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TEACHING EARLY BRAILLE LITERACY SKILLS WITHIN A STIMULUS EQUIVALENCE PARADIGM TO CHILDREN WITH DEGENERATIVE VISUAL IMPAIRMENTS

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Despite the need for braille literacy, there has been little attempt to systematically evaluate braille-instruction programs. The current study evaluated an instructive procedure for teaching early braille-reading skills with 4 school-aged children with degenerative visual impairments. Following a series of pretests, braille instruction involved providing a sample braille letter and teaching the selection of the corresponding printed letter from a comparison array. Concomitant with increases in the accuracy of this skill, we assessed and captured the formation of equivalence classes through tests of symmetry and transitivity among the printed letters, the corresponding braille letters, and their spoken names.

Key words: braille, instruction, stimulus equivalence, visual impairment

Braille is a system that enables individuals to read and write through touch. Each letter of the English alphabet is represented by a unique dot configuration represented by the presence or absence of six dots, each approximately 1 mm in diameter, within a matrix of two columns and three rows, with 1.5 mm between the midpoints of each adjacent dot. These small patterns differ only by the presence or absence of dots, making braille alphabet learning difficult (Millar, 1978).

The American Printing House for the Blind (2008) reports that there are currently 1.3 million legally blind individuals in the United States. According to the National Braille Press only 12% of legally blind individuals can read braille, in contrast to 50% of blind individuals who could do so in the 1960s (see Brittain, 2007). One of the greatest reasons for this decline in braille literacy has been the controversy of whether or not to teach braille when a blind child has some residual vision, in which case it has become more popular to rely on magnification equipment or large print. Children with some residual vision account for approximately 85% of blind children because they are blind by the legal definition (i.e., vision is worse than 20/200 and cannot be improved with corrective lenses) but have some vision remaining (Holbrook & Koenig, 1992).

Certain degenerative conditions, such as glaucoma and degenerative myopia, have an onset early in childhood with vision worsening over time. Low-vision students, in particular those with degenerative visual impairments, are at risk for not receiving appropriate braille instruction while some level of sight remains (National Federation of the Blind, 2009). The use of augmentative technology with this population may delay the need to learn braille, but the transition to braille reading will be ultimately necessary to maintain literacy. These individuals in particular may benefit from braille instruction prior to losing their functional sight because relations can be established between braille and other symbols that already exist in their repertoires (i.e., letters and numerals; Hall & Newman, 1987).

One of the earliest skills for braille literacy development is the ability to name individual characters correctly. Difficulty in this basic skill

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impedes learning more complex braille-reading skills, such as producing and combining letter sounds (Hampshire, 1975). These combined phonics skills are a key component of reading acquisition (National Institute of Child Health and Human Development, 2000). Despite the need for braille letter naming as a precursor for braille reading, limited research exists on effective methods for teaching this skill, and it is rarely included in commercially available braille curricula.

We have identified only two studies that have evaluated procedures for teaching braille-letter identification. Both studies shared the approach of establishing a novel relation between the tactile stimulus (i.e., a braille symbol) and an auditory or vocal stimulus (i.e., the spoken letter name). Mangold (1978) taught congenitally blind students to vocalize letter names while touching the braille stimulus. Crawford and Elliott (2007) sang songs to low-vision braille learners as they touched the braille symbols (e.g., as students placed their finger over the braille p, the experimenter sang "p is in the alphabet, p, p, p," three times) and prompted the students to repeat this song. Although both of these approaches have been shown to be effective in establishing early braille-letter naming, teaching the relation between the braille symbol and a visual stimulus (i.e., a printed letter), as opposed to the spoken letter, may benefit learners with some level of vision who have acquired textual knowledge of the alphabet already. First, the presentation of visual stimuli will allow a motor-selection response. By requiring a motor response, teachers or therapists ensure that they will be able to prompt correct responses to facilitate learning (as opposed to vocal responses in Mangold and Crawford & Elliott). Also, many students with degenerative visual impairments often begin learning to read in print. Including a familiar printed stimulus into the instructional milieu may facilitate the transfer of stimulus control across modalities (visual, auditory, and tactile) and enter into a stimulus equivalence class.

A stimulus equivalence class is demonstrated by the emergence of relations between previously unassociated stimuli (Green & Saunders, 1998; Sidman & Tailby, 1982). In particular, there are three tests of emergent relations that are commonly assessed in a matching-to-sample (MTS) format. The first is a test of reflexivity, which is demonstrated when each member of the stimulus class can be matched to itself. For instance, an individual would select the braille letter Z from an array of comparison stimuli when presented with an identical sample stimulus, the braille letter Z. Second is the test for symmetry, which is demonstrated when bidirectionality exists between two stimuli. For instance, if one is taught to select the printed letter Z when presented with the braille letter Z, symmetry would be demonstrated should he or she then be able to select the braille letter Z when shown the printed letter Z. The third and final test is that for transitivity, which is demonstrated when uninstructed conditional relations emerge in the presence of novel discriminative stimuli (Fienup, Covey, & Critchfield, 2010). Given the previous example, following instruction to select the printed letter Z when presented with the braille letter Z and to name the letter "Z" when presented with the printed letter Z, transitivity would be demonstrated if the individual could then select the braille letter Z when presented with the spoken letter name and if the individual could state the letter name when touching the braille letter Z.

