Emergence of Intraverbal Responding Following Tact Instruction with Compound Stimuli

Bailey Devine¹ · Charlotte L. Carp^{1,2} ·
Kiley A. Hiett¹ · Anna Ingeborg Petursdottir¹

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Abstract Effective intraverbal responding often requires control by multiple elements of a verbal stimulus. The purpose of this study was to examine the emergence of such intraverbal relations following tact instruction with compound stimuli and to analyze any resulting error patterns. Participants were seven typically developing children between 3 and 5 years of age. After being taught to tact four overlapping compound stimuli that differed along color and shape dimensions, participants were tested for emergent intraverbal responding. Three participants performed with high accuracy and four with intermediate accuracy when correct intraverbal responding required control by multiple elements (i.e., color names and shape names) of the verbal stimulus. Five participants performed with high accuracy when intraverbal responding required control by only a single stimulus element, and all participants showed emergence of reverse intraverbal relations when the response required naming only a single stimulus element (i.e., color or shape). There was an insufficient number of errors to perform detailed error analyses at the individual level, but overall, the first element of a verbal stimulus was more likely to exert control over the response than the second element, and color words were more likely to exert control than shape words. Results suggest that individual stimulus elements acquired independent control over the responses that had been established as tacts.

Keywords Intraverbal · Stimulus control · Tact

Skinner (1957) defined intraverbal behavior as a verbal operant in which the response is under the control of an antecedent verbal stimulus that shares no physical similarity or

✉ Anna Ingeborg Petursdottir
a.petursdottir@tcu.edu

¹ Department of Psychology, Texas Christian University, Box 298920, Fort Worth, TX 76129, USA

² Present address: McNeese State University, Lake Charles, LA, USA

³ Present address: Baylor University, Waco, TX, USA

point-to-point correspondence with the response (p. 71). Intraverbals encompass diverse instances of verbal behavior that range from some of an infant's first vocalizations under the control of verbal stimuli (e.g., saying "woof" upon hearing the word "dog") to complex academic discourse.

Effective intraverbal behavior often requires control by multiple elements of a verbal stimulus. As an example, saying "The Joker" in response to the question "Who is Batman's arch nemesis?" likely requires control by the verbal stimuli/*Batman*/ and /*arch nemesis*/, at a minimum. These types of discriminations have sometimes been referred to as verbal conditional discriminations (e.g., Axe, 2007; Sundberg & Sundberg, 2011), implying that one stimulus functions as a conditional stimulus that alters the evocative effect of another (e.g., the presence of/*arch nemesis*/ as a conditional stimulus may increase the probability that/*Batman*/will evoke the response "The Joker"). Alternatively, /*Batman*/and /*arch nemesis*/may independently contribute to the strength of "The Joker" through prior involvement in simple discriminations, exemplifying convergent (Michael, Palmer, & Sundberg, 2011) or compound (Eikeseth & Smith, 2013) stimulus control. Yet another possibility is that such responses are under configural stimulus control (e.g., Pearce, 1987, 2002), in which the response "The Joker" is controlled by the whole of the verbal stimulus (/Who is Batman's arch nemesis?/) with no independent control by its individual elements (see also Michael et al., p. 13). It is possible that different types of stimulus control are involved in different instances, depending on prior reinforcement history.

Sundberg and Sundberg (2011) reported that young, typically developing children made frequent errors when presented with questions that required control by at least two elements of a verbal stimulus, such as "What grows on your head?" Children under the age of 3 years typically gave incorrect responses, with error content suggesting predominant control by the last part of the verbal stimulus (e.g., answering "shoulders"). Children between the ages of 3 and 5 years made increasingly fewer errors, but even at age 5, difficulties remained when stimulus elements included "prepositions, adjectives, negation, ordinal positions, and time concepts" (p. 33). Children diagnosed with autism spectrum disorder (ASD) showed variability in intraverbal repertoires that was not highly related to chronological age. However, children with ASD were reported to make similar types of errors as typically developing children with similar scores on the Verbal Behavior Milestones Assessment and Placement Program (VB-MAPP) (Sundberg, 2008).

Although Sundberg and Sundberg (2011) provided data on their participants' VB-MAPP (Sundberg, 2008) scores, no quantitative data were provided on the types of errors that were made; instead, errors were described qualitatively with examples. In addition, the participants' histories with respect to the intraverbal relations tested were unknown. More information on the types of errors that occur when children are presented with verbal stimuli containing multiple elements may help shed light on the nature of the stimulus control involved and ultimately be of value in programming interventions.

