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Accounting for Musical Perception Through Equivalence Relations and Abstraction: An Experimental Approach

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Abstract

The present study aimed to establish equivalence classes between musical chords, the corresponding chord grids, and the labels for each chord type (major, minor and 7th). Seven adults participated in a computerized matching-to-sample procedure. During training sessions, participants learned relations between chords of the same root note and either their corresponding chord grids or the words labeling their type. Equivalence relations between grids and words were then verified, and a generalization test assessed abstraction of the chord type with previously untrained chords. Phase 1 used chords having C as the root note. Phases 2 and 3 were programmed similarly, using chords having E and G as their root notes. Most participants had positive results on equivalence tests. Across the experimental phases, the percentage of correct choices in the generalization tests increased gradually for four out of seven participants. A behavioral account of musical perception through the concept of abstraction is discussed.
Key words: stimulus equivalence, multiple exemplar training, abstraction, musical perception, chords.

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Novelty and Significance

What is already known about the topic?

- Previous studies have already investigated derived relational responding involving musical stimuli.
- Participants from previous research were able to respond to novel relations and also recombine units taught during training.
- Previous studies taught participants to respond discriminatively to isolated musical notes and to sequences of notes.

What this paper adds?

- The present paper adds to the literature by investigating stimulus relations involving chords.
- Extended previous findings by showing responses under control of common properties of different auditory stimuli (i.e. major, minor and 7th chords in different tones) using multiple exemplar training to account for musical perception.

According to Sidman and Tailby (1982; see also Sidman, 1994) conditional discrimination training (e.g., AB/BC) may give raise to other relations that were not directly taught. Equivalence class formation is attested if the participant is able to respond to stimuli programmed to belong to the same class when those are presented

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in novel combinations and sequences, in accordance with the properties of reflexivity (AA), symmetry (BA and CB) and transitivity (AC).

The stimulus equivalence paradigm has been used in Behavior Analysis to account for symbolic behaviors and has been widely applied to teach complex repertories related to language use such as reading, spelling, etc. (e.g., de Rose, de Souza, & Hanna, 1996; de Souza, de Rose, Faleiros, Bortoloti, Hanna, & McIlvane, 2009; Hanna *et alii*, 2011; Hübner, Gomes, & McIlvane, 2009; Sidman, 1971; Sidman & Cresson, 1973). It has also been used to teach other symbolic systems such as musical notation (Acín, García, Zayas, & Domínguez, 2006; Batitucci, 2007; Hanna, Batitucci, & Natalino-Rangel, 2016; Hayes, Thompson, & Hayes, 1989; Tena & Velazquez, 1997). Tena and Velázquez (1997), for example, taught seven kids to relate the dictated and written names of seven musical notes to the corresponding letter symbols and pictorial representation on a staff. The results from the symmetry, transitivity and reflexivity tests showed equivalence class formation for all participants.

Taking into account the behavior of the musician, it is important not only to "know" the names of the notes and its notation, but also to respond discriminatively to the sounds related to their visual representation. Some studies have advanced a few steps in the sense of using auditory-visual matching-to-sample tasks before testing for equivalence. Hayes, Thompson, & Hayes (1989), in a part of their training, taught participants to discriminate the temporal properties of music such as a half and a quarter note. Two other studies taught the participants to respond discriminatively to isolated musical notes (Acín *et alii*, 2006) and to sequences of notes (Perez & de Rose, 2010).

In all these studies, single notes were played alone or successively. The visual counterpart of the auditory-visual training was also the staff or the letter symbols of the notes. In music, however, notes can be played simultaneously as a chord and other notations such as the chord grid may be used, especially for guitar players.

