The purpose of the reported study was to determine whether the generalization of stimulus equivalence relations to dimensional variants of class members could be brought under contextual control. Contextual control has been shown to prevent the merging of equivalence classes; contextual control might similarly prevent equivalence classes and perceptual classes from merging into one infinite-sized, all-encompassing class. Twelve subjects were taught 12 contextually controlled conditional discriminations. They were then tested for the emergence of 6 contextually controlled symmetry and equivalence relations. Subjects were also tested for the establishment of contextual control over the generalization of those relations. Eleven subjects showed the emergence of contextually controlled symmetry relations, and 7 subjects showed the emergence of contextually controlled symmetry and equivalence relations. Five subjects demonstrated contextual control over the generalization of the symmetry and equivalence relations. Hence, contextual cues controlled the dimensional variants to which the equivalence relations generalized. These findings suggest that contextual control may limit the degree to which stimulus equivalence relations generalize to novel stimuli.

It is now acknowledged that stimulus equivalence relations may generalize to novel stimuli that are physically similar along some dimension to a member of an existing equivalence relation. It has been shown that after one member of a perceptual class is established as a member of an equivalence class, other members of the perceptual class will enter into the equivalence class (e.g., Fields, Adams, Buffington, Yang, & Verhave, 1996; Fields & Reeve, 2001; Fields, Reeve, Adams, Brown, & Verhave, 1997; Fields, Reeve, Adams, & Verhave, 1991; Rehfeldt, Hayes, & Steele, 1998; Rehfeldt & Hayes, 2000). This catalog of findings has led Fields et al. (1997) to propose that the generalization of stimulus equivalence relations reflects the merging of conceptual
classes with perceptual classes. That stimulus equivalence relations generalize is adaptive, for individuals are able to respond appropriately in a variety of different settings and situations in the absence of direct training. That stimulus equivalence relations generalize also suggests that the physical similarity between class members and other stimuli may be one means by which stimuli become equivalent. Indeed, because conceptual classes and perceptual classes may merge, it has been suggested that stimulus equivalence classes may be open-ended and of infinite size (Fields et al., 1997).

One variable that has been shown to influence the establishment of stimulus equivalence relations is the context in which the baseline conditional discriminations are established. For example, if subjects are taught to relate stimuli A1-B1 and A1-C1 in Context 1 and A3-B1 and A3-C3 in Context 2, they are likely to demonstrate the emergence of equivalence classes A1B1C1 in Context 1 and A3B1C3 in Context 2. In this example, the two equivalence classes are controlled by the two different contexts. A number of studies have verified that when subjects are taught to make conditional discriminations in particular contexts, they will subsequently demonstrate equivalence relations that are contextually controlled (Bush, Sidman, & de Rose, 1989; Gatch & Osborne, 1989; Lazar & Kotlarchyk, 1986; Wulfert & Hayes, 1988). Contextual control clearly places a limit on the establishment of stimulus equivalence relations. Without contextual control, all environmental stimuli could merge into one infinite-sized, all-encompassing class (Sidman, 1994, p. 514).

Although it is conceivable that the merging of conceptual classes with perceptual classes may give rise to an open-ended, infinite-size class (Fields et al., 1997), there may, in fact, be a limit to the size of a generalized equivalence class. The controlling context may restrict the degree to which stimulus equivalence relations generalize to dimensional variants. For example, subjects may come to demonstrate equivalence classes A1B1C1 and A3B1C3. The generalization of those relations to dimensional variants of stimulus B1 is likely to be controlled by the two different contexts in which the relations were established. In Context 1, dimensional variants of stimulus B1 are likely to occasion the selection of stimulus A1 and C1; and in Context 2, dimensional variants of stimulus B1 are likely to occasion the selection of stimulus A3 and C3. Hence, context may control the merging of perceptual classes with equivalence classes. Without contextual control, classes of equivalent stimuli and perceptual stimuli might very well merge into one large, all-encompassing class.