The present study was a preliminary investigation that aimed to more closely examine typically developing children's performance when responding intraverbally to questions that required control by at least two stimulus elements. In order to control prior history, participants were first taught to tact a set of overlapping compound stimuli, using nonsense syllables, such that correct tacting required control by both

the color and the shape of each stimulus. For example, correctly tacting a red star stimulus required discriminating it from both a red heart stimulus and a blue star stimulus. Subsequently, we tested transfer of control over the nonsense response forms to verbal stimuli containing both color and shape elements (e.g., “red” and “star”) and verbal stimuli containing only one of these elements (e.g., “red”). Thus, the intraverbal responses tested had no prior reinforcement history. However, tact instruction was designed to establish control by compound visual stimuli over the vocal response forms that could potentially be conditional (with one stimulus dimension serving as conditional stimuli and the other as discriminative stimuli), elemental (both color and shape dimensions gaining evocative control over the response form), or configural (with responses controlled by unique color–shape combinations).

The first objective of the study was simply to examine the extent to which intraverbal responses controlled by multiple stimulus elements would emerge following tact instruction that required corresponding control by nonverbal stimulus dimensions. In addition to testing intraverbal control over the responses established as tacts, we tested the emergence of reverse intraverbal responding that required participants to respond to questions containing the previously taught stimulus names by stating a color, a shape, or both. Some studies suggest tact instruction does not reliably generate related intraverbal responding among typically developing preschoolers (e.g., Miguel, Petursdottir, & Carr, 2005; Partington & Bailey, 1993; Petursdottir & Hafliadottir, 2009), but this research has not previously been extended to intraverbal responses that require control by multiple stimulus elements. Based on the existing research, coupled with the frequent errors that children make when presented with multi-component questions (Sundberg & Sundberg, 2011), we expected variable performance across participants and predicted that at least some participants would make a large number of errors on tests for emergent intraverbal responses. The second objective of the study was to analyze these errors for (a) the presence of primacy or recency effects (i.e., predominant control by the first- or last-presented stimulus element) and (b) the presence of other error patterns that might shed light on the type of stimulus control exerted by the verbal stimuli.

Method

Participants and Setting

Seven children participated in the study with their parents’ permission. Their ages ranged from 3 years, 10 months (P2) to 5 years, and 1 month (P1). No participants were reported by their parents to have any developmental delays. Five participants were of Caucasian, non-Hispanic backgrounds, and two were of Hispanic backgrounds. All participants were reported to speak English as a primary language in their homes. Table 1 shows each participant’s age, gender, and standard score on the Peabody Picture Vocabulary Test—fourth edition (PPVT-4; Dunn & Dunn, 2007) if available. P7 also participated in a study on procedures for teaching children to tact compound stimuli, and his tact instruction data were a part of that study.

Table 1 Participant characteristics

Participant	Age in months	Gender	PPVT-4 standard score
P1	61	Male	–
P2	46	Female	–
P3	49	Male	113
P4	58	Male	–
P5	54	Male	100
P6	53	Female	134
P7	50	Male	95

The PPVT-4 was administered to P3 through P7; P4's score could not be interpreted due to lack of cooperation during testing

PPVT-4 Peabody Picture Vocabulary Test, fourth edition

P1 and P2 were recruited from a child care center in a suburban location, and P3 through P7 were recruited from two child care centers in an urban location. Sessions were conducted at the recruitment sites' facilities, in areas free of significant distractions. Two to five sessions occurred per week depending on participant availability. Each session continued until the participant had filled his or her token board, and duration generally ranged from 10 to 20 min.

Stimuli

Visual stimuli for each participant, used during tact instruction, consisted of four colored stick figures that each contained a colored shape within its torso. Each figure measured 9 cm from top to bottom. Two colors and two shapes were included in each participant's stimulus set, and the four stimuli represented four possible color–shape combinations (e.g., red heart, red star, blue heart, and blue star). The colors used for all participants were red and blue. Shapes included hearts and stars for P1 and P2 and stars and suns for the remaining participants (hearts were replaced with suns to prevent issues with pre-existing relations between heart shapes and the color red). A nonsense syllable was assigned to each stimulus. The specific syllables differed across participants, as did their assignment to stimuli, but always consisted of four of the syllables “dek,” “jid,” “ohmp,” “prat,” “qui,” “rom,” “unk,” and “zut.” A representative stimulus set is

Fig. 1 Sample set of visual stimuli and associated nonsense syllables. The *lighter shade of gray* represents the color red and the *darker shade* represents the color blue

Table 2 Intraverbal test

Section	Trials	Max. score
Section 1: compound stimuli	16	16
Who is blue and has a star?		
Who is blue and has a sun/heart?		
Who is red and has a star?		
Who is red and has a sun/heart?		
Who has a star and is blue?		
Who has a star and is red?		
Who has a sun/heart and is blue?		
Who has a sun/heart and is red?		
Section 2: reverse intraverbals	4	8
Tell me about Qui ^a		
Tell me about Unk ^a		
Tell me about Zut ^a		
Tell me about Rom ^a		
Section 3: simple intraverbals	8	16
Who is red? [Who else is red?]		
Who is blue? [Who else is blue?]		
Who has a star? [Who else has a star?]		
Who has a sun/heart? [Who else has a sun/heart?]		
Section 4: color questions	8	8
What color is Qui?		
What color is Unk?		
What color is Zut?		
What color is Rom?		
Section 5: shape questions	8	8
What does Qui have?		
What does Unk have?		
What does Zut have?		
What does Rom have?		
Repeat section 2	4	8
Repeat section 1	16	16

^a Stimulus names varied across participants

shown in Fig. 1. Stimuli used during intraverbal testing included a series of vocally administered questions about the four visual stimuli (see Table 2).

