International Journal of Comparative Psychology

Title

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Journal

International Journal of Comparative Psychology, 30(0)

ISSN

0889-3675

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Publication Date

2017

DOI

10.46867/ijcp.2017.30.01.03

INTERNATIONAL
JOURNAL OF COMPARATIVE PSYCHOLOGY

2017, 30
Catherine Plowright
Special Issue Editor
Peer-reviewed

Relation between Exclusion and Stimulus Equivalence Class Formation in Auditory-Visual and Visual-Visual Matching in Preschoolers

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Fundación Universitaria Konrad Lorenz

The hypothesis that exclusion performance is a prerequisite for the stimulus equivalence class formation was assessed in preschoolers of about 5 years of age. In Experiment 1, two groups of children were trained in a set of conditional discriminations in a two-choice matching to sample format, Group 1 in an auditory-visual modality baseline, and Group 2 in a visual-visual modality baseline. Exclusion test trials included an undefined (not previously related) comparison stimulus, and a defined (i.e., related in the baseline) comparison stimulus, in the presence of an undefined sample stimulus. Selection of the undefined comparison was recorded as a correct response. Stimulus equivalence class formation was assessed by way of symmetry and transitivity test trials. Experiment 2 replicated the design of the first experiment, with the difference that exclusion was assessed independently and with a different baseline from symmetry and transitivity. Exclusion scores were higher for the auditory-visual groups than the visual-visual groups. In both modalities symmetry scores were superior to those in transitivity. Symmetry showed independence from the exclusion performance, but transitivity was presumably dependent on it in the auditory-visual modality.

Conceptualization and categorization have been considered central aspects of our cognition and the structure of our knowledge (Cohen & Lefebvre, 2005). Typically for cognitive sciences, concepts “represent our knowledge of classes of entities (categories), which we then use to understand new things.” (Murphy & Hoffman, 2012, p. 151). Categorization is seen as “the problem of sorting them [things] correctly, depending on the demands of situation.” (Harnad, 2005, p. 28). Contrary to cognitive scientists, behavior analysts do not deal with *concepts* and *categories* as technical terms (Palmer, 2002, p. 605), and they include the phenomena related to conceptualization and categorization within the stimulus control of the behavior given the contingency of reinforcement (e.g., McIlvane, 2013; Pearce, 1994). As it is posed by Zentall, Galizio, and Critchfield (2002):

> …categorization may be said to incorporate a pattern of systematic differential responding to classes of nonidentical, though potentially discriminable, stimuli… A category is a class of stimuli that occasion common responses in a given context. Such classes include stimuli involved in an explicit learning history plus, potentially, novel stimuli to which the fruits of this history may transfer (p. 238).

Reinforcement contingencies can be arranged in such a way that they generate differential responding according to different properties of the stimuli (for reviews, see McIlvane, 2013; Urcuioli, 2006, 2013; Zentall, 2006; Zentall, Wasserman, Lazareva, Thompson, & Rattermann, 2008; Zentall, Wasserman, & Urcuioli, 2014). Differential responding could be grounded on the physical resemblance among stimuli (e.g., Huber & Aust, 2006; Jitsumori, 2006). For example, in the classic study of Herrnstein and Loveland (1964), pigeons differentially responded to photographs that show human beings from those which do not. Differential responding on human and not human subjects also could be grounded on the relational properties of the stimuli; for instance, the same/different relation (e.g., Cook, 2002; Wright & Katz, 2007). Comparative psychologists

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have also been interested in the partition among stimuli grounded not on their physical similarity, but in their shared functional properties for the establishment of arbitrary functional stimulus classes that control differential responding in the subjects. For example, pigeons may be trained to give the same selection response R1 in the presence of the dissimilar stimuli A or B. Then, they are trained to give the response R2 in the presence of the stimulus A, and subsequently, stimulus B will control R2, despite their lack of an explicit training (e.g., Urcuioli, Zentall, & DeMarse, 1995; Wasserman, DeVolder, & Coppage, 1992).

