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BRIEF REPORT

The Use of the Go/No-Go Successive Matching-to-Sample Procedure with Nonverbal Auditory Stimuli to Establish Equivalence Classes and Speaker Behavior

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Abstract

The purpose of the current study was to extend the findings on the use of the go/no-go successive matching-to-sample (S-MTS) procedure to establish auditory equivalence classes. Eight college students learned to conditionally relate nonverbal auditory stimuli into three, 3-member classes. Following training, all participants met the emergence criterion for symmetry, and six out of eight participants met the emergence criterion for transitivity/equivalence. Furthermore, all participants responded with either an experimenter-defined or a unique tact, and five participants related these names intraverbally. Although these results replicate previous findings, albeit with stimuli that cannot be echoed, possible verbal mediation via tact and intraverbal behavior seems to have occurred.

Keywords Auditory · Emergence · Equivalence · Mediation · Matching-to-sample

Research suggests the successive matching-to-sample (S-MTS) procedure with a go/no-go requirement to be effective in establishing conditional relations and equivalence classes among visual and auditory stimuli (e.g., Hanson & Miguel, 2021; Howland et al., 2021; Lantaya et al., 2018; Zhelezoglo et al., 2021). An S-MTS trial usually involves the presentation of a sample stimulus, followed by an observing response (e.g., touching or selecting the sample), which is then followed by the presentation of a single comparison in the same location as the sample. Participants

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are taught to select class-consistent comparisons (i.e., go trial) and to refrain from selecting class-inconsistent comparisons (i.e., no-go trial). Given that the S-MTS procedure presents only one stimulus at a time, it allows for both samples and comparisons to be auditory. Furthermore, previous research has demonstrated that auditory discrimination is an important prerequisite for other skills such as listener behavior (e.g., Kodak et al., 2015).

In a recent study, Hanson and Miguel (2021) utilized the S-MTS procedure across two experiments to establish three, 3-member equivalence classes using verbal auditory stimuli. In Experiment 1, 16 college students learned conditional relations (AB and AC) comprising of unrelated familiar words, after which all (100%) met emergence criterion for symmetry and 12 (75%) for transitivity/equivalence. Moreover, nine participants (56%) related the stimuli intraverbally. In Experiment 2, another 16 participants performed similarly when exposed to the same procedure using words from an unknown language (i.e., Klingon). All participants (100%) met emergence criterion for symmetry, 13 (81%) for transitivity/equivalence, and 8 (50%) for intraverbal. Thus, stimulus familiarity did not seem to impact equivalence yields as has been previously shown (e.g., Nartey et al., 2014). Post-experimental interviews suggested that participants who learned to intraverbally relate stimuli may have done so by engaging in echoic behavior during baseline training. Moreover, it is possible that intraverbal behavior produced supplemental stimuli that aided in some participants' equivalence performance (Miguel, 2018). For example, after repeating the words "soch" and "boj," as well as "soch" and "megh," during their successive presentation in training, participants could have responded on equivalence tests by saying, "megh goes with soch and soch goes with boj," the product of which could have served to evoke the correct selection (e.g., Chastain et al., 2022; Jennings & Miguel, 2017). However, given the short reaction times from the presentation of the sample to the selection of comparisons, it is unclear whether verbal behavior occurred or played any role in mediating participants' matching performances.

Thus, the current study extended previous findings on the use of the go/no-go S-MTS procedure by employing nonverbal auditory stimuli. Even though these stimuli cannot be echoed, they can be named. For this reason, we probed for the emergence of tacts, as well as intraverbal behavior.

Method

Participants and Setting

Participants included eight typically developing adults who were enrolled in undergraduate psychology courses at a large public university. They could exit the study at any time, received extra course credit for participation regardless of how they responded, and were not exposed to any experimental procedures beforehand. Sessions were conducted remotely with all participants based on the session protocol reported in Hanson and Miguel (2021). Upon the conclusion of the study, the experimenter explained the purpose of the study to participants and answered any questions. All procedures described below were approved by the university's Institutional Review Board (IRB).

Apparatus and Materials

The apparatus and materials were identical to those used in Hanson and Miguel (2021) for remote participants. Stimuli included nine unrelated sounds across three classes with three members per class (i.e., A1, B1, C1; A2, B2, C2; A3, B3, C3; see Table 1). Sounds were 2–4 s each and were downloaded from a free online sound bank (audiomicro.com). Pretraining stimuli consisted of familiar and related dictated words (i.e., X1, X2; Y1, Y2, Z1, Z2; see Table 1) and were identical to the pretraining stimuli used in Hanson and Miguel (2021). Written instructions were also adapted from previous research (see Table 2), and participants were required to read and summarize instructions aloud before each condition.