Poker chips were used as tokens that participants could earn during pre-experimental procedures and tact instruction. Participants placed their tokens on laminated token boards that held either 36 (P1 and P2) or 24 (P3 through P7) tokens. After filling the token boards, the session ended and the participants received access to a “fun box” containing a variety of toys and an opportunity to play with the experimenter for several minutes.

Data Collection and Interobserver Agreement

Data were collected on the participants' vocal responses during tact instruction and intraverbal tests. In each trial, a correct response was scored if the participant emitted the response experimentally defined as correct within 5 s. Otherwise, an incorrect response was scored. If the participant emitted two or more responses in a trial in which only one correct response was possible, only the first was scored as correct or incorrect.

A second observer independently scored at least 25 % of all trial blocks completed during tact instruction with each participant, either live or from video. An agreement between observers was scored for each trial in which both observers recorded a correct or both recorded an incorrect response. Point-by-point agreement for each participant was calculated by dividing the number of agreements by the total number of trials conducted and converting the quotient to a percentage. Agreement ranged from 99 % for P1 to 100 % for all other participants. For P1, agreement was never under 75 % (i.e., three of four trials) for a single trial block. A second observer independently scored the entire intraverbal tests of P1, P3, P4, P5, and P6 and 72 % of P7's intraverbal test. Point-by-point agreement was calculated in the same manner as for tact instruction and ranged from 97.2 % for P3 to 100 % for the other participants.

Procedure

Experimental Design A posttest-only design was used to assess the effects of tact instruction on intraverbal test performance; an experimental design was not deemed necessary to rule out acquisition outside of the experiment due to the arbitrary nature of the verbal relations taught. Errors patterns for individual participants were analyzed descriptively. A within-subjects design was used to compare aggregate performance in different types of trials with order of stimulus elements (i.e., color first vs. shape first) as the within-subjects factor for the analysis of performance on section 1 on the intraverbal test and type of stimulus element (i.e., color vs. shape) as the within-subjects factor for the analysis of performance on section 3 and the comparison of performance on sections 4 and 5 (see Table 2).

Pre-experimental Screening Prior to tact instruction, the experimenter verified that the participants could tact the colors and shapes that characterized the visual stimuli. This was done with a formal eight-trial probe for P1 and P2. In each trial, the participant was shown one of the four experimental stimuli and asked either "What color is he?" (i.e., color trial) or "What does he have?" (i.e., shape trial). A correct response produced praise and a token. An incorrect response would have resulted in a vocal prompt, but no incorrect responses occurred. Each stimulus was initially presented in one color trial and one shape trial. Both P1 and P2 responded with 100 % accuracy; lower accuracy would have resulted in instruction. This assessment was omitted for participants P3 through P7; instead, presence of the relevant color and shape tacts was verified via informal classroom observation.

P3 through P7 underwent brief identity matching probes with the experimental stimuli to ensure that they could discriminate their features. In each trial, four cards containing the four visual stimuli were placed on the table in front of the participant.

The experimenter then held up a sample card that was identical to one of the cards on the table and asked the participant to “point to the one that matches.” No differential consequences were provided for correct and incorrect responses; instead, the experimenter simply moved to the next trial. Participants could earn tokens during the probe for cooperation (e.g., sitting still) and answering distractor questions (e.g., “How old are you?”). In each four-trial block, each stimulus was presented once as a sample. If responding was at 100 % in the first block, no further trial blocks were conducted. If one or more errors were made in the first trial block, three additional trial blocks were conducted and the participant was only included in the study if accuracy was at 100 % in all three blocks. P4, P5, P6, and P7 responded with 100 % accuracy in the first block, whereas P3 made an error in the first block but responded with 100 % accuracy in the next three blocks. One child was excluded from participation because she was unable to match the stimuli accurately within four-trial blocks in this assessment. Prior to tact instruction, P3 through P7 were also asked to echo each of the four stimulus names once (e.g., “Say Qui”) to ensure that they could respond accurately to vocal prompts; all participants echoed all four names correctly.

Tact Instruction Participants were taught to tact all four visual stimuli simultaneously. Trials were arranged in blocks of four (i.e., one per stimulus). A trial began with the presentation of one visual stimulus and the experimenter’s question “Who is this?” Correct responses were differentially reinforced with tokens and praise, and incorrect responses were followed by a vocal prompt.