A phenomenon associated with that of functional classes which has been widely studied in the field of the Experimental Analysis of Behavior is the formation of stimulus equivalence classes, or formal equivalence (Zentall et al., 2008). Stimulus equivalence is frequently evidenced through the training and testing of some arbitrary conditional discriminations. A conditional discrimination is typically trained and tested with the matching to sample arrangement, in which a subject has to make a selection response among B1, B2, and B3 stimuli, but the selection of B1 stimulus is only reinforced in the presence of the sample stimulus A1. In the same way, the selections of stimulus B2 and B3 are made conditional on the presence of A2 and A3 sample stimuli. The formation of stimulus equivalence classes is evidenced when a subject displays the emergence of performances that accomplish the properties of a mathematical equivalence relation: reflexivity, symmetry, and transitivity on probe trials without feedback (Sidman & Tailby, 1982). Reflexivity consists of the relation between each stimulus and itself, and it is tested when the selection of A1 stimulus is conditional on the presence of the same stimulus as a sample. Symmetry is evident when sample-S+ trained relations are reversed, and in accordance with the previous example, a subject selects the A2 comparison stimulus in the presence of B2 as a sample. Finally, transitivity consists of the emergence of relations among stimuli that were not directly related in training, but were related through another common stimulus; thus if the selection of C1 in the presence of A1 is also trained, then the selection of the B1 comparison stimulus will be controlled by the presence of the C1 sample stimulus.

Accurate performances in the test trials imply that for a subject the stimulus equivalence classes A1B1C1, A2B2C2, and A3B3C3 have been formed, which, despite their lack of physical resemblance involve differential responding among them and functional equivalence within them. Thus, if a new stimulus function is trained with stimulus A1, then this function transfers itself to stimuli B1 and C1 without any additional training. Among the effects that have been found in stimuli thus related by equivalence are: transfer of conditional reinforcement or punishment function (Hayes, Devany, Kohlenberg, Brownstein, & Shelby, 1987; Hayes, Kohlenberg, & Hayes, 1991); transfer of contextual control, like the control on the membership of some stimuli to some classes (Kohlenberg, Hayes, & Hayes, 1991; Lynch & Green, 1991); transfer of respondent elicitation and extinction (Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Roche & Barnes, 1997), and of self-discriminative responses, such as “give none, one, or two responses” (Dymond & Barnes, 1994, 1995), among others.

The formation of equivalence classes has been widely evidenced in normally developing human adults (e.g., Arntzen & Hansen, 2011; Ferro & Valero, 2008), normally developing human children (e.g., Arntzen & Nikolaisen, 2011; Sidman, Rauzin et al., 1982), and in humans with intellectual disabilities (e.g., Carr, Wilkinson, Blackman, & McIlvane, 2000; O’Donnell & Saunders, 2003; Sidman, 1971; Sidman & Cresson, 1973). However, several attempts to replicate it in non-human animals have failed (e.g., Dugdale & Lowe, 2000; Lipkens, Kop, & Matthijs, 1988; Sidman, Rauzin et al., 1982). Clear evidence of symmetry in pigeons has been reported, but only in a successive (go-no go) matching-to-sample task, and with explicit reflexivity training (Frank & Wasserman, 2005; Urcuioli, 2008). Transitivity has also been reported in a chimpanzee, but only after the explicit training and generalization of symmetry responding (Yamamoto & Asano, 1995). A California sea lion showed generalized reflexivity, symmetry, and transitivity after the explicit training of these relations (Schusterman & Kastak, 1993). However, to the best of our knowledge, no study has shown the establishment of equivalence relations in the same conditions as observed in human beings (McIlvane, 2014). Accordingly, some authors have assumed that equivalence class formation is a phenomenon that encompasses the symbolic aspects of human behavior, and particularly those related to the employment of natural languages (e.g., Sidman, 1994; Barnes-Holmes, Barnes-Holmes, Smeets, Cullinan, & Leader, 2004). Murray Sidman, the pioneer of the contemporary study in stimulus equivalence, has argued that the words and their referents are in an equivalence relation, and the transfer of function between them accounts for the capability of language to modify the behavior without direct exposure to contingencies (Sidman, 1994).

A second phenomenon associated with functional equivalence among arbitrarily related stimuli is that of exclusion (Zentall et al., 2008). Exclusion responding involves the selection of an undefined, or previously unrelated comparison stimulus, rather than another defined, or previously related, stimulus in the presence of an undefined sample stimulus (Dixon, 1977; McIlvane et al., 1987; McIlvane, Kledaras, Lowry, & Stoddard, 1992). For example, in the study of Dixon (1977), participants with intellectual disabilities were trained to select the written Greek letter Π rather than Θ after hearing the instruction "Point to Pi." Later, in a test trial, they selected Θ rather than Π after hearing "Point to Theta," even though this relation had not been trained before. In the field of the Experimental Analysis of Behavior, this phenomenon is frequently called emergent symbolic mapping, because new arbitrary relations between stimuli happen without explicit training (e.g., McIlvane, 2013; Wilkinson, Dube, & McIlvane, 1998; Wilkinson & McIlvane, 1997).