The purpose of the reported experiment was to demonstrate contextual control over not only the establishment of equivalence relations, but also their generalization. Twelve subjects were taught 12 contextually controlled baseline conditional discriminations. Training occurred with the same stimuli in two contexts, but the relations that were established between the stimuli were different in the two contexts. In Context 1, subjects were taught to relate A1-B1; A2-B2; A3-B3; A1-C1;
A2-C2; and A3-C3. In Context 2, subjects were taught to relate A1-B2; A2-B3; A3-B1; A1-C1; A2-C2; and A3-C3. Subjects were then tested for (a) the emergence of contextually controlled symmetry and equivalence relations and (b) the establishment of contextual control over the generalization of those relations. During the generalization test, dimensional variants of stimuli B1, B2, and B3 were presented as sample stimuli, and the number of comparison stimulus selections occasioned by each dimensional variant was recorded. If the generalization of stimulus equivalence relations can be brought under contextual control, it was expected that the low range B variants would occasion selection of A1 and C1 in Context 1, and A3 and C3 in Context 2. Further, it was expected that the medium range B variants would occasion selection of A2 and C2 in Context 1, and A1 and C1 in Context 2. Finally, it was expected that the high range B variants would occasion selection of A3 and C3 in Context 1, and A2 and C2 in Context 2. These results would support the notion that the merging of equivalence and perceptual classes can come under contextual control.

Method

Participants

Twelve adults (8 male and 4 female) who had no known conditions of color blindness participated as subjects and were compensated with course credit for doing so. Participants were recruited through either in-class announcements or by word of mouth. Before the experiment, all participants signed a statement of informed consent and were informed that they were free to withdraw from the experiment at any time, although none chose to do so. Upon completion of the study, all participants were thoroughly debriefed.

Apparatus and Stimulus Materials

Stimulus presentation and data collection were computer controlled. The experiment was controlled by an IBM-compatible personal computer, equipped with a color monitor and a two-button mouse. The computer was centered on a 2 ft x 2 ft (0.61 m x 0.61 m) table. Experimental sessions were conducted in a 14 ft x 10 ft (4.27 m x 3.05 m) room containing several tables and chairs. The experiment was programmed in Microsoft Visual Basic (version 6.0) by the author. As shown in Figure 1, six of the nine stimuli consisted of black arbitrarily configured figures, with the exception of the stimuli which were designated as B1, B2, and B3, which were yellow, blue, and red trapezoids, respectively. The remaining stimuli were arbitrarily designated as stimuli A1, A2, A3, C1, C2, and C3. The contextual cue that was designated as Context 1 was a black oval of 7 cm in width. The contextual cue that was designated as Context 2 was a light gray square of 5 cm in width. When a contextual cue was presented, it surrounded the periphery of the computer screen. The stimuli were created in Microsoft® Paint and Microsoft Visual Basic (6.0).
Eighteen dimensional variants of stimuli B1, B2, and B3 were presented during the test for generalization. The dimensional variants were created in Microsoft® Paint. The hue of the stimuli was the only dimension that varied. The hue of stimuli B1, B2, and B3 (as established in Microsoft® Paint) was 40, 140, and 240, respectively. The hue of the variants (as established in Microsoft® Paint) increased in increments of 10, such that the dimensional variants between stimuli B1 and B2 were varying shades of yellow and blue, and the dimensional variants in between stimuli B2 and B3 were varying shades of blue and red.

Procedure
The experiment consisted of two phases. Throughout both phases, sample stimuli were presented in the top center of the screen, followed 1 s later by the display of three comparison stimuli below the sample stimulus, evenly spaced across the bottom of the screen. Subjects selected a comparison stimulus by clicking the computer mouse upon it. The onset of each new trial was marked by the presentation of a sample stimulus. When correct matches were made during Phase 1, the matching sample and comparison stimuli became outlined in black for 1.5 s. An auditory tone sounded, and 1 point was added to the subject's current point-total. Incorrect matches were followed by a new trial. All trials were separated by a 1-s intertrial interval. Point totals were displayed in the lower left-hand corner of
the computer screen during Phase 1. The entire experiment lasted between 2 and 2.5 hours. Subjects were allowed to take a short break between Phases 1 and 2 of the experiment.

Subjects were given the following instructions before the experiment:

Your job in this experiment is to perform your best. A figure will appear in the center of the screen. Next, 3 figures will appear below the first figure. It is your job to choose one of the three figures. To choose one of the 3 figures, click the mouse once on the figure that is your choice.