A few aspects of stimulus presentation, token delivery, and prompting varied across participants. For P1 and P2, stimuli were presented on laminated cards. Vocal prompts for these participants consisted of the experimenter modeling the correct response (e.g., “It’s Qui”). The first trial block of instruction included a 0-s prompt delay that was increased to 2 s in the second trial block and 5 s in the third trial block. Prompt delay then remained at 5 s throughout all subsequent trial blocks. P1 and P2 earned one token for each correct response and no token for prompted responses. For participants P3 through P7, stimuli were presented on the screen of a laptop computer. Vocal prompts consisted of the experimenter modeling the correct response and repeating the question (e.g., “This is Qui, who is it?”). A 0-s prompt delay was used in the first two trial blocks of instruction and subsequently increased to 5 s for all remaining trial blocks. P3 through P7 earned three tokens for each correct response and one token for each prompted response. These changes in protocol reflected general revisions of laboratory practices over time and were not uniquely related to the performance of participants in this study.

Tact instruction continued until mastery, which was defined as three consecutive trial blocks of 100 % correct responding. P1 and P2 were additionally required to respond with 100 % accuracy in three additional trial blocks in which no tokens or praise were delivered following correct responding. This step was omitted for P3 through P7. The number of trials required to complete tact instruction for each participant ranged from 48 for P6 to 492 for P2 (see Table 3). For P7, the instructional procedure was modified after 124 trials due to lack of an upward trend in correct responding. The modification was implemented as part of the other study in which P7 participated and involved requiring a nonvocal differential observing response to the stick figure at the beginning of each trial before being asked “Who is this?” P1 and P2 also demonstrated lack of an

upward trend for extensive periods of time, but no modifications were implemented for these participants. Other participants exhibited steady progress throughout training.

Intraverbal Testing Once mastery was reached in tact instruction, the intraverbal test (see Table 2) was administered. The order of questions within each section was randomized. The entire test was usually conducted in one session with no break, on the first school day that followed tact mastery, but was divided across two sessions on separate days for P5 and P7. No visual stimuli were present during the intraverbal test. Each trial began with the experimenter recruiting the child's attention and vocally presenting a question. The experimenter then waited up to 5 s for a response before proceeding to the next trial. No differential consequences were provided for correct or incorrect responses.

Section 1 (i.e., compound stimuli) consisted of eight questions requiring participants to provide a nonsense response form (e.g., “Qui”) given a color–shape combination (e.g., “Who is red and has a star?”). There were two questions corresponding to each of the visual stimuli that differed in the temporal order of elements: one in which the color was named first and one in which the shape was named first (e.g., “Who has a star and is red?”). The eight questions were each presented twice for a total of 16 trials.

Section 2 contained four questions that probed the reverse of the section 1 intraverbals by asking, for example, “Tell me about Qui.” A correct response consisted of naming the color and the shape associated with the name presented in the question. These questions were presented one time each.

Section 3 (i.e., simple stimuli) consisted of questions requiring participants to provide nonsense response forms given either color (e.g. “Who is red?”) or shape (e.g., “Who has a star?”). If the participant provided only one response to the initial question, a follow-up question (e.g. “Who else is red?”) was presented. The four questions were each presented twice for a total of eight trials and a total of 16 possible correct responses.

Section 4 consisted of questions requiring the participant to provide a color name given the name of one of the stick figures (e.g., “What color is Qui?”). The four questions were each presented twice for a total of eight trials. Section 5 consisted of questions requiring the participant to provide a shape given the name of a stick figure (e.g., “What does Qui have?”); these questions were also presented twice each for a total of eight trials.

Following section 5, section 2 questions were repeated. Finally, section 1 questions were repeated to gauge whether exposure to the simpler questions in sections 3 through

Table 3 Trials to criterion in tact instruction

Participant	Trials to criterion
P1	156
P2	492
P3	172
P4	172
P5	60
P6	48
P7	296

5 would be followed by improved performance. The passing criterion for each section was defined as 87.5 % accuracy (14 of 16 or 7 of 8 correct responses).

Error Analysis Section 1 of the intraverbal test (see Table 2) contained questions to which a correct response required control by multiple stimulus elements (i.e., color and shape). Participants' errors on this section were classified two ways: first as primacy errors, recency errors, or other and second as color errors, shape errors, and other. The definition of each type of error is shown in Table 4.

Results

Transfer of Function

The left panel of Fig. 2 shows each participant's accuracy in section 1 of the intraverbal test at the beginning and at the end of the test. P3, P4, and P5 passed the test on its first administration; P3 and P4 also passed on the second administration at the end of testing, whereas P5's performance declined to 69 % accuracy. The remaining four participants performed with intermediate accuracy (above 65 % but below passing) on both administrations. Participants performed with equal accuracy ($t(6) = -.354$; $p = .736$) in trials in which the color name was presented first ($M = 82.1$ %; $SD = 11.7$ %) and trials in which the shape name was presented first ($M = 83.0$ %; $SD = 10.0$ %); the largest discrepancy was seen for P7 who performed with 69 % accuracy when color was presented first and 81 % accuracy when shape was presented first.