In the field of developmental psychology, this phenomenon has been associated with the vocabulary spurt in toddlers around 18 months of age, and is called fast mapping (e.g., Capone & McGregor, 2005; Heibeck & Markman, 1987; Spencer & Schuele, 2012). For example, in the study of Halberda (2003), infants of 17 months of age look at a novel object more than a known object after they hear the instruction "Look at that…", including the novel word "dax." Exclusion performance has also been reported in a variety of mammals such as primates (Beran, 2010; Beran & Washburn, 2002; Call, 2006; de Faria, Bemerguy, da Silva, de Faria, & McIlvane, 2010; Kojima, Izumi, & Ceugniet, 2003; Tomonaga, 1993), sea lions (Kastak & Schusterman, 2002), dogs (Aust, Range, Steurer, & Huber, 2008; Kaminski, Call, & Fischer, 2004; Zaine, Domeniconi & Costa, 2014), and rodents (Felipe de Souza & Schmidt, 2014).

Some authors have suggested a relation between exclusion responding and equivalence class formation (e.g., Wilkinson, Rosenquist, & McIlvane, 2009), but little research has been devoted to establish the nature of this relation. It has been shown that control by exclusion can reverse the membership of preexisting classes (Meehan, 1995), and that stimuli related by exclusion might display properties in accordance with the equivalence relations (Lipkens, Hayes, & Hayes, 1993, Exp. 4; Wilkinson et al., 2009), and can be integrated to preexistent classes (Kastak & Schusterman, 2002), or extend the number of existent classes (Plazas & Villamil, 2017). In the latter study, it was found that exclusion responding could account for correct responses in transitivity test trials among stimuli that were not related among them by explicit training but they did by exclusion.

Exclusion performance has been readily observed in non-human animals and toddlers, but stimulus equivalence class formation has not been clearly evidenced in non-humans; however, some evidence suggests the presumed participation of exclusion in the emergence of transitivity (Plazas & Villamil, 2017). In consequence, we sought to establish if exclusion performance is a prerequisite to the formation of equivalence classes in preschoolers. If this is true, no cases of scores in symmetry or transitivity higher than those in exclusion would be observed.

A relevant variable associated to the acquisition of conditional discriminations and the formation of equivalence relations in children is the matching modality. It has been found that auditory-visual conditional discriminations are acquired faster than visual-visual matching, and the establishment of equivalence relation is more likely with the former in adults with developmental disabilities (Green, 1990), and children (Smeets & Barnes-Holmes, 2005). In Experiment 1, a within-subject comparison between exclusion performance and equivalence class formation was conducted, and also a between-subjects comparison of these performances was made, regarding the acquisition of an auditory-visual or visual-visual baseline repertory.

Experiment 1

Method

Participants. Twenty-two children, aged 4 to 6 years old (*M* = 4.954, *SD* = 0.375) participated in this experiment. They were recruited in two private kindergarten schools. One of the parents of each child authorized the participation by signing an informed consent form, and before the start of the experimental session each child had to complete an informed assent form. At the end of the experimental session each child received a sheet of stickers. Participants were randomly assigned to two groups.

Setting, apparatus and stimuli. The experimental session was carried out in a room inside each of the schools. Each child had to sit in front of a 15.6 inch polychromatic screen laptop with a mouse. A program designed in Visual Basic controlled the trials' presentation, and recorded the responses of the children. Figure 1 shows the stimuli employed in this experiment. For Group 1, the baseline stimuli consisted of two pseudo-words in Spanish: "TROMA" (A1) and "ZIFE" (A2), and four visual symbols (B1, B2, C1, and C2). Exclusion test trials included other four pseudo-words "FISO" (N1), "LICA" (N3), "BIMA" (N5), and "ONTO" (N7) as undefined stimuli, and four visual symbols (N2, N4, N6, and N8). For Group 2, the baseline stimuli were two hues: *yellow* (G1) and *purple* (G2), and the same visual symbols as in Group 1. The same visual symbols for Group 1 were employed as undefined stimuli in the exclusion test trials, plus another four (N9-N12). The silhouettes of a mountain and a rock-climber designed in cardboard were employed to indicate progress through the phases. When the climber reached the top, the experiment ended and the child received the sheet of stickers.