Phase 1: Matching-to-sample training. During Phase 1, 12 contextually controlled conditional discriminations were established, as shown in Figure 2. The contextually controlled A-B relations were trained first. In the presence of Context 1 points were provided contingent upon making the following conditional discriminations: A1-B1, A2-B2, and A3-B3. In the presence of Context 2 points were provided contingent upon making the following conditional discriminations: A1-B2, A2-B3, and A3-B1. Each sample stimulus was presented five times, in each of the two contexts. For Subjects 1-6, the A-B relations were trained in Context 1 first. When a stability criterion of 14/15, or 93%, correct was attained, the A-B relations were trained in Context 2. Subjects 6-12 began the training of the A-B relations in Context 2 first, and once stability was attained, these subjects were trained on the A-B relations in Context 1 next. The contextually controlled A-B relations were then trained together, with each contextual cue presented 15 times each per 30-trial block, and the order of presentations of contextual cues alternating randomly. Each sample stimulus was presented five times each in each of the two contexts.

When a stability criterion of 28/30, or 93%, correct was attained, the A-C relations were trained. The contextually controlled A-C relations were trained together, with each contextual cue presented 15 times each per 30-trial block, and the order of presentations of contextual cues alternating randomly. In the presence of both contexts, points were provided contingent upon making the following conditional discriminations: A1-C1, A2-C2, and A3-C3. Hence, the conditional discriminations were the same in each of the two contexts. Each sample stimulus was presented five times each in each of the two contexts. When a stability criterion of 28/30, or 93%, correct was attained, the contextually controlled A-B and A-C relations were trained together. The two contextual cues were presented 18 times each during mixed A-B and A-C training, with each sample stimulus presented six times during each context. Mixed A-B and A-C training ended when subjects attained a stability criterion of 33/36, or 92%, correct.

Phase 2: Symmetry, equivalence, & generalization test. A 504-trial generalization test was conducted next. As shown in Figure 2, the emergence of contextually controlled stimulus equivalence relations was examined during this phase. Specifically, the extent to which subjects
would demonstrate the following symmetry and equivalence relations in Context 1 was examined: B1-A1, B2-A2, B3-A3 (symmetry relations); and B1-C1, B2-C2, and B3-C3 (equivalence relations). In addition, the extent to which subjects would demonstrate the following symmetry and equivalence relations in Context 2 was examined: B1-A3, B2-A1, B3-A2 (symmetry relations); and B1-C3, B2-C1, and B3-C2 (equivalence relations). Test trials assessing the emergence of each individual contextually controlled relation was presented six times each. There were thus 72 trials assessing the emergence of contextually controlled symmetry and equivalence relations.

The generalization of contextually controlled generalized stimulus equivalence relations was also examined during this phase. Eighteen dimensional variants of stimuli B1, B2, and B3, along the dimension of hue, were presented as sample stimuli on test trials in place of stimuli B1, B2, or B3, on 432 test trials. For the generalized contextually controlled B-A symmetry relations, each of the 18 dimensional variants were presented in each context six times each. There were thus 216 test trials assessing the generalization of contextually controlled B-A relations. For the generalized contextually controlled B-C equivalence relations, each of the 18 dimensional variants were presented in each context six times each. There were thus 216 test trials assessing the generalization of contextually controlled B-C relations.

**Results**

All 12 subjects demonstrated mastery of the contextually controlled conditional discriminations during training. Shown in Table 1 is the number of trial blocks required for each subject to attain criterion for each set of contextually controlled baseline conditional discriminations.

**Contextually Controlled Equivalence Class Formation**

Contextually controlled stimulus equivalence relations were inferred to have been established if a subject made at least 5/6 comparison stimulus selections for a particular relation that were consistent with the contextually controlled baseline conditional discriminations: If subjects demonstrated the B1-A1, B2-A2, and B3-A3 relations in Context 1, and...
Table 1

Trial Blocks to Criterion for Each Set of Contextually Controlled Baseline Conditional Discriminations, per Subject

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the B2-A1, B3-A2, and B1-A3 relations in Context 2, with at least 5/6 correct responses for each relation, it was inferred that contextually controlled symmetry relations had been established. Likewise, if subjects demonstrated the B1-C1, B2-C2, and B3-C3 relations in Context 1, and the B2-C1, B3-C2, and B1-C3 relations in Context 2, with at least 5/6 correct responses for each relation, it was inferred that contextually controlled equivalence relations had been established.

