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A further Experimental Step in the Analysis of Hierarchical Responding

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Abstract

This study is a step forward in the difficult task of analyzing the transformation of functions via hierarchical relations. Eight participants underwent a computer task with five phases. During Phase 1, four stimuli were trained to become the following relational cues: INCLUDES, BELONGS TO, SAME, and DIFFERENT. In Phase 2, three equivalence classes were trained and tested (A1-B1-C1-D1; A2-B2-C2-D2; A3-B3-C3-D3). During Phase 3, inclusion relations were first established, by using the INCLUDES and BELONGS TO relational cues, between the to-be lower levels of the hierarchy, namely A1/B1, A2/B2, and A3/B3; and stimuli X.1, X.2, and Y.1, respectively. Then, the INCLUDES relational cue was used to establish inclusion relations between X.1/X.2 and X, and between Y.1 and Y, so that X and Y would become the most inclusive levels of two separate hierarchical networks. In Phase 4, X.1 was established as cold, D2 as heavy, and C3 as sweet. Lastly, in Phase 5 (Critical Test), seven stimuli from both hierarchical networks were tested for the transformation of functions. Five of the six participants who made it to this test responded correctly. Implications, limitations, and further research are discussed.
Key words: Hierarchical relational responding, transformation of functions, hierarchical classification, relational frame theory, derived relations.

Novelty and Significance

What is already known about the topic?

- The literature about hierarchical classification in behavior analysis is very scarce.
- Hierarchical categorization has been found as result of a combination of contextually controlled conditional discrimination training, stimulus generalization and stimulus equivalence.
- Some studies had analyzed transformation of functions though hierarchical classification.

What this paper adds?

- This paper is among the first to include hierarchical relational cues.
- This paper adds evidence of the transformation of functions through hierarchical relations.

A typically developed young student is able to organize the category animals into different groups according to many contextual cues. For example, if the cue is “oviparous animals,” animals as eagle, snake, pigeon or lizard are categorized as different from others animals grouped under the cue “mammals.” In addition, the members of the

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category "oviparous animals" can be grouped into smaller subgroups according to other contextual cues such as "flying" or "crawling animals." In the latter case, eagle and pigeon will be grouped as different from snake and lizard. As well, these animals can be grouped differently on the basis of other contextual cues (e.g., "fast or slow animals").

The previous example shows a flexible grouping of stimuli into different networks based on their specific functional properties and features. This grouping is referred to as contextually controlled classification or hierarchical classification (Bush, Sidman & de Rose, 1989; DeRosse & Fields, 2010). Hierarchical networks are established on the basis of a higher inclusive characteristic that is shared by all members of the group. For instance, the most inclusive context of the hierarchy "animals" may be identified with the property of heterotrophic and multicellular organisms. Accordingly, all of its members share these features although, as in the previous examples, they can be organized in different ways according to different contextual cues or functions.

To date, little is known with regard to the conditions under which the repertoire of hierarchical classification is established. From the functional contextual framework represented by Relational Frame Theory (RFT; Hayes, Barnes-Holmes, & Roche, 2001; Luciano, Valdivia-Salas, Berens, Rodríguez-Valverde, Mañas, & Ruiz, 2009; Rehfeldt & Barnes-Holmes, 2009), hierarchical classification would have its origins in the multiple-exemplar training of contextually controlled patterns of relational responding which are initially based on nonarbitrary relations of inclusion (or *is formed by stimuli with common functions*) and belonging to (or *is a member of X because it shares something with others of its members*). For instance, a child soon learns to tact his body parts (e.g., eyes, ears, mouth) as elements of his body. He also learns that, although each of these parts has their own functional properties, they all share something that turns them into parts of the same thing, i.e., his body. Through similar multiple interactions, the repertoire of classifying objects comes under contextual control of the words that are used as hierarchical relational cues for involving or including (e.g., "includes", "has" or "is formed by") and belonging (e.g., "belongs to," "is a member of" or "is in"). Subsequently, these hierarchical cues will be brought to bear in additional arbitrary and complex ways (e.g., like a particular family that is formed by the parents, siblings, uncles, etc, for example, because of some biological cue) that allows the flexible grouping of the members forming the hierarchical category (e.g., the parents, the siblings, and the uncles might be organized in different ways according to specific characteristics like their professions or the kind of things they like). One more example to illustrate this point is the following.

Let's say a child gets scared when he sees a crocodile in the zoo. Later on, his father tells him that crocodiles and snakes belong to a type of animals named reptile. When the father offers the child to go and check the snakes, the child refuses. He might get very excited, however, when approaching the birds, which his father told him "are also animals but not reptile." That is, while both reptiles and birds share the general characteristics of the hierarchy animals as the most inclusive level of the hierarchy (e.g., they breathe, have bodies, are motile, etc.), reptiles have specific functions (e.g., in this example, they are scary) that birds do not share. It could be said that the characteristics of the stimuli in the lower levels of this hierarchy are defined by the contextual characteristics of the top level, or the most inclusive context and also, by the contextual characteristics of the lower level. That is, the child would say that there are scary and friendly animals (i.e., the category animal *includes or is formed by* scary and friendly animals). If he wants to scare somebody, he would pick reptiles instead of birds; if he wants to choose a pet, he would pick a parrot instead of a lizard. These examples show that the functions derived in hierarchical categories are very complex and that an unlimited pattern of hierarchies can be established in arbitrary and specific ways.

Research on hierarchical responding is still very scarce. Within the functional standpoint, the first experiment was conducted by Griffe and Dougher (2002) and used a combination of contextually controlled conditional discrimination training, stimulus generalization and stimulus equivalence in order to simulate the emergence of hierarchical categorization in natural settings. As predicted, participants showed the naming of new stimuli based on the contextually controlled common physical dimensions of the stimuli involved. A recent study (Slattery, Stewart & O'Hora, 2011) replicated key components of Griffe and Dougher (2002) and adapted the protocol such that participants did begin to show behavior consistent with transitive class containment. According to cognitive developmental literature, transitive class containment is one of the properties of hierarchical classification, and it means to classify a stimulus as a member of a higher order class because of being a member of a lower-order class contained in the higher one. One more recent study by Slattery and Stewart (2014) aimed at modeling this and the rest of properties of hierarchical classification according to the cognitive developmental literature, namely, transitive class containment, asymmetrical class containment (i.e., a higher order class contains a lower order class but vice versa is not true), and unilateral property induction (i.e., the properties of a higher order class have to be found in a lower order class, but not vice versa). As in Gil, Luciano, Ruiz, and Valdivia-Salas (2012), they used two arbitrary shapes as relational responding contextual cues for MEMBER OF and INCLUDES. A hierarchical network was then formed and derived relations and transformation of functions were assessed within the network. Throughout the two experiments presented, the three properties described above were satisfactorily modeled. However, as indicated by the authors themselves further work should extend these findings by investigating transformation of functions through combinatorial entailment, so as to examine whether it occurs only unidirectionally, or bidirectionally as well. Part of this track was analyzed in the series of experiments included in Gil *et al*. (2009).