From a teaching perspective, stimulus equivalence technology may be particularly useful given its efficiency. Namely, teaching a few conditional relations between stimuli may result in the emergence of a number of uninstructed relations. Stimulus equivalence procedures have been demonstrated to teach a variety of prereading and reading skills such as classifying vowels and consonants (Lane & Critchfield, 1998), matching letters to their corresponding names and sounds (Connell & Witt, 2004), and matching pictures to printed and spoken words (de Rose, de Souza, & Hannah, 1996). Rosales and Rehfeldt (2007) taught 2 participants with severe mental retardation to select the correct picture and text of preferred items when provided with the corresponding name of the items. By teaching these auditory–picture and auditory/printed-word relations, the participants demonstrated the emergence of the picture/printed-word relation by requesting preferred items using printed words rather than pictures.

Bush (1993) provided some initial evidence that the formation of equivalence classes among printed, braille, and the spoken names of these stimuli may be likely. Bush presented 6- and 7-year-old children with tactile displays of two-dot configurations (arranged vertically, horizontally, and diagonally) or Greek letters (gamma, lambda, and xi), visually similar displays (i.e., the same characters presented on a computer screen), and arbitrarily assigned spoken names ("zel," "mot," and "raf"). Following instruction to select the tactile characters when presented with the spoken names, each child demonstrated the formation of equivalence relations in which he or she was then capable of naming the tactile displays and selecting the visual representations that matched the tactile displays (i.e., could select a picture of two dots arranged vertically after feeling two dots arranged vertically). This study provided support that training relations between tactile and visual or auditory stimuli could result in the crossmodal transfer of stimulus control and equivalence relations, but given that this was a basic laboratory procedure and included relatively simple tactile stimuli (i.e., two-dot configurations), the efficacy of a procedure that arranged the formation of equivalence relations between auditory, visual, and braille tactile stimuli in a learning curriculum has yet to be ascertained.

No studies have examined the use of stimulus equivalence methods during braille instruction to date. The purposes of the current study were twofold. First, we conducted a preliminary evaluation of a teaching procedure in which students were taught to select printed letters when presented with braille sample stimuli in an MTS task. Second, we assessed the emergence of an equivalence class consisting braille, printed, and spoken letters as a result of this instruction with 4 children with degenerative visual impairments.

METHOD

Participants and Setting

Four children with degenerative visual impairments, nominated by the director of a state school for children with visual impairments, participated. All students at the school received braille instruction based on the *Patterns* curriculum (Caton, Pester, & Bradley, 1982). The 4 participants had received prior braille instruction based on this curriculum, but still demonstrated limited proficiency in reading braille words. Fred was a 7-year-old boy with high myopia. He had received 1 year of classroom-based braille instruction prior to participation in the study. Jeremy was a 12-year-old boy with a hypoplastic optic nerve in his left eye and neurofibromatosis. Prior to participation, Jeremy had received 3 years of classroom-based braille instruction. Danielle was a 9-year-old girl with congenital glaucoma and congenital nystagmus. She had received 2 years of classroom-based braille instruction. Cole was a 7-year-old boy with retinopathy of prematurity. He had received 1 year of classroom-based braille instruction. We did not assess students' braille or printed-word reading abilities beyond our assessments described below. Sessions were conducted in an unoccupied common room in a dormitory on the school's campus.

Materials

We presented the 26 English letters, printed in 72-point Times New Roman font, as visual stimuli, and braille letters, printed using a Perkins Braillewriter on 26 small cards of standard braille paper, as tactile stimuli. We presented all braille letters under identical cardboard boxes with a small opening through which participants' hands were placed. This ensured that participants experienced braille letters only through touch (i.e., they could not see the symbols). The teacher read aloud the appropriate letter names in a uniform tone and volume level during the presentation of auditory stimuli.

Measurement and Interobserver Agreement

We defined a correct response as the participant selecting (touching) the correct comparison stimulus and vocalizing their selection (i.e., "this one") during sessions that required a selection response or stating the correct name of a stimulus during sessions that required a vocal response, and an incorrect response as selecting or vocalizing any other letter. One or two independent observers collected data on a trial-by-trial basis, with a second observer present during 63%, 57%, 40%, and 58% of sessions for Fred, Jeremy, Danielle, and Cole, respectively, across all assessments to provide a measure of interobserver agreement. We calculated agreement scores by comparing observers' records on a trial-by-trial basis and scored each trial in which both observers coded a correct response or both coded an incorrect response as an agreement; we scored all other trials as a disagreement. We then calculated the percentage of agreement by dividing the number of trials in agreement by the total number of trials and then converting this ratio to a percentage, resulting in a mean agreement score of 99% (range, 89% to 100%) for Fred, 98% (range, 75% to 100%) for Jeremy, 99% (range, 93% to 100%) for Danielle, and 99% (range, 90% to 100%) for Cole.