Table 2 and Figures 3-5 show that all subjects, with the exception of Subject 3, demonstrated the emergence of six contextually controlled symmetry relations, as stimuli B1, B2, and B3 occasioned at least five comparison stimulus selections that were consistent with the contextually controlled baseline conditional discriminations. Table 2 and Figures 3-5 also show that Subjects 4, 5, 6, 8, 12, 2, and 11 demonstrated the emergence of

Table 2

Experimental Outcomes for Each Subject

<table>
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<tr>
<th>Subject</th>
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<th>Equivalence</th>
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six contextually controlled equivalence relations, as stimuli B1, B2, and B3 occasioned at least five comparison stimulus selections that were consistent with the contextually controlled baseline conditional discriminations. Thus, 58% of the subjects demonstrated contextually controlled equivalence class formation. In all cases but one, failures to demonstrate class formation resulted from failures to demonstrate equivalence relations.

**Contextually Controlled Generalized Equivalence Relations**

The contextually controlled symmetry relations were held to have generalized to the dimensional variants that were presented during the generalization test if the low range of dimensional variants of B stimuli reliably occasioned the selection of A1 in Context 1 and A3 in Context 2; if the medium range of dimensional variants reliably occasioned the selection of A2 in Context 1 and A1 in Context 2; and if the high range of dimensional variants reliably occasioned the selection of A3 in Context 1 and A2 in Context 2. Likewise, the contextually controlled equivalence relations were held to have generalized to the dimensional variants that were presented during the generalization test if the low range of dimensional variants of B stimuli reliably occasioned the selection of C1 in Context 1 and C3 in Context 2; if the medium range of dimensional variants reliably occasioned the selection of C2 in Context 1 and C1 in Context 2; and if the high range of dimensional variants reliably occasioned the selection of C3 in Context 1 and C2 in Context 2.

Shown in Figures 3-5 are the generalization test performances for the 12 subjects. The figures present the number of comparison stimulus selections occasioned by stimuli B1, B2, B3, and by each of the 18 dimensional variants (the hue of stimuli B1, B2, B3, and each of the 18 dimensional variants is presented along the x axis). The outcomes observed for each subject are shown in Table 2. Table 2 and Figure 3 show that Subjects 4, 5, 6, 8, and 12 all demonstrated the generalization of contextually controlled symmetry and equivalence relations. Table 2 and Figure 4 show that Subjects 2 and 11, who demonstrated the emergence of contextually controlled symmetry and equivalence relations, failed to demonstrate the generalization of those relations. Table 2 and Figure 4 also show that Subjects 7 and 10, who demonstrated the emergence of contextually controlled symmetry relations also demonstrated the generalization of those relations. Table 2 and Figure 5 show that Subjects 1 and 9, who demonstrated the emergence of contextually controlled symmetry relations, failed to demonstrate the generalization of the symmetry and equivalence relations. The same is true for Subject 3, who failed to demonstrate the emergence of the symmetry and equivalence relations.

As can be seen in Figure 3, the subjects who demonstrated successful generalization performances generally showed overlap between the generalization gradients obtained for the symmetry relations and those obtained for the equivalence relations. For most of the subjects, the contextually controlled equivalence classes generalized to include 5 to 7 dimensional variants. The obvious exception is Subject 5. For this subject, the B1-A3 relation generalized to include 12 dimensional variants, and the B1-C3 relation generalized to include 14 dimensional variants. Likewise, the B2-A2 and B2-C2 relations generalized to include 9 dimensional variants.
Figure 3. Generalization test performances for Subjects 4, 5, 6, 8, and 12.
Figure 4. Generalization test performances for Subjects 2, 11, 7, and 10.
Figure 5. Generalization test performances for Subjects 1, 9, and 3.
Discussion

This study demonstrated that the merging of equivalence classes and perceptual classes can be contextually controlled. The responding of 5 subjects was indicative of contextual control over equivalence class formation and generalization. Two additional subjects demonstrated the emergence and generalization of symmetry relations, but did not demonstrate the emergence and generalization of equivalence relations. Eleven subjects demonstrated the emergence of contextually controlled symmetry relations, and 7 of those subjects demonstrated the emergence of contextually controlled equivalence relations as well. The demonstration of contextually controlled symmetry and equivalence relations is consistent with other findings (e.g., Bush et al., 1989; Gatch & Osborne, 1989; Wulfert & Hayes, 1988), as is the observed merging of equivalence classes with perceptual classes (e.g., Fields et al., 1996; Fields et al., 1997; Fields et al., 1991; Rehfeldt & Hayes, 2000; Rehfeldt et al., 1998).