The right panel of Fig. 2 shows each participant's accuracy on color and shape questions in section 3 (i.e., simple stimuli) of the intraverbal test. The accurate section 1 performance of P3, P4, and P5 was accompanied by passing performance on section 3; P3 made two errors on shape questions (e.g., "Who has a star?"), whereas P4 and P5 responded with 100 % accuracy. Of the participants who did not pass section 1, P1 and P7 achieved passing performance in section 3, whereas P2 and P6 did not, with P6

Table 4 Error classification

Error type	Definition	Example
Primacy error	Participant provides name consistent with first but not second stimulus element	Names red star stimulus when asked "Who is red and has a sun?"
Recency error	Participant provides name consistent with second but not first stimulus element	Names red star stimulus when asked "Who has a sun and is red?"
Color error	Participant provides name consistent with shape specified in question but not color	Names red star stimulus when asked "Who is blue and has a star?"
Shape error	Participant provides name consistent with color specified in question but not shape	Names red star stimulus when asked "Who is red and has a sun?"
Other	Participant provides name inconsistent with both color and shape specified in question or does not provide a name	Names red star stimulus when asked "Who is blue and has a sun?"; says "I don't know"

Fig. 2 Performance on section 1 (compound stimuli such as “Who is blue and has a star?” and “Who has a star and is blue?”; *left panel*) and section 3 (e.g., “Who is blue?” and “Who has a star?”; *right panel*) of the intraverbal test. Section 1 performance is broken down by first and second administration. Section 3 performance is broken down by question type. The *dashed horizontal line* represents the passing criterion

responding at only 50 % accuracy. Overall, performance on color ($M = 91.0$ %; $SD = 7.1$ %) and shape questions ($M = 83.9$ %; $SD = 7.1$ %) was similar ($t(6) = 1.922$; $p = .103$). The correlation between performance on the first administration of section 1 and performance on section 3 was $r = .52$.

Participants responded with equal accuracy ($t = 1.922$; $p = .103$) to color questions ($M = 91.1$ % accuracy; $SD = 18.7$ %) and shape questions ($M = 83.9$ %; $SD = 18.7$ %). P3 performed with 100 % accuracy on color questions and 75 % accuracy (six of eight responses) on shape questions, but other participants’ performance differed by no more than one correct response on color and shape questions. Performance on the first administration of section 1 was uncorrelated with age ($r = .05$).

Emergent Reverse Intraverbals

The upper panel of Fig. 3 shows participants’ performance in sections 4 (i.e., “What color is ___?”) and 5 (i.e., “What does ___ have?”). All participants achieved passing performance in section 4, and five of seven participants achieved passing performance in section 5. P2 performed with 50 % accuracy in section 5, whereas P4 answered “I don’t know” to all questions in this section.

By contrast, no participant showed passing performance on the first administration of section 2 (i.e., “Tell me about ___”) and only P6 showed passing performance on the second administration (Fig. 3; lower panel). P2, P4, P5, and P7 gave few or no correct responses, and most of their responses did not include color or shape names. P2 responded with “No” or “I can’t” in most trials. P4 responded with “I don’t know” in every trial and P5 responded with “I don’t know” in most trials in which he did not respond with a correct shape or color name. P7 consistently provided answers that did not include color or shape names, such as “Does some work” and “Does good in a castle” (in response to “Tell me about Qui”; a possible effect of generalization from “queen”). P1 and P3 gave more frequent correct responses but often included elements other than color and shape in their answers (e.g., P1, “Heart, head, eyes, legs” and “Star, legs, eyes, no ears”; P3, “Star, stands still” and “Red, she’s a girl”).

Fig. 3 The *upper panel* shows performance in sections 4 (e.g., “What is the color of Qui?”) and 5 (e.g., “What does Qui have?”) of the intraverbal test, and the *lower panel* shows performance in section 2 (e.g., “Tell me about Qui”)

Error Analyses

Error analyses utilized data from both the first and the second administration of section 1. Overall, the seven participants made 39 errors, 15 of which were classified as “other” errors, as the response was not consistent with either the color or shape contained in the question. Of the remaining 24 errors, 15 were classified as primacy errors and nine as recency errors. Nine were classified as color errors and 15 as shape errors. Figure 4 shows the percentage of errors that fell into each category for each of the four participants who did not achieve passing performance in section 1. P1 made several primacy but no recency errors (left panel), and these errors were more often color errors than shape errors (right panel). P2 made slightly more primacy than recency errors, and

Fig. 4 Primacy and recency errors (*left panel*) and color and shape errors (*right panel*) of participants who did not pass section 1 (compound stimuli such as “Who is blue and has a star?” and “Who has a star and is blue?”). The graphs show the percentage of each participant’s errors that fell into each category, and *n* denotes the total number of errors made by each participant

they were equally likely to be color and shape errors. P6 made slightly more recency than primacy errors, and all errors were shape errors. Most of P7’s errors (seven of eight) fell into the “other” category and consisted of naming the red stimulus with a sun when asked about the blue stimulus with a star. P1, P2, and P6 made three, one, and two “other” errors, respectively. Except for one “I don’t know” response by P1, all of these errors also consisted of providing a name that was inconsistent with both color and shape.