A chord is a group of musical notes played together, at the same time. Chords differ from each other by the intervals that compose them. An interval is the distance between two notes. The distance of the notes from a root note defines what kind of chord is played. If the second and the third note are 2 and 3.5 tones from the root note, respectively, a major chord is formed. A C *major chord* (C on the musical notation) is composed by the notes C (root), E (2 tones from the root) and G (3.5 tones from the root). Using different notes but keeping the same intervallic relations, the E major chord is formed by the notes E (root), G# (2 tones from the root) and B (3.5 tones from the root). Thus, the notes themselves do not define a chord. The relevant property is a property of the sound that corresponds to the intervallic relation between the notes that are played together. Taking the distance pattern into account, if the second and the third note are 1.5 and 3.5 tones from the root, respectively, a *minor chord* is formed. Yet another chord type is called a 7^{th} chord, formed when a fourth note, 5 tones from the root note, is added, a major chord.

Multiple exemplar training (MET) has proved to be an effective procedure to establish stimulus control by abstract and subtle stimulus features, in humans (e.g., DeQuinzio, Townsend, Sturmey, & Poulson, 2007; Garcia, Baer, & Firestone, 1971; see also Barnes-Holmes, Barnes-Holmes, Roche, & Smeets, 2001a, b; Berens & Hayes, 2007; Luciano, Gómez Becerra, & Rodríguez Valverde, 2007) and nonhumans (e.g., Otsuka, Yanagi, & Watanabe, 2009; Porter & Neuringer, 1984; Watanabe, Sakamoto, & Wakita, 1995; Watanabe & Sato, 1999).

In a MET procedure, participants are presented with a set of different exemplars, that possess the same abstract property (e.g., C major, E major, and G major are different chords which share the property of being major chords), contrasted with other exemplars that do not possess this property and may possess a different abstract property (e.g. sets of minor or 7th chords, with the same root notes). Participants are trained to respond under control of the abstract properties (e.g., telling whether the chords are major, minor, or 7th) with this set of exemplars, and after they reach a mastery criterion, they are tested with different exemplars, not used in training (major, minor, and 7th chords with other root notes) to ascertain that responding is indeed under control of the abstract property.

A typical example of MET to establish control by a subtle abstract property is the study of Watanabe *et alii* (1995), who trained pigeons to distinguish between paintings by Monet and Picasso. Pigeons were trained with two sets of paintings by Monet and Picasso. A group of pigeons was reinforced by pecking on the paintings by Monet and another group was reinforced by pecking on the paintings by Picasso. After they reached a discrimination criterion, they were tested with other paintings by Monet and Picasso, not used in training, and performed with high accuracy, showing that responding was controlled by subtle abstract properties that distinguish the style of these two painters. Pigeons performed with accuracy above chance even when paintings by Renoir and Bracque, respectively, substituted the paintings by Monet and Picasso, indicating that they were under control of stylistic properties of impressionism and cubism.

For musicians, the ability to abstract (Skinner, 1953, pp. 134-135) these patterns of intervals is an important part of “musical perception”. Because non-musicians often lack the training to discriminate abstract properties of musical sounds, they tend to perform poorly in basic musical tasks. For instance, musicians usually don’t have difficulty discriminating major and minor chords, whereas non-musicians often may find this quite difficult. The present study aimed to teach participants without musical training to discriminate major, minor and 7th chords. Another aim was to form equivalence classes between the chords, their representations in the chord grid, and the words MAJOR, MINOR and 7TH (in Portuguese, MAIOR, MENOR and SÉTIMA). In each phase of the experiment, participants were taught to respond discriminatively to major, minor and 7th chords having the same root note. Each new phase used chords with a different root note, in order to provide the participants with a multiple exemplar training. As they were exposed to a class of auditory stimuli that kept some common properties (intervallic relations defining major, minor and 7th), it was expected that participants would progressively improve their discrimination of the patterns of musical intervals that distinguish chords from each other.