Procedure

Throughout all assessments, we used an MTS format to assess and teach stimulus–stimulus relations. In each trial, we presented a sample stimulus along with a comparison array of three stimuli, except where otherwise noted. The teacher instructed the participant to select the stimulus from the comparison array that matched the sample stimulus. Both the sample stimulus and comparison array were presented simultaneously (as opposed to delayed MTS, in which the sample stimulus is removed prior to the presentation of the comparison array). During trials in which the sample stimulus was the letter name, the teacher said the letter name once at the beginning of each trial and repeated the name only following a request from the participant (which rarely occurred). During trials in which vocalizing the letter name served as the target response, no comparison stimuli were presented. During trials in which braille letters served as either the sample or comparison stimuli, the teacher instructed the participant to feel the stimulus with a light touch using a left-to-right movement. The teacher did not provide additional instructions, nor was the participant prevented from repeatedly feeling the tactile stimuli. Across all assessments we will use A to denote the braille letters, B to denote the printed letters, and C to denote the names of those stimuli (e.g., the AB relation refers to the relation in which given a braille sample, the target response was for the participant to select a printed letter). The first author served as the teacher during all sessions.

Pretest and pretraining of braille readiness skills. We conducted a number of pretests to determine skills that students demonstrated prior to the intervention. Any skills that were not demonstrated at 100% mastery were instructed directly. Those skills and instructional procedures are noted below.

Printed-letter naming. One aspect of our instructional procedures capitalized upon an existent relation between printed letters and their spoken or heard counterparts to enter into an equivalence class. Our first pretest determined if students could correctly select a printed letter after hearing its auditory counterpart and could state the name of a letter vocally after seeing it in print. This pretest was completed during two sessions. The first session involved a test of the printed-letter-to-name (BC) relation and consisted of 26 trials (i.e., one trial for each letter of the alphabet) in which the teacher presented the participant with a printed letter and asked him or her to name it. The second session involved a test of the name-to-printed-letter relation (CB) in which the teacher spoke the name of each letter and asked the participant to select the correct letter from an array of three printed letters (one correct and two comparisons selected randomly). Letter presentation order was randomized for each session. All students obtained 100% accuracy for both BC and CB relations.

Identity matching. Next, we conducted identity-matching tests across three sessions to ensure that students could match printed (BB relation), spoken (CC relation), and braille (AA relation) letters to themselves. During the printed-letter identity-matching session, the teacher presented a printed letter and prompted the participant to select the identical comparison stimulus from an array of three printed letters (one identical and two comparisons selected randomly). During the spoken identity-matching sessions, the teacher spoke the name of a letter and prompted the participant to repeat the same letter name. During the braille identity-matching sessions, the teacher presented a braille letter and prompted the participant to select the identical braille letter from an array of three braille letters. Again, each pretest involved 26 trials, with each letter presented one time. All students demonstrated 100% accuracy during text and spoken identity-matching pretests; 2 of the 4 students (Fred and Danielle) did not demonstrate 100% accuracy during braille identity-matching pretests and therefore received additional instruction.

Braille identity-matching instruction (Fred and Danielle only). We conducted a daily probe session to ascertain mastered and nonmastered letters using the same procedures described for the braille identity-matching pretest. The teacher did not provide feedback, nor did she name letters during this probe. Letters incorrectly matched during this probe entered into a teaching set. The teacher presented those letters in a similar identity-matching arrangement, except that correct responding was praised and incorrect responding resulted in a vocal prompt to immediately retouch the sample and then the correct comparison stimulus twice. These teaching sessions continued until the participant correctly identified all letters in the instructional set three times. Sessions were repeated daily until the participant achieved 100% accuracy during the initial probe session. Fred received 52 training trials, and Danielle received 13 training trials prior to meeting this accuracy criterion.

Pretest of target relations. We conducted a final pretest to determine any existing relations among braille, printed, and spoken letters. Specifically, we assessed four target relations: the braille-to-printed-letter relation (AB), the printed-letter-to-braille relation (BA), the name-to-braille relation (CA), and the braille-to-name relation (AC). (The BC and CB relations were not assessed further because this skill was demonstrated to be at mastery levels in the previously described pretests.) We assessed each target relation during separate 26-trial sessions and repeated each session three times. Sessions were similar to those of previous pretests. During AB sessions, braille letters served as the sample stimuli and printed letters served as the comparisons; during BA sessions, printed letters served as the sample stimuli and braille letters served as the comparisons; during CA sessions, the spoken letter name served as the sample and braille stimuli served as the comparisons; and during AC sessions, braille stimuli served as the sample and the participant was required to vocalize the correct letter name. We did not provide any programmed consequences for correct or incorrect responding.

We evaluated the results of these pretests on a letter-by-letter basis and excluded any letter that was selected correctly during 100% of trials during the AB session (i.e., the would-be directly instructed relation) or 100% of trials in two of the other three relations from further assessment and instruction. We randomly assigned all other letters into letter sets. This resulted in four sets of five letters and one set of six letters for Fred, two sets of four letters for Jeremy, one set of four letters and one set of five letters for Danielle, and one set of five letters for Cole.