In the preliminary but pioneering study of this series, published in Gil *et al*. (2012) analyzed the derived transformation of functions within a hierarchical category similar to the one in the example above. Briefly, hierarchical relations between stimuli were established and, then, some functions were provided to part of the stimuli. The transformation of functions was then tested with different stimuli of the trained network. Specifically, in Phase 1, participants were presented with multiple-exemplar training (MET) to establish four arbitrary shapes as the relational cues INCLUDES (or IS FORMED BY), BELONGS TO (or IS A PART OF), SAME, and DIFFERENT. In Phase 2, three four-member equivalence classes were trained and tested (A1-B1-C1-D1; A2-B2-C2-D2; A3-B3-C3-D3). These equivalence classes were established as the bottom level of two hierarchical categories. The middle and top levels of the hierarchical categories were formed during Phase 3. The middle level was established by using both hierarchical cues (INCLUDES and BELONGS TO) to relate novel stimuli with some of the stimuli of the equivalence classes (e.g., X.1 included A1/B1; X.2 includes A2/B2; and Y.1 includes A3/B3). Two novel stimuli (X and Y) were then established as the most inclusive levels of the two hierarchies by using both hierarchical cues (e.g., X includes X1/X2; Y includes Y.1; X1/X2 belong to X). In Phase 4, X.1, D2 and C3 were given functions as, respectively, always cold, heavy, and sweet. In Phase 5 (Critical Test), six stimuli from both hierarchical categories (Y, X, C1, X.2, D3, C2) and a non-related stimulus (M) were used to test the derived or untrained functions. Nine of the ten participants responded according to the arbitrary relations established among the stimuli. For instance, in the presumably most complex trial (when asking for the characteristics of X), participants responded that X had the characteristics of each lower level. The findings provided a preliminary demonstration of transformation of functions in accordance with the type of hierarchical network trained in this study.

In this first approach to the establishment of a hierarchical network and test for transformation of functions through hierarchical relations, the modifier “is always” was used during both the acquisition and testing phases of stimulus functions. That is, X.1 was established as always cold, D2 as always heavy, and C3 as always sweet. When testing for the functions of X, the correct response was “X is always cold and heavy” which, in itself, may be misleading in that cold and heavy may be therefore taken as defining features of the hierarchy (same as breathing and being motile are defining features of the hierarchy animals and thus common to all its members) instead of incidental functions of each subcategory or member. Although we might assume that the relational cue “is” expresses specific or non-inclusive functions of the top stimulus and therefore is functionally equivalent to responding to “has a part,” this deserves further examination. And this is what we did in Gil *et al*. (2009). In order to avoid transformation of functions that might be considered an experimental artifact, such as responding that “X is cold and heavy” just because it contains things that are cold and things that are heavy; in the present study we replaced such response option with “X has a part that is cold and a part that is heavy,” the truly correct answer in this case. In addition, to avoid confusion, the cue “always” was eliminated in the present study when establishing the functions and in the Critical Test.

Another limitation in Gil *et al.* (2012) was that the hierarchical relations were trained in both directions (e.g., X includes X.2, and X.2 belongs to X) and consequently, derived relations were not clearly isolated. In the present experiment, the most inclusive context of the hierarchical relational networks will be established in only one direction (e.g., X includes X.2).

Methods

Participants

Eight graduate and undergraduate students (4 females and 4 males; age range: 17-39) from diverse disciplines (e.g., psychology, journalism, computer science) volunteered to participate in the experiment. None of them had previous experience with the procedures employed in the present study. All participants were recruited through bulletin board announcements and personal contacts. No compensation was given to them for their participation. Upon completion of the tasks, the participants were fully debriefed.

Setting, Apparatus, and Stimuli

The experiment was conducted in a quiet room equipped with a table, a chair and a laptop computer. A computer program designed in Visual Basic 6.0© served to present visual stimuli and record participants' responses. The stimuli were the same as those employed in the original study by Gil *et al.* (2012). All stimuli were presented in black-and-white. Arbitrary symbols in the upper portion of Figure 1 were used as the to-be relational cues INCLUDES (or IS FORMED BY), BELONGS TO (or IS A PART OF), SAME, and DIFFERENT. Thirteen sets of visual stimuli (including drawings and pictures of known objects) served to train the relational cues (see Table 1). Figure 1 (middle and bottom parts) shows the abstract figures and nonsense syllables used to form the hierarchical categories.

Procedure

Upon agreeing to participate in the experiment, participants were escorted to the experimental room and sat in front of the computer. The experimenter asked participants to follow the instructions on the screen in order to complete the tasks, and left the room.

The whole experiment included five phases (see Figure 2) and two brief breaks (at the end of Phases 2 and 3), all conducted in one session that lasted between 65 and 90 minutes. Participants were run through the tasks individually. All the instructions

Table 1. Sets of stimuli used during Phase 1.