Method

Participants

Seven adults with no experience in musical training. They were all volunteers and agreed to participate after signing informed consent. Two of the experimenters were also participants, thus they will be identified by their true initials (LR and JC). All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committees and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Equipment and setting

The experiment was carried out in a quiet room in the laboratory at the university (UFSCar). An iMac® computer, a mouse and a keyboard were placed on a desk. The participant would sit on a chair, facing the computer keyboard. There was a couch beside the table, and a bookshelf between the table and the couch. The MTS 11.6.7 software (Dube & Hiris, 1999) controlled presentation of stimuli, recorded participants' responses and delivered consequences in the experimental sessions.

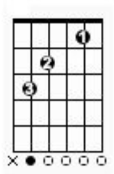
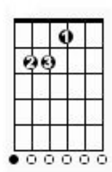
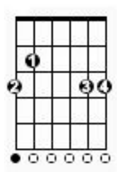
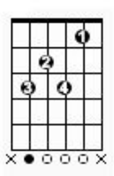
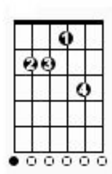
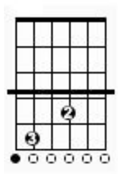
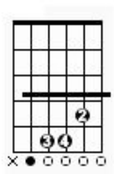
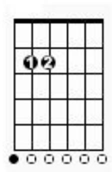
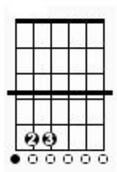
Stimuli

Table 1 shows the stimuli sets (A, B, C, D, E, F and G) on the columns and the programmed classes on the rows (1, 2 and 3).

Sets A, D and F were comprised of chords played on the acoustic guitar (as auditory stimuli they will be referred between quotes). Three kinds of chords were used: *major* (class 1), *minor* (class 2) and *7th* (class 3). In set A, *C* was the root note; in set D, the root note was *E*; and in stimuli set F, the root note was *G*. These stimuli were recorded using a synthesizer software.

Sets B, E and G were comprised of the guitar notation (chord grid) for the respective chords. Set C comprised the words MAIOR, MENOR and SÉTIMA, corresponding, respectively, to the labels major, minor and 7th, in Portuguese.

Table 1. Stimulus sets (columns) and programmed equivalent classes (rows). Stimulus sets A, D and F where composed by auditory stimuli (chords played in the guitar). Its correspondent guitar grids compose the stimulus sets B, E and G, respectively. Stimulus set C were composed by the printed words in Portuguese corresponding to major, minor and 7th.

		Stimulus Sets						
		A	B	C	D	E	F	G
Stimulus Classes	1	"C"		MAIOR	"E"		"G"	
	2	"Cm"		MENOR	"Em"		"Gm"	
	3	"C7"		SÉTIMA	"E7"		"G7"	

Experimental task

The participants were submitted to a matching-to-sample task. Each trial presented a sample stimulus (either auditory or visual) with two or three visual comparison stimuli. Comparison stimuli were presented randomly in the four corners of the screen and their position varied in order to avoid control by location. Each comparison appeared the same number of times on each position. Responses to the comparisons were mouse clicks on the stimulus. During the training, responses to the correct comparison (S+) were followed by the presentation of stars on the screen and an ascending sequence of tones; responses to the incorrect comparison were followed by one second of a black screen. Once the programmed consequences were delivered, another trial began after a 5-s inter-trial-interval (ITI). During the tests, no differential consequences were presented and responses were followed only the ITI.

In auditory-visual trials, samples were chords played for 2s (chord wave files were generated using a computer software). The chord would be repeated every second, until a comparison stimulus was chosen. Before starting a session with audio-visual trials, the following written instruction was presented on the screen: "A sound will be presented with some pictures or written words. After listening to it, you must choose the correct picture or word using the mouse". During the training sessions, the following instruction was added: "If a correct choice is made, the computer will display stars with a short music"; before the test sessions began, participants read the instruction: "The computer will not tell you if your response is correct or not. Therefore, stars and music will not appear anymore."