Instruction and evaluation design and procedures. We evaluated our instructional procedure with a multiple-probe design across letter sets with each participant, with the exception of Cole, for whom we included only one letter set. Following a minimum of three baseline probe sessions of each of the four target relations (AB, BA, CA, and AC), the teacher then implemented instruction for the AB relation with the first letter set only. After meeting instructional criteria, she conducted additional probe sessions for each letter set of each target relation prior to implementing instruction of the AB relation with the next letter set. Following meeting mastery criteria of the AB relation of the second and each subsequent letter set, a booster session was conducted to ensure that previously mastered relations remained at strength prior to conducting the next round of probe sessions.

Probes. We conducted probe sessions for each of the four target relations individually (i.e., the BA relation was assessed in a separate session from the AB, AC, and CA relations). During each session, the teacher presented each letter as a sample stimulus once with comparison stimuli randomly drawn from all letters for Fred, but only from within the same letter set as the sample letter for Jeremy, Danielle, and Cole. Letter presentation order and the position of the comparison stimuli were randomly alternated across all trials. The teacher did not deliver any programmed consequences for correct or incorrect responding, and always conducted probe sessions in the following order: AB, BA, CA, and AC. These probes served as an initial baseline and allowed the evaluation of (a) the direct effects of instruction on the AB relation and (b) the uninstructed emergence BA (symmetric), CA (transitive), and AC (transitive and symmetric) relations.

AB instruction. AB instructional sessions were similar to those of the AB probe sessions, except that the teacher (a) presented each letter in the instructional set twice each session (the number of trials per session was determined by the number of letters in the instructional set); (b) implemented a three-step prompting procedure consisting of vocal, model, and physical prompting, with 3 to 5 s between prompts, to teach the student to select the correct comparison stimulus with the least amount of assistance; and (c) provided praise and the delivery of a token (exchangeable for 30-s access to the participant's choice of a leisure activity at the conclusion of the day's sessions) following each correct response. We considered a letter set mastered following two consecutive sessions with correct responding at or above 90% of trials.

We made an additional modification during Jeremy's instructional sessions because he failed to meet mastery criterion following repeated exposure to the aforementioned procedure. Instead, we initially presented a single braille letter as a sample across consecutive trials until he selected the correct comparison on 9 of 10 consecutive trials (similar to the blocking or chunking procedure described by Williams, Perez-Gonzalez, & Queiroz, 2005). Then we added and alternated one additional sample letter from the letter set until the 90% accuracy criterion was reached for both letters. We then sequentially introduced the remaining letters from the instructional set as samples until Jeremy reached 90% accuracy with all letters of the set presented twice within a session.

Booster sessions. Booster sessions were identical to AB instructional sessions, except that they included all members of previously mastered letter sets. Again, we conducted booster sessions prior to each emergent relations probe to ensure that this instructed relation was at full strength due to the duration of time between instruction and some probes (a single probe typically occupied a full day's experimental time, so it may have been several days between the completion of instruction and the final emergent relations probe).

RESULTS

Fred

Fred's evaluation (Figure 1) included all 26 letters divided into five letter sets. Correct responding was low for Letter Sets 1, 2, 3, and 4 prior to instruction (*M*s = 29%, 28%, 40%, and 40%, respectively). We then systematically introduced AB instruction across these letter sets in accordance with a multiple probe design; Fred met mastery criterion following 6, 9, 7, and 2 instructional sessions for Sets 1, 2, 3, and 4, respectively (data not shown). The acquisition of this skill was maintained during posttraining probes in each set (*M*s = 98%, 100%, 100%, and 100% correct, respectively). Correct responding steadily increased to mastery criteria in the absence of direct instruction for Set 5; therefore, we did not implement instruction with this letter set.

Data for Fred's BA relation are shown in the second column of Figure 1. Correct responding was low initially during baseline for Letter Sets 1, 2, 3, and 4 (*M*s = 41%, 28%, 40%, and 40%, respectively). Correct responding emerged to high levels in each of these sets following the previously discussed AB instruction (*M*s = 95%, 100%, 100%, and 100%, respectively). These data demonstrate the emergence of the symmetric relation. Similar to the AB relation, we observed a gradual increase with Set 5.

Data for Fred's CA relation are shown in the third column of Figure 1. Correct responding was low during baseline for the first four letter sets (*M*s = 46%, 28%, 40%, and 49%, respectively) but increased and was maintained after instruction for the AB relation (*M*s = 91%, 87%, 76%, and 90%, respectively) during postinstruction probes. These data indicate the emergence of the transitive relation. Again, we observed a steady increase in correct responding for Set 5.

Data for Fred's AC relation are shown in the fourth column of Figure 1. Again, correct responding was low during baseline for each of the first four letter sets (*M*s = 30%, 0%, 9%, and 9%, respectively) but increased to and was maintained at high levels following the AB instruction (*M*s = 92%, 100%, 85%, and 100%, respectively). These data indicate the emergence of the transitive and symmetric relations. We observed a temporally corresponding increase in correct responding with Set 5.