The lower panel of Fig. 5 shows aggregate error classification by trial type. Overall, color errors were less prevalent in color-first than in shape-first trials and shape errors slightly less prevalent in shape-first than in color-first trials. However, there were no statistically significant differences between trial types. Because no participant made a large number of errors, errors were not analyzed by trial type at the individual level.

Fig. 5 Aggregate errors on section 1 (compound stimuli such as “Who is blue and has a star?” and “Who has a star and is blue?”) by trial type. *N* denotes the total number of errors made in each type of trial

Discussion

After learning to vocally tact four compound stimuli with overlapping features, the seven participants in this study showed substantial transfer of control over the vocal responses from visual features to verbal stimuli describing those features. Although only three of seven participants met the passing criterion on the primary measure of transfer (i.e., section 1), the remaining participants achieved high to intermediate performance; performing substantially better than if they had emitted one of the four vocal response forms randomly in each trial. The vocal response forms were shown to be under the control of questions that specified both color and shape (e.g., “Who is red and has a star?”), as well as questions that specified only one dimension (e.g., “Who is red?” and “Who else is red?”). In addition, other forms of intraverbal responding emerged; specifically, participants typically vocalized the correct color or shape name when asked a question that included a specific stimulus name (e.g., “What color is Jid?”). Performance was unrelated to age, possibly due to a ceiling effect. It was also unrelated to the order in which color and shape elements were presented in section 1 and did not differ across color and shape elements when each trial addressed only one type of stimulus element (i.e., sections 3, 4, and 5).

The fairly accurate performance of all participants was unexpected given previous reports of errors that children make when responding to questions that require control by multiple stimulus elements (Sundberg & Sundberg, 2011), as well as studies showing that typically developing preschoolers often fail to give appropriate intraverbal responses after relevant tact training experiences (Miguel et al., 2005; Partington & Bailey, 1993). However, several factors may have contributed to these results. First, Sundberg and Sundberg (2011) reported that after 3 years of age, children began to make some correct responses to questions requiring control by multiple stimulus elements, and the prevalence of errors thereafter declined with age. The youngest participant in the present study (P2) was 3 years, 10 months old, and it is possible that younger participants would have performed more poorly. Second, the history of Sundberg and Sundberg’s participants was unknown with respect to the stimulus elements contained in the questions. By contrast, participants in the present study all had the same instructional history that ensured the vocal response forms were under the control of visual compound stimuli prior to intraverbal testing. That is, they had already learned to make the discriminations required for correct responding on section 1 (e.g., “Who is blue and has a star?”) of the intraverbal test, only with visual stimuli instead of verbal stimuli. Finally, the results are not necessarily discrepant with studies that suggest independence of tact and intraverbal repertoires, considering that different intraverbal repertoires have been tested in different studies. For example, Miguel et al. and Partington and Bailey tested divergent stimulus control over intraverbal responding, in which criterion-level performance necessitated providing multiple responses in succession when presented with a single stimulus (e.g., responding to “What are some musical instruments?” by listing at least 10 instruments). In the present study, by contrast, correct responding entailed providing only one (e.g., “Jid”) or two (e.g., “Qui” and “Zut” in response to “Who is red?” and “Who else is red?”) responses to each stimulus. Studies that have required only a single intraverbal response (e.g., “What is a cow in Italian?”) have documented greater emergence of intraverbal responding following tact instruction, albeit not always to criterion level (Petursdottir &

Haflidadottir, 2009; Petursdottir, Ólafsdóttir, & Aradóttir, 2008). Similarly, children with ASD have been found to engage in accurate intraverbal responding following tact training when only one (May, Hawkins, & Dymond, 2013) or a few (Grannan & Rehfeldt, 2012) intraverbal responses have been required in each trial.

It is likely that the participants' prior histories with regard to color and shape names contributed to the positive results. For example, if the participants covertly tacted the color and shape of the stimuli during tact instruction, it is possible that the training contingencies directly established intraverbal control by color and shape names over the novel stimulus names. Alternatively, pre-existing equivalence relations between colors and color names and shapes and shape names may have resulted in transfer of function without any involvement of color or shape tacting during tact instruction. Both of these hypotheses would easily account for the emergence of intraverbal control over the novel stimulus names in section 1 (e.g., "Who is blue and has a star?") and section 3 (e.g., "Who is blue?"). The emergence of intraverbal control by the novel stimulus names over color and shape names in sections 4 and 5 (e.g., "What color is Unk?") may be less straightforward to explain. However, a few possibilities may be offered. First, covert color and shape tacting during tact instruction may have established bidirectional intraverbal responding, such that not only did color and shape name gain control over the novel stimulus names, but the novel stimulus names also gained control over color and shape names. Second, previous histories involving colors and shape may have established a relational operant (cf. Hayes, Barnes-Holmes, & Roche, 2001) involving mutually entailed relations between color and shape names and names of specific exemplars (e.g., if you have learned to name "grass" as an example of something that is green, "green" is generally reinforced when asked "What color is grass?"). Third, participants may have engaged in visual imagining as a problem-solving strategy in these trials (Kisamore, Carr, & LeBlanc, 2011) or the novel stimulus names may have evoked conditioned seeing (Skinner, 1953) of the stimuli that enabled color and shape tacts in intraverbal trials.