In visual-visual trials a sample was presented on the center of the screen and a mouse click on the sample would produce the comparisons. Before starting a session with visual-visual trials, the following instruction was displayed on the screen: "A picture or a word will be presented on the center of the screen. If you click on it, three other pictures or words will appear. Choose the one you think is correct". Since visual-visual trials were presented only during tests, the information about withdrawal of consequences was always presented before visual-visual trials started.

No explanation about the meaning of chords and their corresponding visual stimuli was presented before trial sessions.

Procedure

A multiple-probe design was programed to evaluate the effects of multiple exemplar training with different root notes upon generalization tests (probe sessions 1-3). After a brief pre-test period, the procedure was divided into three phases. In all of them, the participants were trained to relate the auditory chords to its corresponding chord grid and to its corresponding printed label (MAJOR, MINOR, 7*th* -C stimuli set). After training, equivalence and probes (generalization tests) were carried out, respectively. The relations that were taught and tested are shown in Figure 1. In Phase 1, participants learned to respond discriminatively to major, minor and 7th chords that had C as the root note. In Phase 2 and Phase 3, they learned to respond to the same types of chords having E and G as the root note, respectively. Thus, taken together, phases 1, 2 and 3 comprised a multiple exemplar training in which some properties of the auditory sample (i.e., the patterns concerning the distance between notes that configure major, minor and 7th chords) were kept constant across chords with different root notes.

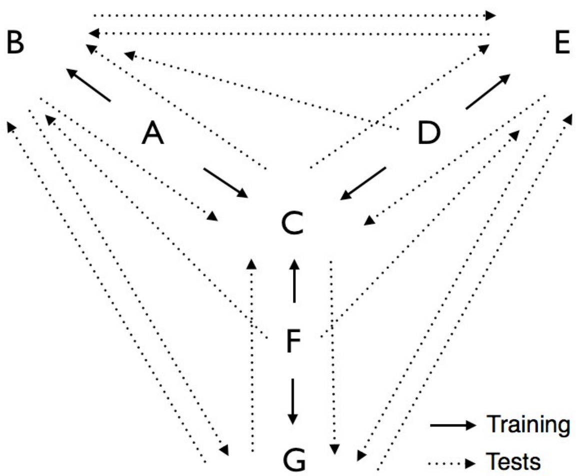


Figure 1. Trained (solid lines) and tested (dashed lines) relations.

Pre-test. Before experimental phases began, a pre-test was conducted using stimuli with the note C. Pre-test 1, verified AB and AC auditory-visual relations. A stimuli (C major, C minor and C 7th) were presented as samples. Comparison stimuli were either the corresponding chord grids (B) or the words MAJOR, MINOR and 7th (C); there were three AB and three AC trials, one trial for each of the three sample stimuli. During Pre-test 2, BC and CB visual-visual relations were tested; there were three BC trials and three CB trials, one for each sample stimuli. During such tests, there were no differential consequences for responses.

Phase 1. Consisted of a one-to-many training in which participants learned the relations between sets AB (A1B1, A2B2 and A3B3) and AC (A1C1, A2C1 and A3C3), separately. In the stimulus label the letter corresponds to the stimuli set and the number corresponds to the class that it might belong according to the programmed contingency (e.g., A1). The trainee or test between two stimuli sets is represented by two capital letters joint side-by-side (e.g., AB, BC). The relations that must be learned by the participants taking into account the programmed contingency are represented by the label of two stimuli joint side-by-side (e.g., A1B1); the stimulus on the left is the sample and the stimulus on the right is the correct one (S+). The training of each relation was divided into four steps. During the AB training, for example, in the 1st Step, stimuli from classes 1 (A1B1) and 2 (A2B2) were presented (Step AB12); in the 2nd Step, stimuli from classes 1 (A1B1) and 3 (A3B3) (Step AB13) were presented; in the 3rd Step, stimuli from classes 2 (A2B2) and 3 (A3B3) (Step AB23) were presented; in the 4th step, stimuli from all the three classes were presented (Step AB123). In the training steps involving two stimulus classes, only two comparisons were displayed in each trial; in training steps involving three classes, three comparisons were presented. After teaching AB and AC relations separately, these relations were presented together in a baseline session (Baseline 1).