Jeremy

Jeremy's evaluation (Figure 2) included eight letters divided into two letter sets. Mean correct responding was 33% and 62% during baseline probes of the AB relation for Letter Sets 1 and 2, respectively. Both letter sets met the mastery criterion after 28 and nine instructional sessions, respectively (data not shown); correct responding was maintained at high levels during postinstruction probes (*M*s = 100% and 94%, respectively). For the BA relation, mean correct responding during baseline was 33% and 64% for Sets 1 and 2, respectively, which increased to 95% and 100% following AB instruction, again indicating the emergence of the symmetrical relation. For the CA relation, mean correct responding during baseline was 42% and 56% for Sets 1 and 2, respectively, and increased to 95% and 100% following AB training, again indicating the emergence of the transitive relation. Correct responding was low for both Sets 1 and 2 during baseline of the CA relation (*M*s = 30% and 38%, respectively) and increased and was maintained at high levels following AB instruction (*M*s = 100% and 100%), indicating emergence of the transitive and symmetric relations.

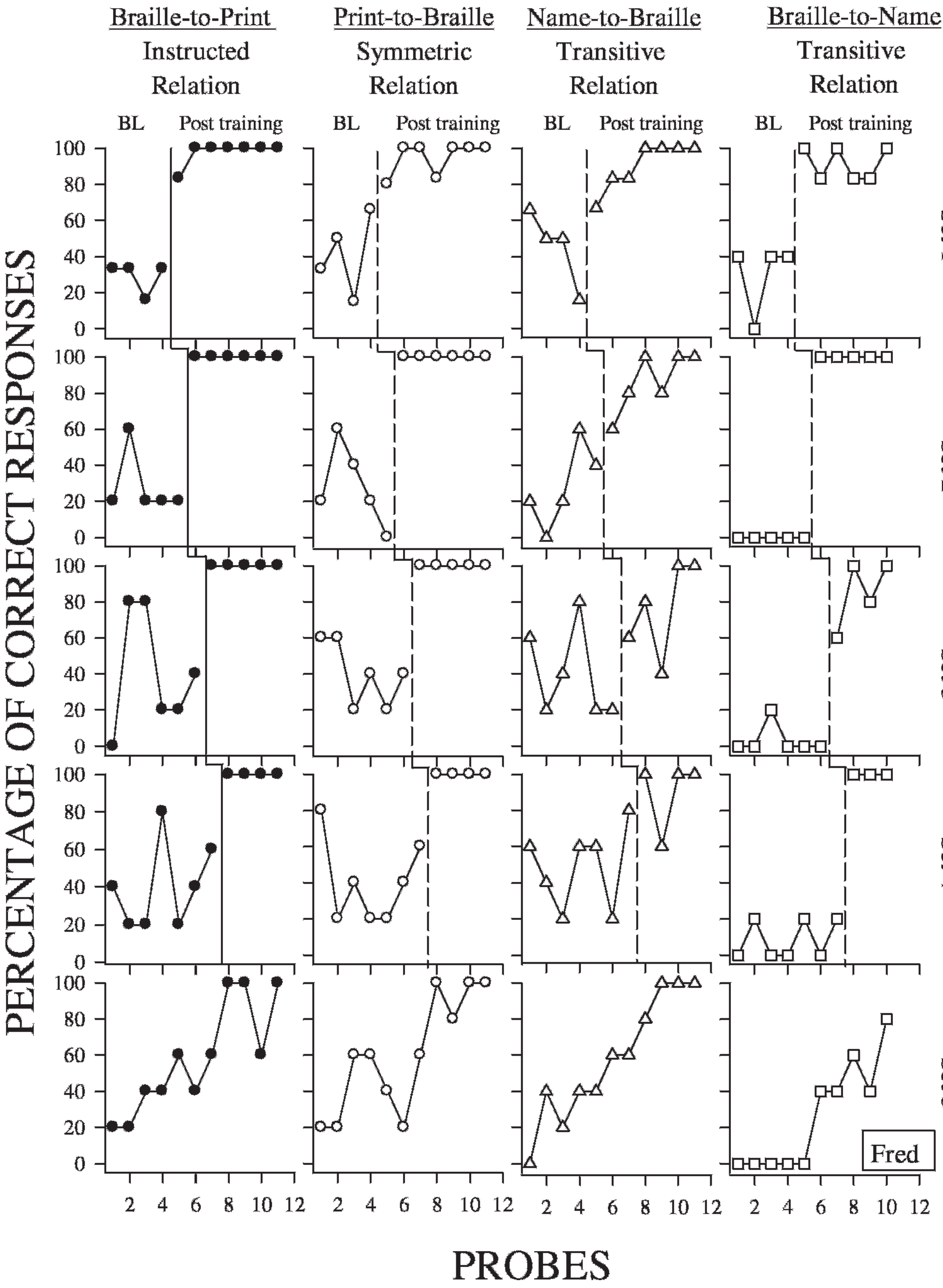

Figure 1. Fred's evaluation results, with the trained relation (braille to printed letters) shown in the left column and the emergent symmetric (printed-letter-to-braille) and transitive (name-to-braille and braille-to-name) relations in the next three columns.