Dependent Variables

The primary dependent variable was correct go and no-go trials across S-MTS conditions. These were defined as independently clicking related comparisons and refraining from clicking unrelated comparisons, respectively. Correct trials were divided by the total number of trials within each trial block and converted to a percentage. Data were also collected on the percentage of trials in which participants responded with experimenter-defined names and with non-experimenter defined unique names during tact tests, as well as the percentage of trials in which participants responded with class-consistent stimuli during intraverbal tests. Additional data were collected on trials to criterion in AB/AC baseline training and reaction times to comparison stimuli when consequences were removed during AB/AC baseline, BA/CA symmetry, and BC/CB transitivity/equivalence posttests as described in Hanson and Miguel (2021). Data were taken by the primary investigator and the computer software during remote sessions. Sessions were also recorded for interobserver agreement (IOA) and treatment integrity (TI) purposes.

Table 1 Experimental (nonverbal auditory) stimuli and pretraining stimuli

Experimental	A	B	C
Class 1	(ice in cup)	(chopping vegetables)	(sliding door)
Class 2	(toaster popping)	(scanner)	(pen writing)
Class 3	(rocket engine)	(electric razor)	(film projector rewind)
Pretraining	X	Y	Z
Class 1	"Spoon"	"Fork"	"Knife"
Class 2	"Blue"	"Green"	"Red"

Table 2 Condition instructions

Condition	Instruction
BA/CA and BC/CB Pretest	Once the task begins, you will hear a sound from the computer. After you hear the sound, a green box will appear on the screen. Click the green box to hear a second sound. After you hear the second sound, a white box will appear on the screen. If you think the first and second sound go together, click the white box and say "click." During this phase, you get no points as feedback. Remember, you can read these instructions at any time. Place the instructions in the designated location.
AB/AC Baseline Training-Consequences	During this phase you will learn how to group sounds together. Once the task begins, you will hear a sound from the computer. After you hear the sound, a green box will appear on the screen. Click the green box to hear a second sound. After you hear the second sound, a white box will appear on the screen. If you think the first and second sounds go together, click the white box and say "click." If the sounds do not go together, then do not click the box and wait for the box to disappear. You will get points when sounds go together, and you will not get points when they don't. For the first few trials I will help you with the answer. After that you will have 4 seconds to respond on your own. If you do not respond, I will help you. You can read these instructions at any time. Place the instructions in the designated location.
AB/AC Baseline Training-No Consequences	Continue clicking the white box and saying "click" for sounds that go together as before. During this time no points will be presented. Remember, you can read these instructions at any time. Place the instructions in the designated location.
BA/CA Symmetry and BC/CB Transitivity/ Equivalence Posttest	This is a new phase. Use what you have learned so far to figure out what sounds go together. Once the task begins, you will hear a sound from the computer. After you hear the sound, a green box will appear on the screen. Click the green box to hear a second sound. After you hear the second sound, a white box will appear on the screen. If you think the first and second sounds go together, click the white box, and say "click." If the sounds do not go together, then do not click the box and wait for the box to disappear. During this phase, you will get no points as feedback. Remember, you can read these instructions at any time. Place the instructions in the designated location.
Tact Test	Once the task begins, you will hear a sound from the computer. You will have 5 seconds to tell me what the sound is for each sound you hear. I will not provide feedback. Remember, you can read these instructions at any time. Place the instructions in the designated location.

Table 2 (continued)

Condition	Instruction
Intraverbal Test	Once the task begins, you will hear a sound from the computer. You will have 5 seconds to respond with two sounds that go with the sound that you heard. I will not provide feedback. Remember, you can read these instructions at any time. Place the instructions in the designated location.

Procedure

Participants were exposed to conditions in the following order: pretraining, BA/CA symmetry pretest, BC/CB transitivity/equivalence pretest, AB/AC baseline training, BA/CA symmetry posttest, BC/CB transitivity/equivalence posttest, tact test, intraverbal test, and post-experimental interview. Each condition (excluding the tact and intraverbal test) was presented in a S-MTS format with a go/no-go response requirement. AB/AC baseline relations training and BA/CA symmetry pre and posttests consisted of 24 trials per block, and BC/CB transitivity/equivalence pre and posttests included 36 trials per block (Hanson & Miguel, 2021). Tact and intraverbal tests consisted of 18 trials per block in which each stimulus was presented twice, and randomized across trials.