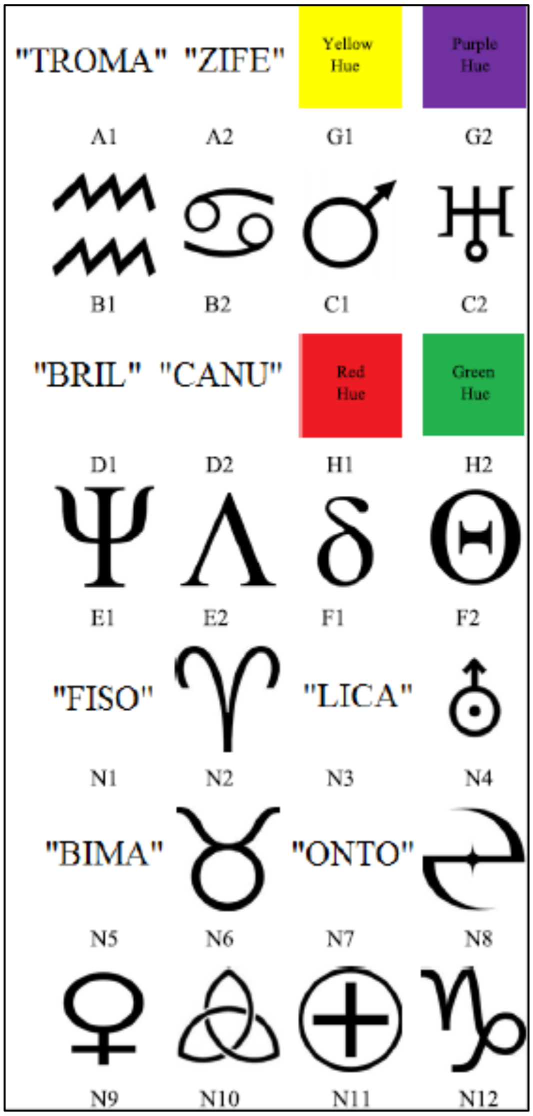

Figure 1. **Stimulus set employed in the experiments**. In Experiment 1 stimuli A1 and A2 were employed as auditory samples in the baseline trials for Group 1, whilst G1 and G2 stimuli were visual samples in the baseline trials for Group 2. Stimuli B and C were comparison stimuli for the baseline trials, and the sample and comparison stimulus in the transitivity trials. Stimuli N were undefined sample and comparison stimuli in the exclusion test trials. Stimuli D, E, H, and F conform the baseline and testing relations, along with N stimulus, for the assessment of exclusion performance in Experiment 2; whilst stimuli A, G, B, and C belong to the baseline and testing trials for the assessing of the equivalence class formation in this experiment.

Design and procedure. Participants were divided into two groups of 11 participants each. Groups differed in the matching modality of the baseline trials. Participants from Group 1 were trained with auditory-visual matching trials, while Group 2 children were trained with visual-visual matching trials. The exclusion test trials were in the same modality as the respective baseline trials for both groups. Symmetry test trials were presented for Group 1 in a visual-auditory modality, and for Group 2 in a visual-visual modality. For both groups, transitivity test trials were presented in a visual-visual modality.

All training and testing trials were presented in a simultaneous two-choice matching to sample format. Each trial started with the appearance of the sample stimulus, in the upper-middle position of the screen. When the trial was in the auditory-visual modality, the sample stimulus was an icon that the child had to click on so that the pseudo-word was reproduced, and then the comparison stimuli appeared in a row below the icon. When the trial was visual-visual, the child had to do an observing response on the sample stimulus, by clicking on it, for the comparison stimuli to appear. The child had to select one of the comparison stimuli by clicking on it. If the trial was one of training, participants received feedback: when the response was correct, the stimuli were removed from the screen and a *smiley face* appeared, accompanied by a *ta-da* tone; when the response was incorrect, the screen became blank and a *chord* tone was played. Then, a 1.5 s. inter-trial interval started. In testing trials, only the inter-trial interval followed the response. In the case of the symmetry test trials for Group 1, the sample stimulus was one of the four visual stimuli that appeared as a comparison stimulus in the training trials, while the comparison stimuli were the written words "TROMA" and "ZIFE", but when the child passed the cursor of the mouse over one of them the respective spoken word sounded.

Before the start of the first phase, the children received the following spoken instructions (translated from Spanish):

> "Hi, now we are going to play in the computer. What you have to do is to choose one of the drawings with the mouse. When you do it right, a smiley face will appear, as well as a sound telling you that you are doing well. Your goal will be to go until the end of the game. If you can finish the entire game, you'll get a sheet of stickers. Good luck!"

