondent conditioning (e.g., Stern, 1972).

A third interpretation is based on relational frame theory, which argues that stimulus class formation results from a generalized operant grouping of stimuli that is evoked in appropriate testing contexts (e.g., Barnes, 1994; Hayes, 1994; Healy, Barnes, & Smeets, 1998). According to this perspective, participants entered the experimental setting with an extensive preexperimental repertoire of looking for predictable relations in environmental events. This interpretation of the results suggests that, due to preexperimental operant learning history, participants in the shock groups attended to the shock presentations and stimuli and thereby observed which visual stimuli directly preceded shock and which visual stimuli did not, without experiencing corresponding fear. This view implies that transfer of function did occur, but that it occurred across an operant-based stimulus class rather than a respondent-based stimulus class. This interpretation of the present findings is plausible, but its evaluation in a manner that allows its potential refutation remains elusive and is a matter for further experimentation.

Finally, the shock presented in Phases 1 and 3 may have functioned simply as a stimulus presented simultaneously with particular stimuli, rather than as an unconditioned elicitor. In this case, the stimulus presentations paired with shock could be interpreted as presentations of a compound stimulus consisting of the visual stimulus and the shock. Research on compound stimuli in stimulus classes has shown that presentations of multielement compound stimuli with common elements can merge the elements of the involved compound stimuli into a single class, even when experimental contingencies do not require attention to the shared element (e.g., Lane & Critchfield, 1998; Schenk, 1995). Accordingly, in the present experiment, the presentations of A1 with shock and B1 with shock may have created two compound stimuli (A1-shock and B1-shock) with the shock as a common element. It thus is possible that the commonality of shock in the two compounds merged A1 and B1 into one stimulus class. This possibility also merits additional experimental evaluation.

Although the data show that respondent

conditioning and thereby respondent-based stimulus class formation did not occur in Phases 1 and 3, transfer of function defines functional stimulus classes; therefore, classes must have in some way formed. Indeed, transfer of function without evidence of initial functional class formation is not unheard of in the transfer literature. For instance, Honey and Hall (1989) did not measure a respondent (e.g., salivation) during the tone–food pairings in initial class training, yet showed subsequent transfer of function. Therefore, like the current study, Honey and Hall did not determine the type of classes across which the relevant behavior (conditioned suppression) showed transfer.

A related implication of the present results concerns the interpretation of class formation based on respondent-type training procedures with humans (Leader et al., 1996, 2000; Smeets et al., 1997). These researchers have shown that simple sequential stimulus presentations (e.g., A1 → B1, C1 → B1, A2 → B2, C2 → B2, A3 → B3, C3 → B3) are sufficient for adults to demonstrate learned relations between stimuli that have never before been directly paired (i.e., after being taught A1 → B1, then C1 → B1, adults selected comparison C1 in the presence of A1 without being directly taught to do so). Because respondent conditioning per se is not measured in these experiments, it is not clear whether the observed class formation is indeed a result of respondent conditioning. The present experiments did directly assess respondent conditioning and found evidence of class formation without evidence of respondent conditioning. These results thus suggest that class formation following respondent-type training procedures does not necessarily result from respondent conditioning.

Much remains to be done before the necessary and sufficient conditions for stimulus class formation and transfer of function are thoroughly understood. One obvious challenge will be to replicate the present investigation using improved procedures to achieve and assess respondent conditioning. At a more general level, experiments are needed to evaluate whether initially covarying stimulus functions is necessary for transfer of function across various types of stimulus classes or under different testing contexts. It may be that, for some classes or contexts, covarying stimulus functions is indeed necessary for transfer of function to occur.

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APPENDIX

Individual participant information.

Initials	Gender	Shock level (mA)	Condition	Button-press rates			
				A1	A2	B1	B2
JT	M	4	Shock-earn	338	40	132	201
AG	F	3	Shock-earn	370	0	220	6
RO	F	2.5	Shock-earn	360	0	224	0
DE	F	3	Shock-earn	274	16	82	24
CP	F	3	Shock-earn	372	0	254	0
RG	M	4	Shock-earn	328	10	313	23
HT	F	3	Shock-earn	212	0	24	42
LD	F	3	Shock-earn	410	20	311	0
DC	M	2.5	Shock-earn	353	11	300	0
GT	F	3	Shock-earn	313	1	102	4
DR	F	3	Shock-earn	35	1	11	0
JA	F	2.5	Shock-earn	316	24	0	292
AF	F	2.5	Shock-lose	274	1	201	0
GM	F	3	Shock-lose	100	10	17	31
CG	F	2	Shock-lose	154	17	49	4
EP	F	3	Shock-lose	290	0	191	26
JM	F	3	Shock-lose	289	0	151	222
MS	F	2	Shock-lose	35	9	21	1
NN	M	2.5	Shock-lose	233	0	273	0
PR	M	3	Shock-lose	375	0	137	0
KO	F	2.5	Shock-lose	266	0	24	53
CC	F	3	Shock-lose	337	0	29	13
CB	F		Shock-lose	318	1	53	1
CM	F	2.5	Shock-lose	282	0	68	0
CT	M		No shock	167	195	21	13
DA	F		No shock	380	0	0	297
JS	M		No shock	425	0	358	51
EB	M		No shock	414	18	0	331
JR	F		No shock	211	15	156	80
JV	M		No shock	353	0	161	0
AD	F		No shock	351	2	0	116
GM	F		No shock	340	60	18	142
JG	M		No shock	345	0	41	80
MU	M		No shock	197	26	95	211
RP	M		No shock	360	14	0	144
GP	F		No shock	162	0	22	25