Danielle

Danielle's evaluation (Figure 3) included nine letters divided into two letter sets. Mean correct responding during baseline of the AB relation was 17% and 64% for Letter Sets 1 and 2, respectively. Correct responding on both letter sets was maintained at 100% accuracy during subsequent test probes following nine and three

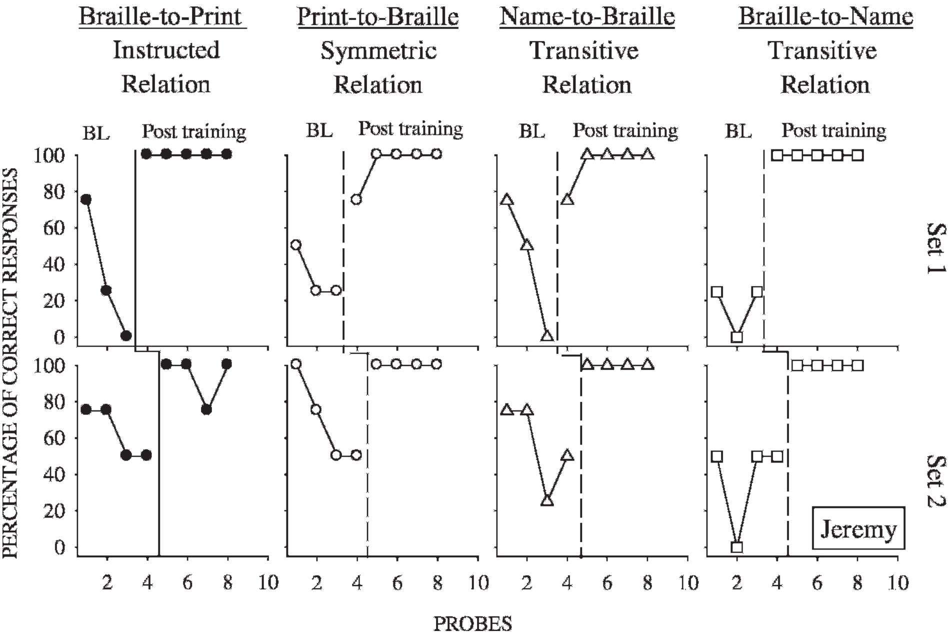

Figure 2. Jeremy's evaluation results, with the trained relation (braille to printed letters) shown in the left column and the emergent symmetric (printed-letter-to-braille) and transitive (name-to-braille and braille-to-name) relations in the next three columns.

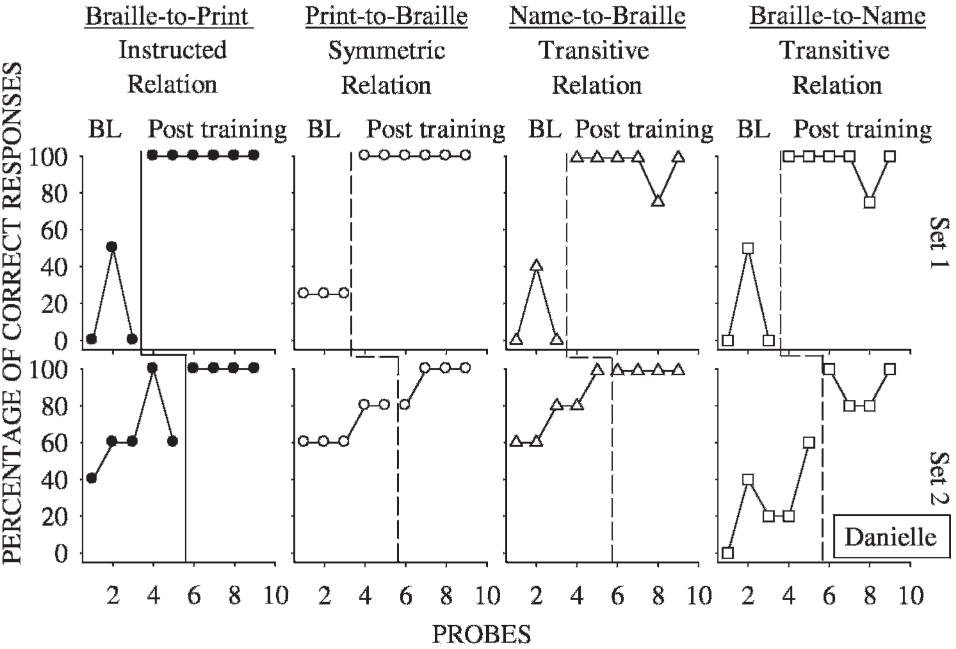

Figure 3. Danielle's evaluation results, with the trained relation (braille to printed letters) shown in the left column and the emergent symmetric (printed-letter-to-braille) and transitive (name-to-braille and braille-to-name) relations in the next three columns.