Each training session was comprised of four presentations of each relation taught in that step. Sessions repeated four times or until the participant scored 90% of correct responses, whichever came first. In sessions with less then 10 trials (e.g., 1st, 2nd and 3rd steps), a score of 100% correct was required. After each session, there would be a break during which the participant would wait in the couch, while the experimenter would check if the criterion was reached and prepare the next session. The number of sessions that would be carried out each day depended on the time limit previously scheduled, which depended on the participant's availability (usually one hour). After training, equivalence tests were conducted (BC and CB). There was one session for each test. Sessions were comprised of four presentations of each tested relation (B1C1, B2C2, B3C3, C1B1, C2B2, C3B3). Equivalence test trials always displayed 3 comparison stimuli. Equivalence tests were followed by a probe session (generalization test), presenting, as samples, chords that shared the properties of the chords used during the training along with the words MAJOR, MINOR and 7th (set C) in a three-choice MTS. Probe sessions presented one trial for each kind of chord (major, minor and 7th) having as the root note each of the following notes: C, D, E, F, F#, G, A, and B, i.e., the seven notes of the diatonic scale and the F sharp. Having three kinds of chords and eight root notes, generalization tests were comprised of 24 trials.

Phase 2. Similarly to Phase 1, during Phase 2 participants were taught relations DE and DC, separately. After meeting mastery criteria, DE and DC were presented together in a baseline session (Baseline 2). Once participants performed in accordance with the programmed contingency, baseline trials of Phase 2 were mixed with those of Phase 1 in a single cumulative session (Baseline 1+2). This training was followed by equivalence tests EC, CE, EB, BE and DB. After that, the generalization test presented in Phase 1 was repeated.

Phase 3. Similarly to Phase 1 and Phase 2, during Phase 3 participants were taught the relations between sets FG and FC, separately. After reaching criteria, these relations were presented together in a baseline session (Baseline 3). Once performing in accordance with the programmed contingency, baseline trials of Phase 3 were mixed with those of Phases 1 and 2 in a single cumulative session (Baseline 1+2+3). Previous baselines were retrained if performance deteriorated or scores did not increase. Participants would retrain Baselines 1, 2 and 3, advancing as they attained criterion in each. Then they would continue training with the cumulative baseline (1+2+3). The training was followed by equivalence tests GC, CG, GB, BG, GE, EG, FB and FE. After that, the generalization test presented in Phase 1 was repeated.

Results

Figure 2 presents results from the five participants (HI, FJ, LR, GL and EM) who completed all the three experimental phases; Figure 3 presents results from the two participants who completed only Phase 1 and Phase 2 (JC and CO). Those participants withdrew from the experiment due to time constraints. The two initial gray bars represent the percentage of correct responses during pre-tests. During Pre-test 1, which involved C as auditory sample, most participants scored low, varying from 0 to 33% of correct responses; two participants (FJ and GL) scored correctly in half of the pre-test-1 trials. During Pre-test 2, which involved the C visual stimuli exclusively, four participants scored low (HI, LR, GL and JC), two scored above chance (FJ and CO) and one responded correctly in all trails (EM).