Performance was substantially poorer on section 2 on the intraverbal test than on other sections. The section 2 questions were essentially open-ended requests to describe the stimuli used during tact instruction (e.g., "Tell me about Qui"). The participants may have performed poorly on these questions because unlike section 4 and 5 questions, stimuli such as /color/ where not available to exert convergent control over the response along with the stimulus name. In other words, participants were not instructed to specifically tell the experimenter about the color and shape of the stimuli. Indeed, although "I don't know" responses were fairly common, many incorrect responses also consisted of describing stimulus features other than color and shape.

Most of the participants performed with high accuracy when control by individual stimulus elements was tested in section 3. If the responses tested in section 1 were under configural control of the whole of the verbal stimulus, participants might have been expected to perform more poorly due to generalization decrement when elements were tested in isolation. Given that this was not generally observed, it is plausible that the individual stimulus elements each exerted control independently over the four vocal response forms. It is not completely clear whether his control by the individual elements can be characterized as conditional stimulus control (e.g., Axe, 2007; Sundberg & Sundberg, 2011). The current study design does not allow for conclusive determination; however, some aspects of the data may be relevant. If the two stimulus

elements contained in each sentence were to serve different functions (i.e., conditional and discriminative) functions, only the stimuli with a discriminative function might be expected to evoke correct responses when presented in isolation. However, all participants except P6 responded with high accuracy to both color and shape elements when presented in isolation in section 3. Additionally, conditional control might be stronger if the conditional stimuli were presented before the discriminative stimulus. For example, if color names generally served as conditional stimuli for a specific participant, that participant might be expected to perform better in trial types in which color names were presented before shape names. However, all participants responded with approximately equal accuracy on color-first and shape-first trials in section 1. It cannot be ruled out that each type of stimulus served a conditional function in some trials and a discriminative function in other, but a more parsimonious interpretation of the data may be that each color and shape name exerted divergent control over two responses, and their influences converged to evoke a correct response when presented together in a trial as a compound, as suggested by Eikeseth and Smith (2013).

It is important to note, however, that different stimulus control functions might characterize different types of intraverbal responding under the control of stimuli containing multiple elements. For example, Ingvarsson, Koelker, Carp, Petursdottir, and Macias (2016) taught children with autism to make appropriate intraverbal responses to pairs of questions that all differed only in that the word “with” was presented as an element of one of the questions (e.g., “What do you sweep?” vs. “What do you sweep with?”). Each participant was exposed to a number of different question pairs of this type. In this situation, it may be less plausible that the stimulus */with/* exerted independent control over the different target responses (e.g., “broom,” “soap,” “crayon”) and more plausible that it served a conditional function.

Overall, primacy errors were more common than recency errors in the present study; in other words, the response was more likely to be consistent with the first than the second stimulus element in a question. These results differ from those of Sundberg and Sundberg (2011) who found more evidence for control by the last part of a verbal stimulus. However, Sundberg and Sundberg reported a recency effect only for the youngest age group that made the most errors and did not provide information on primacy or recency effects for older children. It is also important to note that although primacy errors were more common overall in the present study, participants made both types of errors, and at the individual level, a higher prevalence of primacy errors characterized the responding of only two of the four participants. For individuals who make many primacy errors, interventions that promote observation of the second element in a question might result in more accurate performance.

Overall, participants also made more shape than color errors, suggesting that color names were slightly more likely to control responding than shape names. Again, however, this pattern was not necessarily observed at the individual level and strongly characterized the responding of only one participant (P6) who failed to achieve passing performance in section 1. Stronger control by color than by shape words might reflect longer histories of responding to colors and color names than shapes and shape names. If so, individuals who make many errors related to specific stimulus elements might benefit from interventions that strengthen responses to these individual elements.

With respect to the goal of analyzing error patterns, the participants’ accurate performance in the intraverbal test was a major limitation, as it did not permit detailed

analyses of error patterns at the individual level. If such an analysis had been possible, it might have revealed different patterns of faulty stimulus control for different participants that might have had implications for instructional programming. A second limitation is that although we controlled the participants' prior histories with regard to stimulus control over the novel target response forms, their previous histories with responding to color and shape names were not controlled. As previously noted, pre-experimental learning histories (e.g., histories of tacting colors and shapes, histories that established equivalence relations between color and shape names and corresponding visual stimuli) likely played a role in the transfer of control from visual stimuli during instruction to verbal stimuli during testing. Instead of using previously familiar stimulus elements, future research might employ novel stimulus elements associated with novel names in order to explore the role of these histories. A final limitation is that tacts were not re-tested following the intraverbal test to ensure that they had maintained throughout testing. Given the participants' generally accurate intraverbal performance, it is plausible that the tacts were largely maintained. However, it is possible that consistent errors such as P7's responding with the name of the red stimulus with a sun when asked about the blue stimulus with a star were related to deterioration of stimulus control over the corresponding tact.