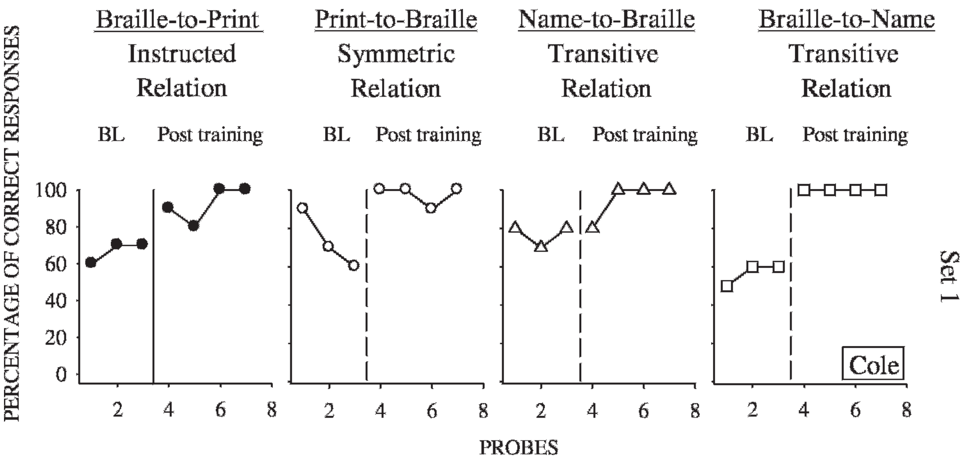

Figure 4. Cole's evaluation results, with the trained relation (braille to printed letters) shown in the left column and the emergent symmetric (printed-letter-to-braille) and transitive (name-to-braille and braille-to-name) relations in the next three columns.

instructional sessions (data not shown). Mean correct responding was 25% for Set 1 and 68% for Set 2 during baseline of the BA relation and increased to high levels (*M*s = 100% and 95%) after AB instruction. Mean correct responding for the CA transitive relation was 13% and 76% for Sets 1 and 2, respectively, during baseline and increased to 96% and 100% after instruction. Correct responding was low in both letter sets (*M*s = 17% and 28%) during baseline for the AC relation and increased to 96% and 90% during postinstruction probes. These data indicate the emergence of each of the equivalence class relations.

Cole

Cole's evaluation (Figure 4) included one set of five letters. Mean correct responding was 67% during baseline of the AB relation. This relation met mastery criteria after five instruction sessions (data not shown), and correct responding was maintained at high levels (*M* = 93%) during postinstruction probes. Mean correct responding was 73% for the BA relation and increased to 98% following instruction of the AB relation. Mean correct responding was 77% during baseline and increased to 95% during postinstruction probes for the CA relation. Mean correct responding was 57% during baseline for the AC relation and increased to 100% during postinstruction probes. Again, these data indicate the emergence of each of the equivalence class relations.

DISCUSSION

We taught 4 children with degenerative visual impairments braille-letter identification skills in which they selected a printed letter when given a braille sample. Following this instruction, selecting braille letters given a printed sample, selecting braille letters given a spoken letter name, and naming braille letters without direct teaching emerged for each participant. These results extend the literature related to braille instruction by providing a systematic approach to teaching early braille-literacy skills specifically targeted at individuals with existing sight and text reading skills. This is the only study that has targeted this population specifically.

In addition to targeting a novel population, this study differed from previous research in a number of important ways. First, this is the only study that assessed the emergence of equivalence relations between previously learned spoken and printed letters and novel braille characters. These results suggest that instruction based on these relations may efficiently develop the prerequisites necessary for more comprehensive braille instruction (i.e., those that involve phonemes and the combination of letters into words and sentences) and are similar to the results of Bush (1993) by demonstrating the crossmodal formation of equivalence classes involving tactile, auditory, and visual stimuli.

Second, this study differed from previous braille-instruction research in that instruction focused on selection of a visual stimulus in the presence of a braille stimulus rather than teaching letter naming (as was the case in Mangold, 1978) or selection of the braille stimulus given the letter name (as was the case in Crawford & Elliott, 2007). Although we did not specifically target braille-letter naming through our instructional methods, this skill was acquired for all participants as well as name-to-braille and braille-to-printed-letter matching. Thus, our instructional procedures should be considered at least as effective as those of Mangold and Crawford and Elliott in producing braille-letter naming, even though it was not the direct target of our instruction, and at best superior in that all of these additional skills were acquired.

We chose to teach the AB relation (a) to ensure that the required response (i.e., touching a printed letter) was one that could be prompted physically and (b) to promote the transfer of stimulus control of the participants' prior printed-letter reading ability to braille letters. Some children with weak motor or vocal imitative repertoires may benefit particularly from physical prompting, which ensures the emission of a correct response on every trial. Although physical prompting was never necessary in the current study, the value of this procedure will likely be realized across larger participant samples. Further, the inclusion of a selection response should permit the development of a computerized version of this instructional procedure using a refreshable braille display and a mouse or touchscreen.