Set 1. Circle that includes a clock. A chair and a dog.
Set 2. Rhombus that includes a pencil and an umbrella. A radio, a trumpet and a rose.
Set 3. Circle that includes a lamp and an envelope. Rectangle that includes a stair and a boot. A ball of wool, a car, a doll and a chef hat.
Set 4. Two arbitrary geometric shapes. Shape 1 includes letter "A". Shape 2 includes letter "R". Letters "P" and "Z".
Set 5. Glass that includes a heart and a dartboard. Octagon that includes a snowman and an apple. A racket, a table and a sun.
Set 6. Three arbitrary geometric shapes. Shape 1 includes a briefcase and a hairdryer. Shape 2 includes a pair of ladies shoes. Shape 3 includes a toy and a boat. A bulb, a tent, a leaf and a barber's chair.
Set 7. Circle that includes the moon, the letter "x", a pentagon and a triangle. In turn, the pentagon includes a computer and a crown, and the triangle includes a calculator. Cross includes a glasses and a planet. A pack of cards and the numbers "7" and "5".
Set 8. (Set Body): Drawings of: a human body, a robot, a human head, a crocodile head, a nose, an elephant's trunk, a brain, a nut, an eye and a marble.
Set 9. (Set Continents): Drawings of the following continents, countries and cities: Europe, Asia, España, France, Santiago, Almería, México City, Madrid and Buenos Aires.
Set 10. (Set Alphabet): The following words: alphabet, numbers, vowels, consonants. The letters: A, F, E, K, U, R.
Set 11. (Set Religions): The following words: Religions, Islam, Christianity, Catholic church, Priest.
Set 12. (Set Vegetables): The following words: Flower shop. Drawings of a rose and a carrot.
Set 13. (Set Universe): Drawings of: The Universe, the planets Saturn and Earth, a comet and a rocket

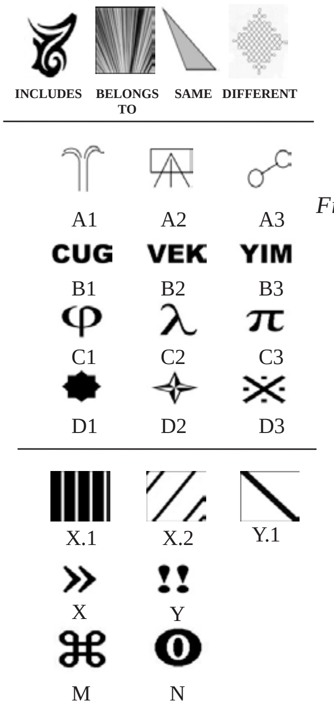

Figure 1. Arbitrary stimuli used during the procedure. Upper panel: stimuli used as the to-be relational cues INCLUDES, BELONGS TO, SAME, and DIFFERENT during Phase 1. Middle panel: stimuli employed to train three 4-member stimulus classes during Phase 2. Bottom panel: stimuli employed to complete the middle and top level of hierarchies X and Y during Phase 3.

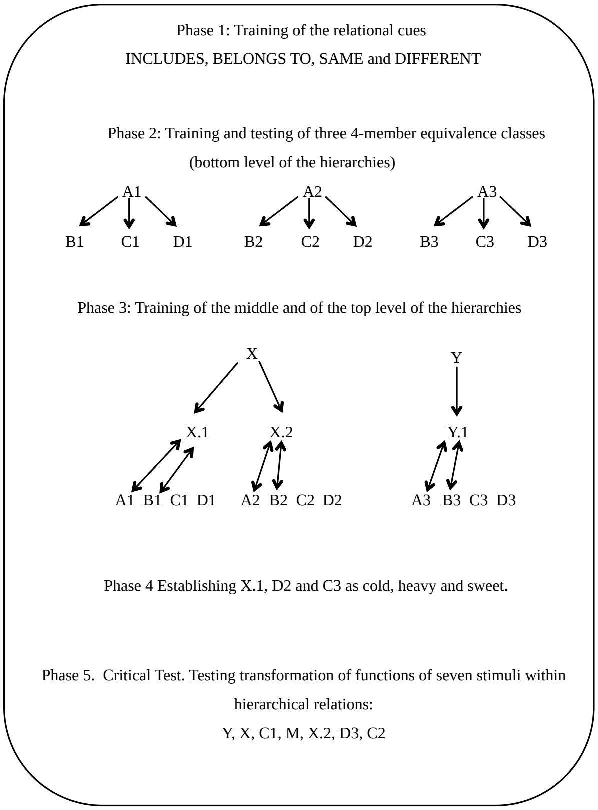

Figure 2. Schematic overview of the procedure.

were presented on the screen. Participants who achieved the mastery criterion but responded correctly to less than 80% of the trials in Phases 1, 2 and 3 were dismissed from further participation because, according to previous pilot studies, an experimental training history with numerous errors resulted in relevant difficulties for the abstraction of the relational cues and the training of the hierarchical relational networks.

Phase 1. Training of the relational cues INCLUDES, BELONGS TO, SAME, and DIFFERENT.

The purpose of this phase was to establish four arbitrary stimuli as different relational cues: INCLUDES (or IS FORMED BY), BELONGS TO (or IS A PART OF), SAME, and DIFFERENT. This phase was identical to that employed by Gil et al. (2012). By means of a multiple-exemplar training (MET), the to-be-established as INCLUDES and BELONGS TO cues were first trained with Sets 1 to 7. Subsequently, SAME and DIFFERENT relational cues were established with Sets 8 to 10 (sets Body, Continents and Alphabet). In addition, sets 8 to 10 served for additional training trials of INCLUDES and BELONGS TO relational cues. Three new sets were used to test all four relational cues (Sets 11-13: Religions, Vegetables and the Universe).

The MET had the following characteristics: (a) there were two types of trials: select-the-stimulus (e.g., stages 1 to 4) and select-the-cue (e.g., stages 4 and 5). In any given select-the-stimulus trial, a sample stimulus appeared at the top of the screen, followed by a stimulus in the middle (the to-be relational cue) and three or four comparisons at the bottom (positions were randomized across trials). In any select-the-cue trial, a sample stimulus appeared at the top of the screen, followed by one stimulus in the middle and four stimuli (the to-be relational cues) at the bottom (positions were randomized across trials). (b) Each relational cue was trained across multiple trials and across multiple sets of stimuli. (c) The order of trial presentation was prefixed and kept constant across participants. Also, participants had to respond correctly to any trial for the next trial to be presented. An incorrect response in any part of the sequence was followed by the repetition of the same trial. Consequently, the mastery criterion was achieved when participants responded correctly to the last trial of the sequence. And (d) novel sets were introduced to test for the four relational functions trained during this phase

Phase 1 consisted of five stages. Each of these stages is described below. The sets of stimuli and examples of trials can be traced in Table 1 and Figure 3.

Stage 1. *Establishing an arbitrary stimulus as the INCLUDES relational cue*.