The experimental procedure for both groups consisted of five phases. The baseline phase used a one-to-many training structure. Table 1 shows the configuration of the baseline and testing trial types employed for each group. For each block of trials in each phase the trials appeared in a random order, and the location of the comparison stimuli was randomly assigned. In Phase 1, children in Group 1 were trained in the A→B relations, while children in Group 2 were trained in the G→B relations. In Phase 2, Group 1 was trained in the A→C relations, and Group 2 in the G→C relations. Phases 1 and 2 consisted of blocks of 10 trials (each trial type was presented twice) and a mastery criterion of 100% was required to advance to the next phase. Phase 3 presented the intermixed training trials of the two previous phases, in blocks of 16 trials (each trial type four times), with a mastery criterion of 94% (15/16 correct responses). Throughout the first three phases responses to each of the trials were followed by feedback. Phase 4 consisted of a single block of eight trials (each trial type twice), with a mastery criterion of 100%, but without any feedback, to prepare children for the testing phase. If a child made at least one error in Phase 4, then he/she was returned to Phase 3. Phase 5 consisted of 24 trials: 12 baseline trials, four exclusion test trials, four symmetry test trials, and four transitivity test trials (see Table 1). None of the trials were followed by feedback.

Table 1

Configuration of Baseline and Test Trials for Each Group in Experiment 1

Type of trials	Group 1	Group 2
Baseline	A1-B1/B2	G1-B1/B2
	A2-B2/B1	G2-B2/B1
	A1-C1/C2	G1-C1/C2
	A2-C2/C1	G2-C2/C1
Exclusion	N1-N2/B1	N9-N6/B1
	N3-N4/B2	N10-N8/B2
	N5-N6/C1	N11-N2/C1
	N7-N8/C2	N12-N4/C2
Symmetry	B1-A1/A2	B1-G1/G2
	B2-A2/A1	B2-G2/G1
	C1-A1/A2	C1-G1/G2
	C2-A2/A1	C2-G2/G1
Transitivity	B1-C1/C2	B1-C1/C2
	B2-C2/C1	B2-C2/C1
	C1-B1/B2	C1-B1/B2
	C2-B2/B1	C2-B2/B1

Note. Each trial type is specified in this way: sample-S+/S- .

Results

Table 2 shows the range, mean, and standard deviation of the number of blocks required by participants from both groups to meet the criterion in Phases 1 to 4. Employing the Mann-Whitney U test, no statistically significant difference was found between them, regarding the number of blocks employed in any of the training phases. In Phase 5 the maintenance of the baseline performance was high for both groups: The number of correct responses for participants from the auditory-visual group ranged between 8 and 12 (*M* = 11.0 *SD* = 1.18) while for participants from the visual-visual group it ranged between 11 and 12 correct responses (*M* = 11.72, *SD* = 0.47). No statistically significant difference was found between both groups in these trials.

Table 2

Descriptive Statistics for the Number of Blocks Required to Reach the Criterion in the Training Phases in Experiment 1

	Group 1			Group 2		
	Range	*M*	*SD*	Range	*M*	*SD*
Phase 1	1-3	2.09	0.70	2-9	3.18	2.04
Phase 2	1-4	2.00	0.89	1-3	2	0.77
Phase 3	1-5	1.90	1.37	1-3	1.27	0.65
Phase 4	1-2	1.18	0.40	1-2	1.09	0.30

Table 3 shows the number of correct responses in the test trials by participant in Groups 1 and 2. For the auditory-visual group, all participants showed perfect performance in exclusion test trials. In no case was the score in transitivity trials accompanied by lower scores in exclusion or symmetry trials, and no score in symmetry trials was accompanied by lower scores in exclusion trials. In the visual-visual group, some participants had symmetry scores higher than exclusion scores, but no participant had transitivity scores higher than those of the symmetry or exclusion performance, with the notable exception of participant 15, who did not make any correct responses in the exclusion trials.

In the auditory-visual group, a Wilcoxon Signed-Ranks Test indicated that the exclusion ranks were statistically significantly higher than those in symmetry, $Z = -2.121$, $p = 0.034$, and transitivity, $Z = -2.831$, $p = 0.005$, and the symmetry ranks were higher than those in transitivity, $Z = -2.913$, $p = 0.004$. In the visual-visual group, only the symmetry ranks were statistically significantly higher than the transitivity ranks, $Z = -2.558$, $p = 0.011$. Figure 2 shows the mean of correct responses of participants from both groups in the test trials of Phase 5. Participants from the auditory-visual group had higher scores in the exclusion test trials (Mean Rank = 14.000) than participants from the visual-visual group (Mean Rank = 9.000), $U = 33.000$, $Z = -2.472$, $p = 0.013$. However, no statistically significant differences were found in the number of correct responses in the symmetry and transitivity trials between both groups.