The black bars represent the number of sessions that each participant took to complete each training step and baseline sessions across the experimental phases. In general, the number of sessions to achieve criterion during the training steps decreased across phases. To complete Baseline 1, participants took from 1 to 30 sessions. To complete Baseline 2 and Baseline 3, they took from 1 to 6 and from 1 to 7 sessions, respectively. Something similar happened to the cumulative baselines (Baseline 1+2 and Baseline 1+2+3). In the first one (Baseline 1+2 -Phase 2), participants took from 2 to 27 sessions to achieve criterion. In the next cumulative baseline (Baseline 1+2+3 -Phase 3) they took from 4 to 11. All participants that completed the experiment had

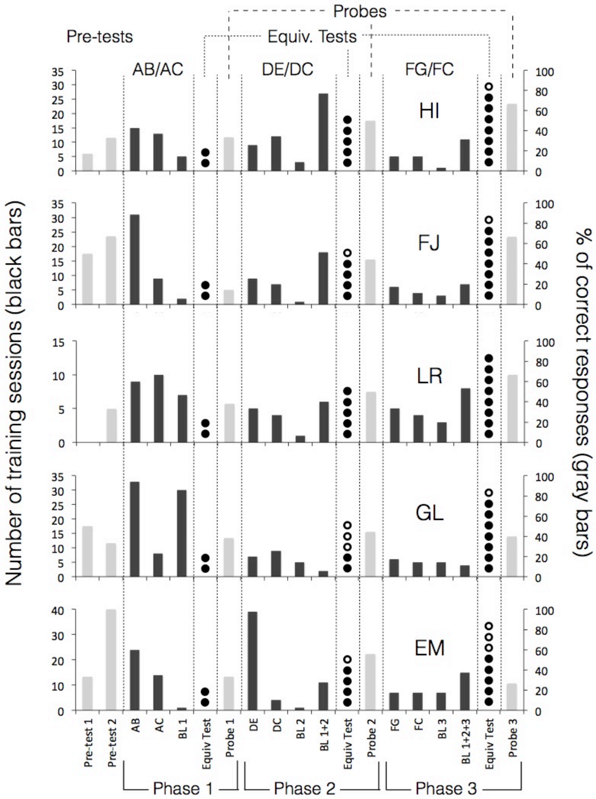


Figure 2. Results from participants who completed all the three experimental phases. Gray bars represent percentage of correct responses during pre-tests and probes. Black bars represent the number of sessions to complete each training step and baseline sessions. Black and white circles represent equivalence test outcomes. Filled circles represent tests with accuracy equal or above 90%; empty circles represent tests with accuracy below 90%.

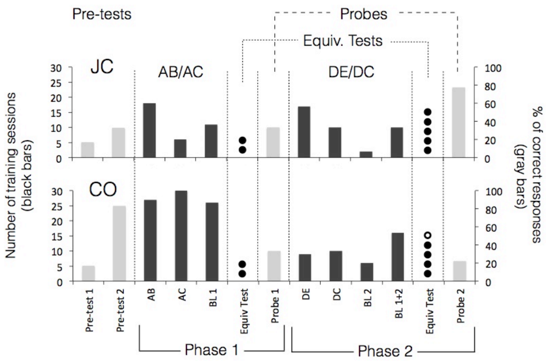


Figure 3. Results for the two participants who did not complete the three experimental phases. Gray bars represent percentage of correct responses during pre-tests and probes. Black bars represent the number of sessions to complete each training step and baseline sessions. Black and white circles represent equivalence test outcomes. Filled circles represent tests with accuracy equal or above 90%; empty circles represent tests with accuracy below 90%.

to retrain baseline relations, at least in one phase, before achieving criterion in the cumulative baseline session.

In Figure 2 and Figure 3, black and white circles represent outcomes in equivalence tests. There is one circle for each test; filled circles represent tests with accuracy equal or above 90%, whereas unfilled circles represent tests with accuracy below 90%. During Phase 1, all participants had a high percentage of correct choices in BC and CB tests. During Phase 2, FJ, GL and CO had poor scores in the DB test. GL also scored below criterion in EB and BE tests. During the tests of Phase 3, almost all participants scored 100% of correct choices. Participants HI and FJ scored 92% correct in FB tests. GL achieved 92% in FE. EM had the lowest scores: 83% in GC, 92% in CG, 42% in FB and 75% in FE tests. In general, errors occurred more often in auditory-visual tests (DB, FB and FE).