Participants read the following instructions on the computer screen:

> "First you will see several drawings centered in the middle of the computer screen. They will then be moved to the top right of the screen. One of the drawings will also appear at the top left of the screen, followed by other drawings at the bottom, and a symbol in the middle. With the mouse, select the drawing at the bottom that best goes with the drawing at the top depending on the symbol in the middle. The computer will inform you with a written message on the screen whether your choice is correct or not. Errors are normal at the beginning. Do your best to accumulate as many correct responses as possible."

In a typical select-the-stimulus trial type a particular set of stimuli (e.g., a rhombus containing a pencil and an umbrella; a radio, a trumpet and a rose) appeared at the top right-half of the computer screen. After 1.5 s, a sample stimulus (e.g., rhombus) appeared at the top left of the screen, followed 1 s later by three comparison stimuli at the bottom left of the screen (e.g., umbrella, rose, radio), and 0.5 s later one of the to-be relational cues (in this case, INCLUDES) was placed between the sample and the comparisons. Participants selected one of the comparisons by clicking on it with the mouse. Selecting one comparison (e.g., umbrella) cleared the screen and the written message "Correct" or "Wrong" was displayed during 1 s. After a 1.3 s inter-trial interval (ITI), a new trial commenced. Training included 13 trials.

Stage 2. *Establishing an arbitrary stimulus as the BELONGS relational cue*. The training had the same characteristics as in Stage 1, and included 12 trials using stimuli from Sets 4, 5, and 6. One example of a specific trial was as following: at the top right of the computer screen participants saw a glass containing a heart and a dartboard; an octagon containing a snowman and an apple; a racket, a table and a sun. In addition, a picture of an apple appeared in the upper left portion of the screen, the stimulus for BELONGS TO appeared in the middle of the screen, and three figures at the bottom of the screen (the correct response is italicized): *an octagon*, a glass and a racket.

Stage 3. *Combining INCLUDES and BELONGS TO trials*. Training included eight trials, four with each relational cue, with Set 7.

Stage 4. *Establishing arbitrary stimuli as the SAME and DIFFERENT cues and additional training of INCLUDES and BELONGS TO cues*. Training included 6 blocks of trials for a total of 72 trials. An example of the training of DIFFERENT was as follows: a nose appeared in the upper place, the stimulus for DIFFERENT relation appeared in the middle and three figures at the bottom (*a trunk*, a head and a nose; see upper-first portion of Figure 3). Several trials were presented in this stage using the select-the-cue format. For example, a picture of Spain appeared both at the top and in the middle of the screen, and the four stimuli for SAME, DIFFERENT, INCLUDES and BELONGS TO appeared at the bottom of the screen (see upper-second portion of Figure 3). In another example, a picture of a human body appeared at the top of the screen, and a human eye in the middle. The four stimuli for SAME, DIFFERENT, INCLUDES and BELONGS TO appeared at the bottom of the screen (see third portion of Figure 3). Another example, a picture of a brain appeared at the top of the screen and a head in the middle, and the four stimuli for SAME, DIFFERENT, INCLUDES and BELONGS TO appeared at the bottom of the screen (see fourth portion of Figure 3). Participants had to click on one of these four options. When participants responded correctly to the six blocks of this phase, testing with new sets followed as indicated in the next stage.

Stage 5. *Testing the SAME, DIFFERENT, INCLUDES and BELONGS TO cues*. The relational properties of the arbitrary stimuli established as cues were tested with sets 11, 12, and 13 (Religion, Vegetables, and Universe) by using select-the-cue type of trials. In a typical trial, the words "Religions" and "Christianity" appeared, respectively, at the top and the middle of the screen, and the stimuli for SAME, DIFFERENT, INCLUDES and BELONGS TO appeared at the bottom. Participants were informed that no feedback would be provided from then on. As an exception, the order of presentation of each trial block was randomized across participants. The mastery criterion was established at 100% correct responses in one 9-trial block. Incorrect responses were immediately followed by a 4-trial retraining block. The test was resumed when participants produced 100% correct responses within one block. Participants who did not achieve the testing criterion within five testing-retraining cycles were dismissed from further participation.

Phase 2. Training and testing of three 4-member equivalence classes (to-be bottom levels of the hierarchies). This phase was identical to the employed by Gil *et al*. (2012). Three 4-member equivalence classes were trained using one-to-many matching-to-sample (MTS) procedures (Class 1: A1-B1, A1-C1, A1-D1; Class 2: A2-B2, A2-C2, A2-D2; Class 3: A3-B3, A3-C3, and A3-D3) (see the 12 stimuli used in the middle portion of Figure 1). Training included select-the-stimulus type of trials only, where A stimuli served as samples; either B, C, or D stimuli served as comparisons; and the SAME

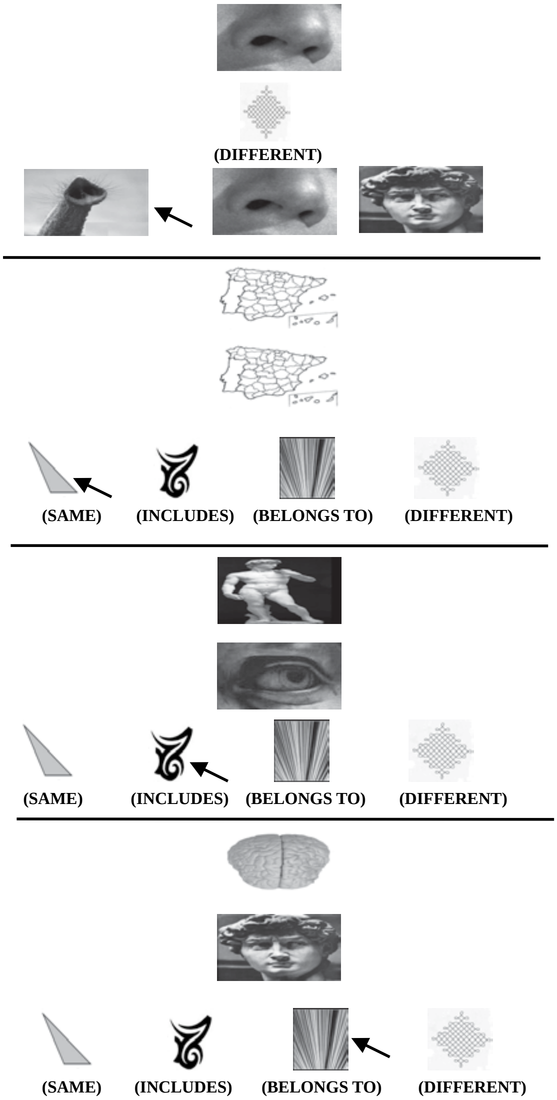

Figure 3. Examples of trials for SAME, DIFFERENT, BELONGS TO and INCLUSION relational cues. The first and second panel shows trials for the training of SAME and DIFFERENT relations, respectively. The third and fourth panel shows trials for the training of INCLUSIONS and BELONGS TO relations, respectively. The arrows indicate the correct answer. The words Different, Same, Includes and Belongs to and the arrows were not visible to participants.

cue served as the relational stimulus.