Table 3

Number of Correct Responses in Test Trials by Participant in Experiment 1

	Participant	Exclusion	Symmetry	Transitivity
Group 1	1	4	4	4
	2	4	3	1
	3	4	3	2
	4	4	4	3
	5	4	4	3
	6	4	3	2
	7	4	3	0
	8	4	4	3
	9	4	4	3
	10	4	4	1
	11	4	2	1
Group 2	12	4	4	4
	13	4	4	4
	14	4	4	3
	15	0	4	3
	16	3	4	2
	17	4	4	1
	18	3	3	1
	19	4	3	3
	20	4	3	2
	21	3	4	3
	22	3	4	1

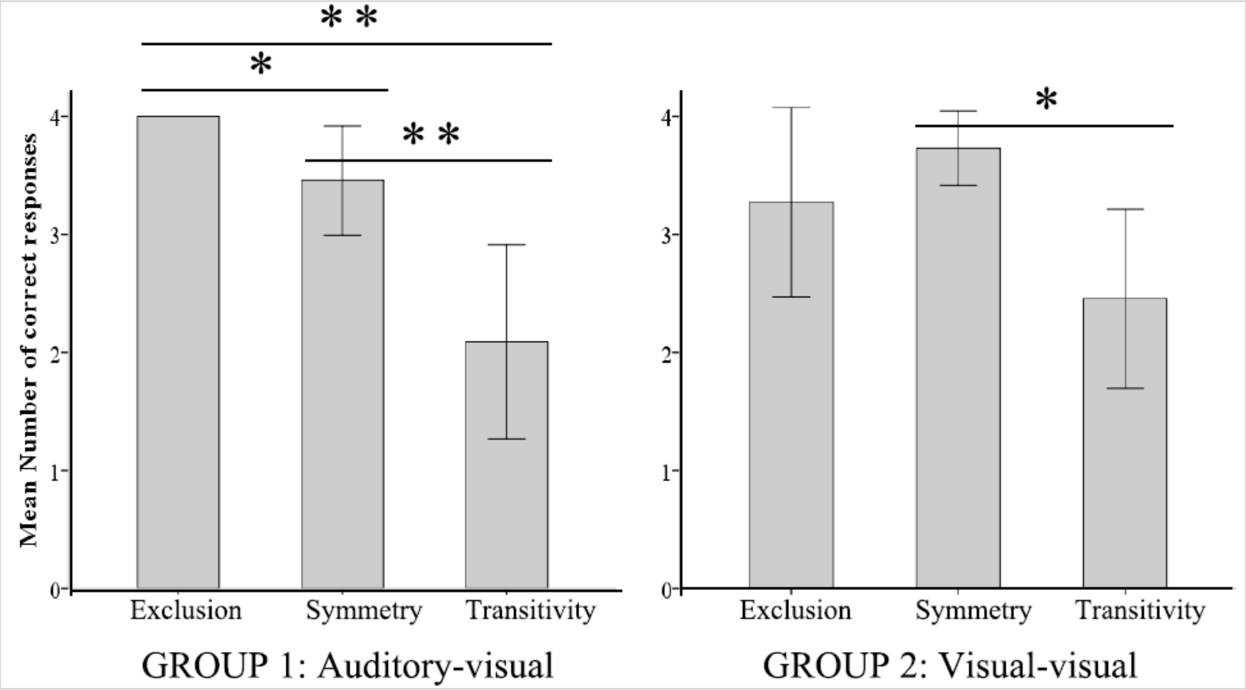

Figure 2. **Mean number of correct responses in test trials for Groups 1 and 2**. Confidence intervals of error bars are 95%. Asterisks indicate significant differences: * $p \leq 0.05$, ** $p \leq 0.01$. Participants of Group 1, trained with an auditory-visual baseline, showed a perfect exclusion performance with lower symmetry and even lower transitivity scores. Participants of Group 2, who had a visual-visual baseline, showed a symmetry performance higher than transitivity and exclusion performance lower than those of Group 1.