For some subjects, the emergence of symmetry and equivalence relations was consistent with the degree to which generalization was observed. In other words, some subjects who showed the emergence of the symmetry and equivalence relations also showed the generalization of those relations. Subjects 2 and 11 were an exception; these subjects demonstrated the emergence of contextually controlled symmetry and equivalence relations, but failed to demonstrate their generalization. The same is true for Subjects 1 and 9, who demonstrated the emergence of contextually controlled symmetry relations, but failed to demonstrate their generalization. These failures might be attributable to the length of the generalization test phase, which consisted of 504 extinction trials. This long extinction phase may have produced considerable response variability. Presenting reinforced baseline trials interspersed between the test trials might have circumvented this difficulty.

All but 1 subject demonstrated the emergence of contextually controlled symmetry relations, but 4 subjects failed to show the emergence of contextually controlled equivalence relations. All of the subjects who demonstrated equivalence relations also demonstrated symmetry relations. This finding supports the notion that symmetry may be a prerequisite for the emergence of other relations (e.g., Sidman, Willson-Morris, & Kirk, 1986), including contextually controlled relations. It is also worth noting that subjects' accuracy was an inverse function of the nodal distance separating the related stimuli (Fields, Adams, Verhave, & Newman, 1990; Fields & Verhave, 1987). It is possible that more subjects would have performed successfully on the equivalence tests if the tests for symmetry and equivalence had been presented serially, versus simultaneously (see Buffington, Fields, & Adams, 1997). One limitation of this procedure is that it did not test for full class formation. Test trials assessing the emergence of C-A and C-B relations were not conducted. It may have been important to evaluate the relationship between contextually controlled class formation and the generalization of the individual relations. It may have additionally been important to conduct the tests for class formation and generalization in separate phases. Some evidence suggests that the transfer of stimulus functions may be facilitated by a prior test for equivalence
(e.g., Hayes, Kohlenberg, & Hayes, 1991; Wulfert & Hayes, 1988; see Dymond & Rehfeldt, 2000). Whether or not testing for class formation facilitates the generalization of equivalence relations remains to be seen.

Of the 5 subjects who demonstrated the generalization of symmetry and equivalence relations, the generalization patterns observed for the symmetry relations were largely consistent with the generalization patterns observed for the equivalence relations. For 4 of the 5 subjects who demonstrated generalization, the contextually controlled equivalence classes generalized to include 5 to 7 dimensional variants. For Subject 5, however, some classes generalized to include up to 14 dimensional variants. This may have been caused by a different history of color discrimination with respect to the particular hues used in the experiment for this subject.

These results showed that the generalization of stimulus equivalence relations can be contextually controlled. This inference is based on the different patterns of generalization that were observed in each of the two contexts. For example, in Context 1, dimensional variants of stimulus B1 typically occasioned the selection of stimuli A1 and C1, but in Context 2, the same dimensional variants typically occasioned the selection of stimuli A3 and C3. If contextual control had not been established, dimensional variants of stimulus B1 would have occasioned the selection of stimuli A1 or A3 and C1 or C3 with equal probability, in which case the generalization gradients would have been flat. Hence, context may control the generalization of equivalence relations, thus restricting the number of dimensional variants that come to function as class members. Because of context, perceptual classes and conceptual classes may not merge into one infinite-sized, all encompassing class.

Future research might further examine the role of context in influencing the generalization of equivalence relations. For example, contextual control over the transfer of stimulus functions to dimensional variants of class members might be examined, as well as the establishment of contextual control over the generalization of relations of difference and opposition (e.g., Steele & Hayes, 1991). This research could have important ramifications in applied arenas, particularly for persons with mental retardation or autism who often have difficulties demonstrating stimulus generalization. An examination of how contextual control might facilitate or hinder the generalization of stimulus equivalence for persons with such disabilities would be of value.

References