The training sequence was as follows. Each new relation (e.g., A1-B1) was trained until participants produced two consecutive correct responses. Then, training followed for the same relation in Class 2 (A2-B2) and Class 3 (A3-B3) until two consecutive correct responses per relation were produced. Subsequently, the three relations (A1-B1, A2-B2, A3-B3) were presented at random in blocks of six trials (two per relation), until participants produced one block with 100% correct responses. The remaining new relations were trained in the same manner, except for the order of training (in A-C training: first A2-C2, then A3-C3 and, finally, A1-C1; in A-D training: first A3-D3, then A2-D2 and, finally, A1-D1). Training blocks containing all relations followed (three 6-trial blocks with A-B, A-C, and A-D relations) until 100% correct responses were produced. A written message then appeared on the screen informing participants that no feedback would be provided after responding during the subsequent trials. After this message, a 9-trial block followed (A1-B1, A2-B2, A3-B3, A1-C1, A2-C2, A3-C3, A1-D1, A2-D2, A3-D3). If participants produced 100% correct responses in one block, the stimulus equivalence test commenced; otherwise, they were presented with an additional 9-trial block with feedback.

Stimulus equivalence testing started without providing any additional instruction to the participants. It consisted of one 9-trial block (three trials per B-C, B-D, and C-D relations). If participants responded correctly to all trials, they were allowed to take a 5 to 15 minute break before proceeding to the next phase. Otherwise, symmetrical testing followed with one trial per relation. Combinatorial testing was resumed after producing 100% correct responses. Participants who did not meet testing criterion after five cycles were dropped from further participation. During the break, participants stayed alone in an adjacent room and were offered a drink.

After the break, relational cues and conditional discriminations were re-trained. First, 4-trial blocks for the retraining of each of the four relational cues with sets 8 to 10 (Continents, Body and Alphabet) were presented until participants produced 100% correct responding in one block. Then, 9-trial blocks for the retraining of each of the A-B, A-C, and A-D relations were presented until participants produced 100% correct responses within one block. Finally, 9-trial blocks for retesting each of the B-C, C-D, and B-D combinatorial relations were presented until participants produced 100% correct responses within a block. The mastery criteria were the same as in Phase 2.

Phase 3. Training of the middle and of the top level of the hierarchies. During this phase, we used A and B stimuli, and the five novel stimuli shown at the bottom of Figure 1. Stimuli labeled as M and N served as negative response options during MTS procedures (i.e., they were not related to any other stimulus). Participants saw the following written message on the computer screen: "Remember everything you have learned before the break because it will help you during this part of the experiment." First, the middle level of the hierarchies was established, followed by the training of the top level or the most inclusive context of the hierarchies. Lastly, all trained hierarchical relations were presented in two blocks.

Stage 1. *Training the middle level of the hierarchies* (X.1, X.2 and Y.1). The following relations were trained: X.1 includes A1, X.1 includes B1, A1 belongs to X.1, and B1 belongs to X.1 (for branch X.1 of hierarchy X); X.2 includes A2, X.2 includes B2, A2 belongs to X.2, and B2 belongs to X.2 (for branch X.2 of hierarchy X); Y.1 includes A3, Y.1 includes B3, A3 belongs to Y.1, and B3 belongs to Y.1 (for hierarchy Y). A total of 37 trials were presented (see Table 2). The order of presentation of the trials was predetermined and kept constant across participants. Responding correctly to all trials was followed by two 6-trial blocks (one trial per relation) in which the order of presentation was randomized across participants. The mastery criterion was set at 100% correct responses in both blocks.

Stage 2. *Training the top level of the hierarchies* (X and Y, see Table 2). Two relations were trained for the first hierarchy: X includes X.1 and X includes X.2. One relation was trained for the second hierarchy: Y includes Y.1. A total of 15 trials were presented in a predetermined sequence that was kept constant across participants. Responding correctly to all trials was followed by one 6-trial block (one trial per relation). The order of presentation was randomized across participants and the mastery criterion was set at 100% correct responses in both blocks (see Table 2).

Stage 3. *Combining the middle and top levels of the hierarchies.* Two 6-trial blocks were presented that contained trials from both levels of the hierarchy. Participants had to produce 100% correct responses in each block to proceed to the next 5-min break.

After the break, participants were presented with five blocks of trials for additional training of all the relations learned up to this point in the procedure (two blocks for the relations established in phases 1 and 3, and one block for the relations established in Phase 2).

Phase 4. Establishing X.1, D2 and C3 as cold, heavy and sweet, respectively. Stimulus-pairing and MTS procedures were used as follows. Firstly, two consecutive stimulus-pairing trials were presented for each stimulus for a total of six trials. On each trial, a stimulus (e.g., X.1) appeared centered on the left half of the screen; 0.5 s later the expression "is cold" appeared centered on the right half of the screen. MTS trials were then presented in 15-trial blocks containing five trials per stimulus until participants produced 100% correct responses within a block. In a given trial, one of the stimuli appeared centered at the top of the screen, followed 0.5 s later by the expression "is" centered in the middle of the screen, and 1 s later by four comparisons: "cold," "heavy," "sweet," and "none of the options is correct" at the bottom. The position of the comparisons was balanced across trials. Feedback (i.e., CORRECT or WRONG) followed participants' responses.

Phase 5. Critical Test. Testing transformation of functions within the hierarchical relations. This phase started immediately after Phase 4. Participants read the following instructions: "The arrangement of the stimuli on the screen will now be different. Please, respond according to what you have learned throughout the procedure. Pay close attention to the response options across trials and select the MOST CORRECT one. Sometimes the computer will tell you whether your choice is correct or not." Feedback was never provided during test trials.