These limitations notwithstanding, the data imply that when tact contingencies have established control by multiple nonverbal stimulus elements over verbal responding, related intraverbal responding may also be appropriately controlled by verbal stimuli containing multiple elements. Thus, they may support the notion that histories with nonverbal stimuli are crucial to establishing complex intraverbal repertoires (Eikeseth & Smith, 2013; Sundberg & Sundberg, 2011). Future research might explore variables (e.g., tact vs. listener instruction; tacting of stimulus elements or stimulus dimensions during instruction with nonverbal stimuli) that potentially affect the emergence of complex intraverbal responding as a result of providing relevant histories with nonverbal stimuli.

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Conflict of Interest The authors have no conflict of interest to report.

References

- Axe, J. B. (2007). Conditional discriminations in the intraverbal relation: a review and recommendations for future research. *The Analysis of Verbal Behavior*, 24, 159–174.
- Dunn, L. M., & Dunn, D. M. (2007). *Peabody picture vocabulary test-4*. Circle Pines, MN: AGS.
- Eikeseth, S., & Smith, D. P. (2013). An analysis of verbal stimulus control in intraverbal behavior: implications for practice and applied research. *The Analysis of Verbal Behavior*, 29, 125–135.

- Grannan, L., & Rehfeldt, R. A. (2012). Emergent intraverbal responses via tact and match-to-sample instruction. *Journal of Applied Behavior Analysis*, 45, 601–605. doi:10.1901/jaba.2012.45-601.
- Hayes, S. C., Barnes-Holmes, D., & Roche, B. (Eds.) (2001). *Relational frame theory: a post-Skinnerian account of human language and cognition*. New York: Plenum Press.
- Ingvarsson, E. T., Koelker, R. L., Carp, C. L., Petursdottir, A. I., & Macias, H. (2016). Evaluation of a blocked-trials procedure to establish complex stimulus control over intraverbal responses with children with autism. *The Analysis of Verbal Behavior*.
- Kisamore, A. N., Carr, J. E., & LeBlanc, L. A. (2011). Training preschool children to use visual imagining as a problem-solving strategy for complex categorization tasks. *Journal of Applied Behavior Analysis*, 44, 255–278. doi:10.1901/jaba.2011.44-255.
- May, R. J., Hawkins, E., & Dymond, S. (2013). Brief report: effects of tact training on emergent intraverbal vocal responses in adolescents with autism. *Journal of Autism and Developmental Disorders*, 43, 996–1004. doi:10.1007/s10803-012-1632-7.
- Michael, J., Palmer, D. C., & Sundberg, M. L. (2011). The multiple control of verbal behavior. *The Analysis of Verbal Behavior*, 27, 3–22.
- Miguel, C. F., Petursdottir, A. I., & Carr, J. E. (2005). The effects of multiple-tact and receptive-discrimination training on the acquisition of intraverbal behavior. *The Analysis of Verbal Behavior*, 21, 27–41.
- Partington, J. W., & Bailey, J. S. (1993). Teaching intraverbal behavior to preschool children. *The Analysis of Verbal Behavior*, 11, 9–18.
- Pearce, J. M. (1987). A model of stimulus generalization for Pavlovian conditioning. *Psychological Review*, 94, 61–73. doi:10.1037/0033-295X.94.1.61.
- Pearce, J. M. (2002). Evaluation and development of a connectionist theory of configural learning. *Animal Learning & Behavior*, 30, 73–95. doi:10.3758/BF03192911.
- Petursdottir, A. I., & Hafliðadottir, R. D. (2009). A comparison of four strategies for teaching a small foreign-language vocabulary. *Journal of Applied Behavior Analysis*, 42, 685–690. doi:10.1901/jaba.2009.42-685.
- Petursdottir, A. I., Ólafsdóttir, A. R., & Aradóttir, B. (2008). The effects of tact training and listener training on the emergence of bidirectional intraverbal relations. *Journal of Applied Behavior Analysis*, 41, 411–415. doi:10.1901/jaba.2008.41-411.
- Skinner, B. F. (1953). *Science and human behavior*. New York: Macmillan.
- Skinner, B. F. (1957). *Verbal behavior*. Acton, MA: Copley.
- Sundberg, M. L. (2008). *The verbal behavior milestones assessment and placement program: the VB-MAPP*. Concord, CA: AVB Press.
- Sundberg, M. L., & Sundberg, C. A. (2011). Intraverbal behavior and verbal conditional discriminations in typically developing children and children with autism. *The Analysis of Verbal Behavior*, 27, 23–43.