The three last gray bars represent the percentage of correct responses during probes. For participants HI, FJ, LR and JC, correct choices increased across the experimental phases. By the end of Phase 1, during the first probe, participants had chance-level scores. In the second test, JC had a sharp increase in the percentage of correct choices (83.3%). The third test was conducted with five of the seven participants, and three of them showed higher scores compared to the first and second probes: HI, FJ, and LR. Therefore, these three participants showed increases in generalization across all the three probe sessions. JC withdrew from the experiment after the second probe, but reached generalization scores above 80% in this test. The other three participants did not show consistent increases in generalization, although EM showed an increase from the first to the second probe, which was followed, however, by a drop in accuracy in the third probe session (This participant reported being worried about a test he would have the next day, for one of his academic courses. According to his report, he was “distracted” during the test).

Discussion

The present study aimed to establish equivalence classes between chords, the corresponding chord grids, and the words designating each chord type. In general, equivalence class formation was observed for all participants. A low percentage of correct choices in the auditory-visual tests was observed for three participants. In two (FJ and GL) out of three cases, the difficulties exhibited in Phase 2 did not persist in Phase 3.

As long as participants were exposed to multiple exemplars of major, minor and 7th chords having different root notes, they were expected to abstract (Skinner, 1953) these properties in the sense of being able to respond discriminatively to them. It was also expected that, across the experimental phases, the percentage of correct choices in the generalization test would increase gradually -as observed in previous studies using multiple exemplar training procedures (e.g., Barnes-Holmes *et alii*, 2001a, b; Berens & Hayes, 2007; DeQuinzio *et alii*, 2007; Garcia *et alii*, 1971; Luciano *et alii*, 2007; Otsuka *et alii*, 2009; Porter & Neuringer, 1984; Watanabe *et alii*, 1995; Watanabe & Sato, 1999). The results of four (HI, FJ, LR and JC) out of seven participants corroborate these suggestions. Nevertheless, since the best result was observed for JC who had not passed through Phase 3, it is still open to investigation how many exemplars are necessary to produce such abstraction.

The present results corroborate other studies that show equivalence class formation using musical stimuli (Acín *et alii*, 2006; Batitucci, 2007; Hayes *et alii*, 1989; Tena

& Velázquez, 1997). Differently from previous studies, it adds to the literature by investigating chord discrimination. Results also show that the multiple exemplar training procedure was effective in teaching participants to respond discriminatively to major, minor and 7th chords. These findings corroborate the efficacy of the equivalence relations paradigm in teaching procedures (Sidman, 1994), which has also been found in studies comparing different methods for music teaching (Tommis & Fazey, 1999).

As there were three participants who did not achieve higher scores across the generalization tests, it is important to ease the procedure in future studies. One way this can be made is by reducing the number of comparison stimuli, training discrimination only between major and minor chords, for instance. During training, correction procedures could also facilitate the acquisition of conditional relations, reducing the amount of trials necessary to reach the mastery criterion.

Music discrimination has been frequently studied with non-humans (e.g., Brooks & Cook, 2010; Hagmann & Cook, 2010; Murphy & Cook, 2008; Otsuka *et alii*, 2009; Porter & Neuringer, 1984; Wright, Rivera, Hulse, Shyan, & Neiworth, 2000). However, few studies in behavior-analytic journals have explored this topic with children or adults. Studies developed so far teach specific stimulus-stimulus relations and have not explored teaching participants to abstract auditory properties, such as chords, intervals, melodies etc. Regarding the generalization test, future studies could use the same chords played by different instruments, in order to further test discrimination of the chord properties. Other intermediary notes from the chromatic scale (C#, D#, G#, A#) could also be used to provide additional generalization trials.

Although the present teaching procedure needs to be refined, these findings may contribute to clarify the role of abstraction in musical perception, which can aid in developing programs targeting a wider audience.

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