During an S-MTS trial, participants heard an auditory sample from the computer speaker followed by a green box appearing on the screen. After clicking the green box, an auditory comparison was played from the computer speaker, after which a white box appeared. The white box remained on the screen for 8 s regardless of participants' responses. A go response consisted of clicking the white box, and a no-go response consisted of refraining from clicking the white box. A 2-s inter-trial interval separated all S-MTS trials.

Pretraining

This condition was conducted to familiarize participants with the computer software and was identical to the pretraining for remote participants described in Hanson and Miguel (2021). Participants were required to respond correctly and independently to XY/XZ stimulus combinations across eight consecutive trials before moving on to pretests with experimental stimuli.

BA/CA and BC/CB Pre- and Posttests

Participants were required to score 67% or below across one or two blocks during both BA/CA and BC/CB pretests. This continuation criterion was used because participants could score 50% correct during BA/CA pretests and 33% during BC/CB pretests if they clicked the white box on every trial and could score 50% correct during BA/CA pretests and 67% during BC/CB pretests if they refrained from clicking the white box on every trial. Emergence criterion during posttests was set at a minimum of 92% across two consecutive blocks during BA/CA symmetry posttests and a minimum of 94% across two consecutive blocks during BC/CB transitivity/equivalence posttests. Participants moved on to BC/CB transitivity/equivalence posttests regardless of their performance on BA/CA symmetry posttests. BC/CB transitivity/equivalence posttests were concluded if emergence criterion was met across two consecutive blocks or if incorrect responses occurred across three consecutive blocks with a stable or decreasing trend. No differential consequences were provided across these conditions.

AB/AC Baseline Training

Participants were provided a vocal prompt (i.e., "Click") following the auditory comparison during go trials at a 4-s delay. Correct go trials resulted in 10 points being displayed at the top of the screen, as well as a tone from the computer speaker; the points increased by 10 for each correct prompted or independent go trial. No prompts or differential consequences were provided for incorrect or correct no-go trials or for incorrect go trials. Participants were required to respond independently for 100% of trials across two consecutive blocks and were then required to respond independently and in the absence of differential consequences (i.e., points and sounds) for 100% of trials across one block.

Tact Test

Tact tests assessed the extent to which experimental stimuli evoked experimenter or self-generated tacts. Each stimulus (i.e., sound) was presented (i.e, played) twice per block. For every trial, a participant's response was categorized as either (a) identical to the name of the audio file the experimenter downloaded, (b) uniquely named by the participant, or (c) no answer or responding with "I don't know." Participants were given 5 s to respond on each trial and no differential consequences were provided.

Intraverbal Test

This condition assessed the emergence of intraverbal behavior and consisted of playing one sound per trial from the computer speaker. To score a correct response, participants were required to name both sounds within the same class as the presented stimulus, regardless of whether the participant responded with experimenter-defined names or unique names. No differential consequences were provided, and participants were given 5 s to respond. Emergence criterion was set at 94% or above across one block.

Post-Experimental Interview

Following BA/CA symmetry and BC/CB transitivity/equivalence posttests, participants were asked two questions by the primary investigator: (1) How did you decide when to click the white box? and (2) How did you decide during the last part when you had to use what you learned?

Experimental Design

The study utilized a nonconcurrent multiple baseline design across participants (Watson & Workman, 1981). Participants in the first tier completed one block of both BA/CA and BC/CB pretests, while participants in the second tier completed two blocks of BA/CA and BC/CB pretests. They were assigned to each tier in the order that they were recruited. Participants in the second tier were limited to two blocks to prevent fatigue. This design served to control for the possibility that repeated exposure would lead to equivalence class formation.

Interobserver Agreement (IOA) and Treatment Integrity (TI)

IOA was assessed across all trials (100%) and conditions. It was calculated by comparing the data between the primary and secondary investigators, as well as the primary investigator and the computer software. TI data was collected during AB/AC baseline training for correct timing of prompt delivery during go trials (i.e., 4 s after presentation of white box following the auditory comparison stimulus). IOA was calculated by dividing the number of agreements by the sum of agreements and disagreements and multiplying by 100 to obtain a percentage. TI was calculated by dividing the number of correctly implemented AB/AC baseline trials by the total number of AB/AC baseline trials and multiplying by 100 to obtain a percentage. IOA averaged 99.5% (range 94–100%) between the primary and secondary investigators and averaged 99% (range 83–100%) between the primary investigator and the computer software. TI averaged 99.3% (range 96–100%) during AB/AC training.