Despite the potential advantages of teaching the AB relation, other advantages for initiating instruction with one of the other relations may exist. Specifically, Stromer, McIlvane, and Serna (1993) suggested that equivalence class formation may be facilitated by labeling sample stimuli; thus, stimulus class formation may have formed more readily by teaching the AC relation. Additional research is needed to compare the efficiency of braille learning depending on the initial relation taught (i.e., it is possible that initiating instruction via the AB relation confers no advantage despite the ability to physically prompt a target response).

We assessed braille-to-braille identity matching and, when necessary, trained this skill to mastery prior to initiating AB instruction. Given the stimulus equivalence paradigm, these relations may have emerged independently following our AB instruction through the reflexive property of equivalence. Instead, we directly taught these skills to ensure that participants were capable of making the tactile discriminations necessary for braille reading. Our presumption was that the lack of braille identity matching would inhibit acquisition of the AB relation. This training was implemented with only 2 participants and resulted in relatively quick acquisition.

Given these participants' histories with braille instruction, it is likely that their rapid acquisition of braille identity matching will not be representative of most novel braille learners. Most people have limited experience with such fine tactile discriminations, and many early intervention advocates recommend exposing children with visual impairments to braille at very young ages to promote these tactile discriminations later in life (Wormsley & D'Andrea, 1997). Our braille identity-matching instruction was successful at teaching the 2 participants who had not yet reached mastery of this skill prior to participating in this study; however, we believe that a more systematic investigation of procedures to teach braille-to-braille identity matching is warranted. We are beginning to develop a programmed sequence in which comparison–stimulus combinations are initially very distinct from the target stimulus (e.g., one-dot characters vs. five-dot characters) and then made progressively more similar by decreasing the comparison density difference across learning trials.

Also related to participants' prior histories with braille, it should be noted that some participants showed moderately high levels of accuracy during baseline tests. Participants' experience with braille instruction ranged from 1 to 3 years. Despite this prolonged exposure, none of these 4 children performed at mastery levels for identifying braille letters; thus, not surprisingly, each was referred due to limited proficiency in braille reading. As a prerequisite to braille reading, letter identification is a skill that cannot afford to fall below mastery levels. The current procedure clearly improved these children's proficiency in braille letter naming beyond moderate to mastery levels and should better prepare the participants for braille literacy. A more stringent test of the current procedures would involve more novice braille learners, such as appeared to be the case with Fred.

We would like to make a note about Fred's increased accuracy with Letter Set 5 despite the absence of direct instruction for these letters. Such a pattern is somewhat troubling in that it violates the logic of the multiple probe design (i.e., we should have observed behavior change when and only when the independent variable had been implemented). It is apparent that learning occurred for the members of Set 5 corresponding to the completion of training with the previous four letter sets (i.e., increases were observed across all assessed relations). Rather than interpret these data as a source of uncontrolled or confounding influence, we believe this learning resulted as an artifact of our procedures. That is, during AB probes, we randomly selected comparison stimuli from any of the five letter sets. Following completion of training for the first four letter sets, there was roughly an 80% probability that when a novel sample stimulus was presented during the probes for Set 5, the other two comparison stimuli had been acquired already, and thus the correct comparison could be identified easily through exclusion. Repeated exposure to this exclusion arrangement could explain the acquisition of skills related to Set 5, including each of the emergent relations. Although this outcome is exceedingly desirable from a practical standpoint (i.e., uninstructed learning), we recommend that researchers either (a) control for this confounding effect in future evaluations, perhaps by drawing comparison stimuli from within rather than across training sets such that all comparison stimuli are equally novel with the sample stimulus (which we did for the 3 children who followed Fred) or (b) systematically demonstrate the impact of exclusion learning either within or across participants (e.g., McIlvane & Stoddard, 1981).

Letter identification is only the first step in braille reading. Participants were by no means fluent braille readers at the conclusion of this study. We intend to evaluate a similar teaching procedure based on stimulus equivalence in which letter sounds (i.e., phonemes) are included in the equivalence relations. Additional instruction would then be necessary to expand reading repertoires from simple phonemes to full words. The development of such a comprehensive curriculum is an important goal for the future.

It is also worth noting that the teacher who implemented these procedures had more training and experience with behavior-analytic principles and direct instruction than is typical of a braille instructor. The utility of these procedures will ultimately be determined by the extent to which individuals with limited behavior-analytic training will be able to successfully implement these procedures.

Despite the questions yet to be resolved, the teaching procedures described in this study were effective in helping children who will lose their sight acquire braille-reading skills prior to further visual deterioration. Similar instructional programming is likely to be useful to other populations as the necessary prerequisite skills appear to be (a) the ability to make tactile discriminations between braille letters and (b) a preexisting printed-word reading repertoire. For example, age-related macular degeneration is the primary cause of vision loss, and the number of adults with eye-related diseases is expected to double within the next three decades (Prevent Blindness America, 2008). Using stimulus equivalence procedures while there is still a functional level of sight may help to prepare these individuals who will need to learn braille for continued literacy, and thus have utility for adult populations at risk for vision loss. It would also be interesting to evaluate our instructional procedures with teachers in training who will be responsible for braille instruction. An efficient braille learning curriculum would expedite their learning as well.

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