Transformation of functions was tested with two stimuli from the top or the most inclusive context of the hierarchies (i.e., X and Y), one stimulus from the middle level of the two-branch hierarchy (i.e., X.2), three stimuli from the lower level of both hierarchies (i.e., C1, C2 and D3), and one negative comparison stimulus (i.e.,

Table 2. Sequence of trials for the training of the middle (columns 1 to 3) and top (column 4) levels of both hierarchical categories.

TRAINING X.1	*TRAINING Y.1*	*Two 6-TRIAL BLOCKS*	*TRAINING X & Y*
A1/C1 [**SAM**-BEL] (2)	A3/C3 [**SAM**-BEL] (1)	*BLOCK 1: RANDOM (6)*	X/X.1 [SAM-**INC**] (1)
A1/X.1 [SAM-**BEL**] (2)	A3/Y.1 [SAM-**BEL**] (2)	X.1/INC [**A1**-A2-A3]	X/X.1 [SAM-DIF-**INC**-BEL] (2)
A1/B1 [**SAM**-BEL] (1)	A3/B3 [**SAM**-BEL] (1)	X.2/INC [B1-**B2**-B3]	X/X.2 [SAM-**INC**] (1)
B1/X.1 [SAM-DIF-**BEL**] (1)	B3/Y.1 [SAM-DIF-**BEL**] (1)	Y.1/INC [B1-B2-**B3**]	X/X.2 [SAM-DIF-**INC**-BEL] (2)
X.1/B1 [SAM-DIF-**INC**] (1)	Y.1/B3 [SAM-DIF-**INC**] (1)	B1/BEL[**X.1**-X.2-Y.1]	Y/Y.1 [SAM-**INC**] (1)
X.1/B1 [SAM-DIF-**INC**-BEL] (1)	Y.1/B3 [SAM-DIF-**INC**-BEL] (1)	B2/BEL[X.1-**X.2**-Y.1]	Y/Y.1 [SAM-DIF-**INC**-BEL] (2)
A1/D1 [**SAM**-DIF-INC-BEL] (1)	A3/D3 [**SAM**-DIF-INC-BEL] (1)	A3/BEL[X.1-X.2-**Y.1**]	X/INC [**X.1**-Y.1-M] (2)
A1/BEL[**X.1**-X.2-Y.1] (1)	A3/BEL[X.1-X.2-**Y.1**] (1)	*BLOCK 2: RANDOM (6)*	X/INC [**X.2**-Y.1-N] (2)
B1/BEL[**X.1**-X.2-Y.1] (1)	B3/BEL[X.1-X.2-**Y.1**] (1)	X.1/B1 [SAM-DIF-**INC**-BEL]	Y/INC [X.1-X.2-**Y.1**] (2)
X.1/INC [**A1**-A2-A3] (1)	Y.1/INC [A1-A2-**A3**] (1)	X.2/A2 [SAM-DIF-**INC**-BEL]	*6-TRIAL BLOCK (RANDOM)*
X.1/INC [**B1**-B2-B3] (1)	Y.1/INC [B1-B2-**B3**] (1)	Y.1/B3 [SAM-DIF-**INC**-BEL]	X/X.1 [SAM-DIF-**INC**-BEL]
TRAINING X.2		B1/X.1 [SAM-DIF-INC-**BEL**]	X/X.2 [SAM-DIF-**INC**-BEL]
A2/C2 [**SAM**-BEL] (1)		B2/X.2 [SAM-DIF-INC-**BEL**]	Y/Y.1 [SAM-DIF-**INC**-BEL]
A2/X.2 [SAM-**BEL**] (2)		A3/Y.1 [SAM-DIF-INC-**BEL**]	Y/INC [X.1-X.2-**Y.1**]
A2/B2 [**SAM**-BEL] (1)			X/INC [**X.1**-M-Y.1]
B2/X.2 [SAM-DIF-**BEL**] (1)			X/INC [N-**X.2**-Y.1]
X.2/B2 [SAM-DIF-**INC**] (1)			
X.2/B2 [SAM-DIF-**INC**-BEL] (1)			
A2/D2 [**SAM**-DIF-INC-BEL] (1)			
A2/BEL[X.1-**X.2**-Y.1] (1)			
B2/BEL[X.1-**X.2**-Y.1] (1)			
X.2/INC [A1-**A2**-A3] (1)			
X.2/INC [B1-**B2**-B3] (1)			

Note: Correct answers appear in bold. Figures in parenthesis indicate the number of correct trials (1 or 2) necessary to proceed to the next trial. SAM= Same relational cue; DIF= Different relational cue; INC= Includes relational cue; BEL= Belongs to relational cue.

M). The latter was used for experimental control purposes. Test trials were presented in MTS format in the following order across participants: Y, X, C1, M, X.2, D3, and C2. The stimulus to be tested served as the sample, and six response options served as comparisons. As in the previous phase, the expression "is" appeared in the middle of the screen between the sample and the comparisons. Comparisons for stimulus Y were (the correct response is in italics): *it is sweet, has a part that is sweet*, it is cold, has a part that is cold, has a part that is cold and a part that is heavy, none of the options is correct. Comparisons for stimulus X were: *has a part that is cold and a part that is heavy*, it is cold and heavy, it is cold and sweet, it is cold, has a part that is heavy and a part that is sweet, none of the options is correct. Comparisons for stimulus C1 were: *it is cold*, has a part that is cold, it is heavy, it is cold and heavy, it is sweet, none of the options is correct. Comparisons for stimulus M were: has a part that is cold and a part that is heavy, it is cold and heavy, it is cold and sweet, it is cold, has a part that is heavy and a part that is sweet, *none of the options is correct*. Comparisons for stimulus X.2 were: *it is heavy, has a part that is heavy*, it is sweet, has a part that is cold, has a part that is cold and a part that is heavy, none of the options is correct. Comparisons for stimulus D3 were: *it is sweet*, has a part that is sweet, it is cold and heavy, has a part that is heavy and a part that is sweet, has a part that is cold, none of the options is correct. And comparisons for C2 were: *it is heavy*, has a part that is heavy, it is sweet, it is cold and heavy, it is heavy and sweet, it is cold; none of the options is correct.