Discussion

If equivalence class formation is defined as accurate performance (4/4 correct responses) in the symmetry and transitivity test trials, most participants of both groups did not established equivalence relations. Although symmetry scores were in general high, transitivity scores were very variable. In contrast, scores in exclusion were very high in both groups. Although performance in exclusion tests was in general higher than transitivity, its relation with symmetry depended on the sensorial modality of the baseline trials. Exclusion performance was higher than symmetry only in the auditory-visual matching baseline group. Results seem to show an apparent independence of the symmetry from the exclusion and transitivity performance. On the contrary, transitivity seems to depend on both symmetry and exclusion, if we exclude the case of participant 15. The superiority of exclusion accuracy in the auditory-visual modality over the visual-visual modality might be related to the earlier skills associated with fast-mapping in the learning of the first vocabulary, as has been reported in many studies in the field of developmental psychology (e.g., Brady & Goodman, 2014; Halberda, 2003; Markman, Wasow, & Hansen, 2003).

Although there were no statistically significant differences across groups in the scores for symmetry and transitivity test trials, these were slightly higher for the visual-visual group. These results conflict with those from studies showing a higher likelihood of establishing equivalence relations in an auditory-visual modality than in a visual-visual one (Green, 1990; Smeets & Barnes-Holmes, 2005). It is possible that the introduction of exclusion test trials in the same phase as, and intermixed with, the trials that tested for the symmetry and transitivity relations might have affected in some way the performance in the latter ones, conceivably decreasing their accuracy given that several tasks were introduced in the same phase. To evaluate this possibility, a second experiment was conducted in which exclusion responding and equivalence class formation were assessed independently.

Experiment 2

Method

Participants. Twenty children, aged 4 to 6 years old, (*M* = 5.000, *SD* = 0.458) were the participants, and they were recruited in the same kindergartens. Their participation had the same conditions of participation and reward as those of participants from Experiment 1. They were randomly assigned to two groups.

Setting, apparatus, and stimuli. This experiment was carried out in the same place and with the same equipment as Experiment 1. The auditory pseudo-words: D1: "BRIL" and D2: "CANU", as well as the figurative stimuli E1, E2, F1, and F2, and the red (H1) and green (H2) hues were included in this experiment. These additional stimuli were employed for the training and assessment of exclusion responding accuracy (Phases 1 to 5). Figure 1 shows these stimuli. The stimuli used in Experiment 1 were used in this experiment as well, for the training of the baseline and the assessment of equivalence class formation (Phases 6 to 10).

Design and procedure. In this experiment the assessment of the exclusion and the equivalence class formation were separated. There were also two groups, one trained and assessed in the auditory-visual modality (Group 3) and other in the visual-visual modality (Group 4). The structure of the trials and the instructions were similar to those of Experiment 1. The experimental procedure for both groups consisted of 10 phases. Table 4 shows the configuration of the training and testing trials for both groups. In Phase 1, participants of Group 3 were trained in the relations D→E, and participants in Group 4 were trained in the relations H→E. In Phase 2, participants from Group 3 were trained in the relations D→F, and participants of the Group 4 were trained in the H→F relations. These phases had blocks of 10 trials and a mastery criterion of 100%. In Phase 3 the training trials of the first two phases were intermixed, and presented in blocks of 16 trials, with a mastery criterion of 94%. Until this phase all responses received feedback. Phase 4 presented the baseline trials in a single block of eight trials, without feedback, and with a mastery criterion of 100%. If a participant did not achieve the criterion, the participant was returned to the Phase 3. Phase 5 consisted of eight baseline trials, and four exclusion trials. In the exclusion trials, stimuli N were employed as undefined stimuli, while stimuli E and F were defined stimuli. Phases 6 to 9 developed the baseline performance for the assessment of equivalence class formation, in a similar way as in Phases 1 to 4 for the groups of the Experiment 1. Phase 10 consisted of twelve baseline trials, four symmetry, and four transitivity trials (see Table 4).

Results and Discussion

Table 5 shows the descriptive statistics corresponding to the number of blocks required by participants of Groups 3 and 4 in the phases of acquisition of the baseline for the assessment of the exclusion performance (Phases 1 to 4). In Phase 3 participants in the auditory-visual group required fewer blocks (Mean Rank = 7.850) than did participants in the visual-visual group (Mean Rank = 13.150), *U* = 23.500, *p* = 0.021. No statistically significant differences were found in the number of blocks required in any other phases. The maintenance of baseline accuracy in Phase 5 was high for the auditory-visual group, *M* = 7.700, *SD* = 0.458, and the visual-visual group, *M* = 7.800, *SD* = 0.421, and no difference between them was found. Figure 3 shows the mean number of correct responses in the exclusion performance for both groups, and Table 6 shows the individual scores in these test trials. Participants from the auditory-visual group showed a higher exclusion performance (Mean Rank = 12.600) than participants from the visual-visual group (Mean Rank = 8.400), *U* = 29.000, *p* = 0.049.