Results

Figure 1 shows the percentage of correct go/no-go responses during S-MTS conditions, percentage of experimenter-defined and unique tacts, and percentage of class-consistent intraverbals for participants 1–8. All participants met continuation criterion during pretests. Participants averaged 273 (range, 168–456) trials to criterion during training. All participants met emergence criterion during symmetry posttests within two blocks. Six participants (P1–P6) met emergence criterion during transitivity/equivalence posttests within two to three blocks. Two participants (P7 and P8) did not meet emergence criterion for transitivity/equivalence (average correct responding of 63% and 61%, respectively).

All participants responded with either an experimenter-defined or a unique tact (averages of 49.25% and 50.75%, respectively). Five participants (P1–P2, P4–P6) met emergence criterion during the intraverbal test by responding with the names of two sounds that were class consistent with the presented sound (e.g., responding with either the experimenter-defined names or unique names for “rocket” and

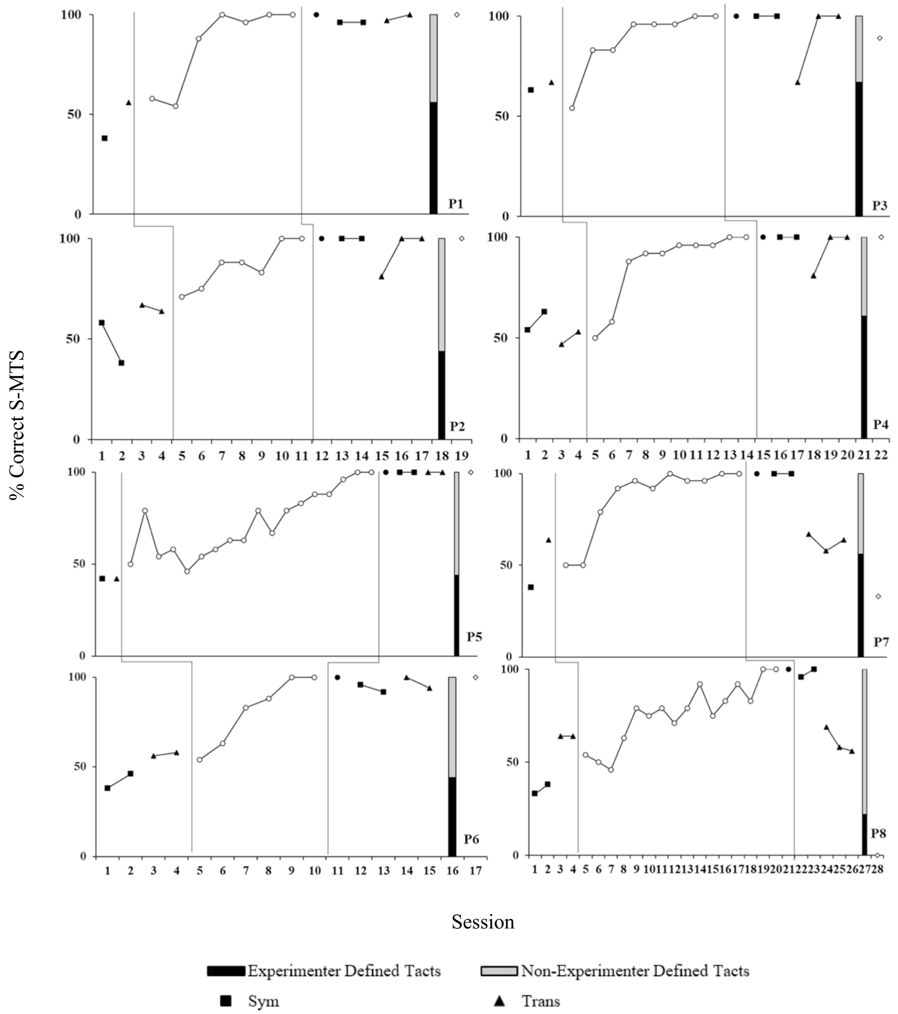

Fig. 1 P1–P8 results. *Sym*, symmetry; *Trans*, transitivity/equivalence; *BL*, baseline; *IV*, intraverbal