The criterion for passing the test was established at six correct responses out of the seven stimuli tested on the condition that the responses to the X and Y stimuli were among them. Both the selection of the stimuli to be tested and their order of presentation were based on the assumption that when a member of a hierarchy acquires a function, how this function transfers will depend on the specific relations established among the members of the hierarchy. In the present experiment, two hierarchies (with X and Y at the top) were established in a highly structured way: one (X) with two branches (X.1 and X.2) and the other one (Y) with only one branch (Y.1). Accordingly, the following effects were expected. First, the function acquired by X.1 (i.e., "is cold") should transfer down to A1, B1, C1, and D1 stimuli and up to X as an incidental feature. Second, the function acquired by C3 (i.e., "is sweet") should transfer not only to the other members of Class 3 (i.e., A3, B3, C3, and D3) but up to Y.1 (since Y.1 includes C3) and to Y (that includes Y.1 and all the members of Class 3). And third, the function acquired by D2 (i.e., "is heavy") should transfer in the same way as for C3. Given that X.1 was established as cold, and X.2 acquired heavy functions by derived means, both cold and heavy functions should transfer to X (i.e., "has a part that is cold and a part that is heavy"). One would expect that both functions then transfer back down to X.1 that would now also be heavy, and X.2 that would now also be cold. However, because X.1 and X.2 contain groups of elements in a relation of distinction due to the MTS training (those in Class 1 and Class 2, respectively), therefore a relation of distinction is derived between X.1 and X.2. The derived relation of distinction between X.1 and X.2 would stop the top-down transfer of functions (i.e., the cold function of X.1 should not transfer to X.2, A2, B2, C2 or D2; and the heavy function of D2 should not transfer to X.1, A1, B1, C1 or D1).

Two response options were deemed as correct for stimuli X.2 and Y ("it is heavy" or "has a part that is heavy," and "it is sweet" or "has a part that is sweet," respectively). This was because stimulus X.2 was trained to contain A2, B2 (both directly), C2 and D2 (both indirectly through derived relations) which were all established as SAME to each other in a previous phase of the experiment. Similarly, stimulus Y only contained one subcategory (Y.1) that contained equivalent stimuli (A3, B3, C3, and D3). To the extent that neither X.2 nor Y contained differing parts, response options "is" and "has a part that is…" could be taken as equivalent and both essentially correct. This also seemed reasonable because stimulus X.1, which did not contain different subcategories, was established as "is cold" and not as "has a part that is cold." However, in order to pass the test, participants had to respond to stimulus X (that was related to X.1 and X.2 subcategories) as having a part that is cold and a part that is heavy provided that X was formed by two different subcategories.

Participants who did not meet the testing criterion were presented with two 6-trial blocks for the retraining of the hierarchical relations, followed by a 6-trial block for the retraining of X.1, D2, and C3 functions (2 trials per stimulus). The test was then resumed. Participants were fully debriefed after completing the test.

RESULTS

All participants met the testing criterion except for P6 who was dismissed from further participation. The number of trials necessary to reach the criterion varied from 105 (P1) to 127 (P8) and the percentage of correct responses from 85.8 % (P8) to 100% (P1) (see Table 3, Phase 1).

All remaining participants, except for P3 who was dismissed from further participation, met the training criteria for the formation of three 4-member equivalence classes (see Table 3, Phase 2). The range of trials needed to complete the training and percentage of correct responses were, respectively, from 66 (P4) to 75 (P1 and P2) and from 88.8% (P8) to 95.4% (P4) (see Table 3, Phase 2). Equivalence classes were retested twice, at the beginning and at the end of Phase 3. All participants met the test criterion on the first attempt.

The six remaining participants met the training criterion. The number of trials necessary to reach the criterion varied from 82 (P7) to 96 (P1) and participants showed a range of correct responses from 93.8% (P4) to 100% (P7) (see Table 3, Phase 3). All the 6 participants achieved the criteria for the establishment of D2, C3, and X.1 functions.

In order to pass the Test for Transformation of Functions, participants had to respond correctly to stimulus X (i.e., "X has a part cold and a part heavy") and stimulus Y (i.e., "Y it is sweet" or "has a part that is sweet"), and to four of the remaining five

Table 3. Number of trials (and percentage of correct responses) to meet the training criterion during phases 1 to 3. Number of correct responses to the test of transformation of functions during Phase 5.

	Phase 1 Hierarchical cues		Phase 2 Bottom level		Phase 3 Middle and top level	Phase 5 Critical test	
	Training	Test	Training	Test	Training	1st attempt	2nd attempt
P1	105 (100%)	OK	75 (90.7%)	OK	96 (95.8 %)	7/7*	
P2	107 (98.1%)	OK	75 (89.3%)	OK	84 (97.6%)	6/7*	
P3	108 (97.2%)	OK	92 (90.2%)	NO			
P4	115 (94.8%)	OK	66 (95.4%)	OK	83 (93.8%)	7/7*	
P5	119 (91.6%)	OK	69 (91.3%)	OK	89 (97.8%)	3/7	3/7
P6	181 (71.8%)						
P7	120 (91.7%)	OK	69 (91.3%)	OK	82 (100%)	7/7*	
P8	127 (85.8%)	OK	72 (88.8%)	OK	90 (96.7 %)	5/7	7/7*

*= Participants who met the Critical Test criterion.

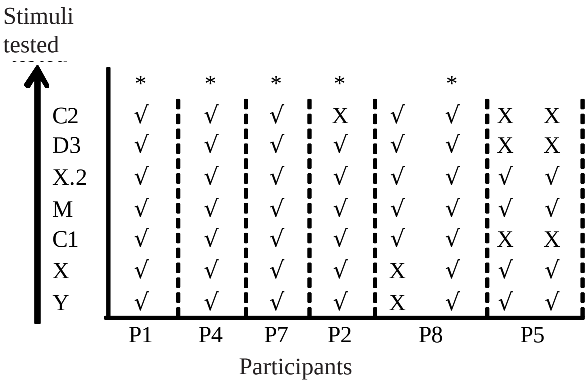

Figure 4. Participants' responses to the Critical Test of transformation of functions within hierarchical relations. Stimuli that were tested appear on the ordinate axis. The symbol √ indicates a correct answer. The symbol X indicates a wrong answer. The symbol * indicates that the participant passed the test.

stimuli at least. Five of the 6 participants who were exposed to this test passed it, four of them on their first attempt (P1, P2, P4, and P7) and one on the second attempt (P8, see Figure 4).

Discussion

The present study replicates and improves the findings reported in a preliminary study by Gil *et al*. (2012). Four stimuli were trained through MET as the relational cues INCLUDES, BELONGS TO, SAME, and DIFFERENT. Subsequently, two 3-level hierarchical networks were trained by using the relational cues previously established. Three different functions were then provided to three different stimuli in the hierarchical networks (i.e., X.1 is cold, D2 is heavy, and C3 is sweet). Finally, transformation of functions was tested with the two stimuli at the top or the most inclusive context of the hierarchies (i.e., X and Y), with an stimulus at the middle level of the two-branch hierarchy (i.e., X.2.), with three stimuli in the lower level of both hierarchies (i.e., C1, C2, and D3), and a negative comparison stimuli (i.e., M). Five of the six participants who made it to the Critical Test responded according to the arbitrary relations established among the stimuli. More specifically, they responded that D3 was sweet, by virtue of its combinatorial (or equivalence) relation with C3 that was directly established as sweet. They also responded correctly that X.2 was heavy (or had a part heavy) by virtue of its derived hierarchical relation with D2 that was directly established as heavy. Finally, they responded correctly that category X had a cold part and a heavy part, by virtue of the hierarchical relations with X.1 (directly established as cold) and X.2, the latter in a derived hierarchical relation with heavy D2.

As compared to Gil *et al*'s. (2012) findings, the present results present several advantages. First, in Gil *et al*. (2012), the hierarchical relations were trained in both directions (e.g., X includes X.2, and X.2 belongs to X) and consequently, derived relations were not clearly isolated. In the present experiment, however, the most inclusive context of the hierarchical relational networks was established in only one direction (e.g., X includes X.2). Consequently, the present findings constitute a more robust demonstration of the transformation of stimulus functions according to hierarchical relations.

The second way the present findings advance with respect to Gil *et al*. (2012) is that the response options in the present study isolate a more precise transformation of incidental or non-inclusive features of the stimuli in hierarchy X. In the previous study, the correct response when testing for the functions of X was "X is always cold and heavy." The very wording of the response option may be misleading in that it may turn incidental functions of each subcategory or member into defining features of the hierarchy. In the presente experiment, the word "always" was eliminated and the cue "part of" was added in the Critical Test to better isolate the transformation of functions from the lower to the higher level of the hierarchy. Specifically, the inclusion of the expression "part of" allowed responding to stimulus X as in the animals example (i.e., some animals are scary and some are friendly).

The participants' performance during the Critical Test seems to be functionally equivalent to the example presented in the Introduction. That is, in the same way that the child chooses a parrot because he likes birds, our participants derived that C1 was cold because it was a member of X.1, which was previously established as cold. This shows the conditions under which the functions might transfer top-down to subordinate stimuli. Likewise, same as the boy thought that there are scary and friendly animals, our participants derived that X was cold on X.1 side, and heavy on X.2 side (or both, cold and heavy). This shows some of the conditions under which functions might transfer bottom-up from subordinate to superordinate stimuli.

Some limitations of the present study are worth noting. Transformation of functions was tested with seven stimuli and the test included seven trials, one per stimulus. The test structure itself might have influenced the likelihood that participants produced correct responses randomly. However the strict testing criterion (six correct responses out of seven trials) and the elevated number of response options per trial were intended to rule out such possibility. Still, future studies may consider increasing the number of testing trials per stimuli. In addiction, future studies may consider replacing the response options "it is…" and "it has a part that is…" with the stimuli previously trained as arbitrary relational cues (i.e., the relational cue SAME instead of "it is…," and the relational cue INCLUDES instead of "it has a part that is…"). This way, we could minimize the influence of the pre-experimental functions of the words used during the Critical Test. Finally, one important limitation of this series of experiments relates to the type of stimuli used during the training of the relational cues INCLUDES and BELONGS TO. The type of trials and the stimuli used through training sets were mostly based on pre-experimental functions (e.g., the picture of a face and the pictures of a nose, a mouth, and an eye) so as to facilitate that the arbitrary to-be cues acquired the intended inclusion/belonging functions. This might have obscured the isolation of the relevant function to establish the hierarchical cues.

As it has been pointed out (Slattery & Stewart, 2014), research on this difficult behavior is still far from providing a clean procedure for the derived transformation of hierarchical framing. As we already have indicated noted, the pattern type of hierarchical relations analyzed in this study is only one among many functionally different hierarchical categories that could be studied. Still we believe the efforts made with this experimental series may well be considered as steps in the right direction, a direction in which many procedures need to be improved and many questions remain unanswered yet. For instance, further research might analyze how transformation of functions occurs when functions are contextually provided to the top or the most inclusive context of a hierarchy that included more than one branch. In our example, if the father tells his children that we have to respect the animals, this function would transfer top-down to all animals. Although the child would still be scared of reptiles and preferred birds, he would respect both of them. Additional studies might also analyze how the transformation of functions takes place when the members of the hierarchy are related through relational frames other than distinction and sameness. For instance, imagine that Maria, a teacher in a catholic school, tells her friend Fernando: "Today is a happy day for me. I'm teaching class A children. They are such hard workers and so respectful! They are just the opposite of my class B students." Fernando can automatically assume that children from class B are lazy and disrespectful due to their opposition relation with class A. If Fernando had to describe the students attending the school where Maria works, he would respond that although they all represent the catholic values of the school, one part of the children are hard working and respectful, while the other part are lazy and disrespectful.

In conclusion, the present findings add on previous evidence on the transformation of functions through hierarchical relations. Indeed, they constitute first steps towards a functional analysis of one example in hierarchical responding, a key aspect of human cognition. With respect to their practical implications, although the present study was not intended to be an analogue of the establishment of hierarchical responding in populations in which it is very weak or completely absent, our procedures could be refined to become a starting point for the design of protocols aiming at such a goal, as it has been the case with other types of relational responding (e.g., Barnes-Holmes, Barnes-Holmes, & Smeets, 2004; Berens & Hayes, 2007; Cassidy, Roche & Hayes, 2011; Luciano, Gómez, & Rodríguez, 2007; Luciano *et al.*, 2009, Stewart, Barnes-Holmes & Weil, 2009).

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