"razor" after hearing the sound for "film rewind"). Three participants (P3, P7, P8) did not meet emergence criterion during the intraverbal test (89%, 33%, and 0%, respectively). Incorrect responses for these participants included class-inconsistent responses such as saying, "ice" and "chopping" after hearing the sound for "rocket," saying, "I don't know" or "I can't remember" or responding in a way that was inconsistent with the instructions given (e.g., saying, "horn" and "traffic" after hearing a sound that was tacted as "car driving"). Mean reaction times for correct go trials across participants in the absence of consequences was 2.01 s (range, 0.86–7.94 s) during baseline training, 1.67 s (range, 0.75–5.41 s) during symmetry posttests, and 1.87 s (range, 0.16–6.81 s) during transitivity/equivalence posttests.

Responses during the post-experimental interview varied across participants. They reported creating scenarios based on the sounds heard (e.g., P3: "After the feedback I continued creating scenarios but now I knew what went together – for example, the ice in the glass and the closet, it was like someone getting ready to go out for drinks with friends"), categorizing or grouping the sounds together (e.g., P5: "Once I grouped the sounds with the words in my head, I was solid. I related the sounds to other sounds I heard in the past. Once I had the groups of three, I realized it could be any combination of the three"), and attempting to identify commonalities between sounds within a class (e.g., P2: "Almost sounded like coins dropping, door opening, and cutting were sounds that went from top to bottom, like the knife starts at the top and then cuts down. Thunder, the phone vibrating, and the tape rewinding seemed like elongated sounds"), among others.

Discussion

The purpose of the current study was to extend previous research on auditory–auditory S-MTS with a go/no-go requirement (Hanson & Miguel, 2021) to nonverbal sounds that cannot be echoed. Six out of eight participants (75%) met emergence criterion during transitivity/equivalence tests further supporting the use of S-MTS for the establishment of auditory conditional relations and equivalence classes with typically developing adults. A limitation of the current study is that class assignments remained consistent across all participants. Thus, the extent that characterstics of the sounds (e.g., "elongated songs" as reported by P2 during the post-experimental interview) within each class contributed to class formation cannot be determined. Although not common practice across equivalence studies, future research should vary class assignments across participants to control for this possibility (Dougher et al., 1994). Furthermore, the results seem to suggest that self-repetitions of stimuli or (overt/covert) echoic behavior may not be necessary during S-MTS tasks, as the stimuli in the current study could not be echoed. However, given that stimuli consisted of everyday sounds, they could have served to evoke either previously established or self-generated tacts. Tact tests showed all participants assigned names to stimuli.

Even though no participant tacted the stimuli overtly during S-MTS trials, it is possible that they engaged in these tacts covertly during training, which may have led to the establishment of intraverbals (e.g., "toaster–scanner–signature"). If this were the case, samples could have evoked tacts and intraverbals which would in turn exert additional control over correct selection responses (e.g., Jennings & Miguel, 2017). This may be supported by the results of intraverbal tests, as five participants verbally related the stimulus names in a class-consistent manner. Furthermore, some participants' responses during post-experimental interviews seem to also indicate that they were relating the stimuli intraverbally. For example, P6 responded with, "Explosion was always with shaving and disc – later no explosion – so I matched shaving and disc, groups of three."

Although participants responded with either an experimenter-defined or a unique tact during tests, it remains unclear whether they were tacting stimuli covertly or relating them intraverbally during training and/or testing, especially because reaction times were very short. Thus, future research might require participants to talk aloud during these conditions (e.g., Diaz et al., 2020).

It is also possible that participants engaged in covert visualization (i.e., conditioned seeing) as a form of mediation (Miguel, 2018). This might be supported by the results of post-experimental interviews, as many participants reported visualizing the stimuli together. For example, P1 stated, "I made little scenarios – images of what the sounds were – like someone knocking over a glass with ice in it while they're in the kitchen chopping food for dinner." However, the role that tacting may play combined with covert visualization cannot be determined. Future research may investigate the role of visual mediation, as well as control for the effects of participants' verbal behavior (i.e., its response products) by employing nonverbal sounds that are difficult to tact such as wave frequencies (Halbur et al., 2021).

Code Availability Not applicable.

Data Availability All data are available upon request.

Declarations

Conflicts of Interest The authors have no conflicts of interest.

Ethics Approval All procedures and recruitment protocols were approved by the university's Institutional Review Board (IRB).

Consent to Participation/Consent to Publish Informed consent was provided by all participants in the study.

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