Table 4

Configuration of Baseline and Test Trials for Each Group in Experiment 2

Type of trials	Group 3	Group 4
Baseline Phases 1 to 5	D1-E1/E2 D2-E2/E1 D1-F1/F2 D2-F2/F1	H1-E1/E2 H2-E2/E1 H1-F1/F2 H2-F2/F1
Exclusion	N1-N2/E1 N3-N4/E2 N5-N6/F1 N7-N8/F2	N9-N6/E1 N10-N8/E2 N11-N2/F1 N12-N4/F2
Baseline Phases 6 to 10	A1-B1/B2 A2-B2/B1 A1-C1/C2 A2-C2/C1	G1-B1/B2 G2-B2/B1 G1-C1/C2 G2-C2/C1
Symmetry	B1-A1/A2 B2-A2/A1 C1-A1/A2 C2-A2/A1	B1-G1/G2 B2-G2/G1 C1-G1/G2 C2-G2/G1
Transitivity	B1-C1/C2 B2-C2/C1 C1-B1/B2 C2-B2/B1	B1-C1/C2 B2-C2/C1 C1-B1/B2 C2-B2/B1

Note. Each trial type is specified as in Table 1.

Table 5

Descriptive Statistics for the Number of Blocks Required to Meet the Criterion in the Training Phases in Experiment 2

		Group 3			Group 4		
		Range	*M*	*SD*	Range	*M*	*SD*
Baseline for exclusion assessment	Phase 1	1-4	2.3	0.78	1-4	2.3	0.82
	Phase 2	1-2	1.7	0.46	1-2	1.7	0.48
	Phase 3	1-4	1.3	0.90	1-3	1.8	0.63
	Phase 4	1-2	1.1	0.30	1-2	1.1	0.31
Baseline for equivalence assessment	Phase 6	1-3	1.7	0.64	1-5	2.2	1.13
	Phase 7	1-2	1.5	0.50	2-3	2.2	0.42
	Phase 8	1-4	1.7	1.00	1-3	1.3	0.67
	Phase 9	1.2	1.1	0.30	1.2	1.1	0.32

Table 5 also shows the descriptive statistics for the number of blocks needed in the phases for the acquisition of the baseline performance for the assessment of equivalence class formation (Phases 6 to 9). In these phases there were no differences between both groups in the number of blocks required, with the exception of Phase 7, in which participants from the auditory-visual group needed less blocks (Mean Rank = 7.500) than participants from the visual-visual group (Mean Rank = 13.500), *U* = 20.000, *p* = 0.007. Table 6 shows the individual scores of the number of correct responses of participants from both groups in symmetry and transitivity test trials, and Figure 3 shows the mean scores by groups in these tests. In the auditory-visual group, no transitivity score was accompanied by lower scores in symmetry or exclusion, and no symmetry scores were preceded by lower scores in exclusion, with the exception of participant 25. In the visual-visual group, none of the participants had transitivity scores higher than symmetry and exclusion scores, with the notable exception of participant 39, but some participants displayed symmetry scores higher than those in exclusion trials.

In the symmetry test trials, participants from visual-visual group had higher scores (Mean Rank = 12.600) than participants from the auditory-visual group (Mean Rank = 8.400), U = 29.000, Z = -1.970, *p* = 0.049. No significant difference was found for the transitivity test trials. In the auditory-visual group, the Wilcoxon Signed-Ranks Test indicated that the exclusion ranks were significantly higher than the ranks of the transitivity score, *Z* = -2.827, *p* = 0.005, and the symmetry ranks were also higher than the transitivity ranks, *Z* = -2.539, *p* = 0.011. For the visual-visual group, the symmetry ranks were significantly higher than the ranks for the transitivity performance, Z = -2.379, *p* = 0.017.

Table 6

Number of Correct Responses in Test Trials by Participant in Experiment 2

	Participant	Exclusion	Symmetry	Transitivity
Group 3	23	4	4	2
	24	4	4	2
	25	3	4	1
	26	4	4	1
	27	4	3	2
	28	4	3	3
	29	4	3	3
	30	4	2	1
	31	4	2	0
	32	4	4	0
Group 4	33	4	4	0
	34	4	4	4
	35	4	4	1
	36	3	4	3
	37	3	3	2
	38	3	4	2
	39	1	4	4
	40	4	4	2
	41	2	4	1
	42	4	4	4

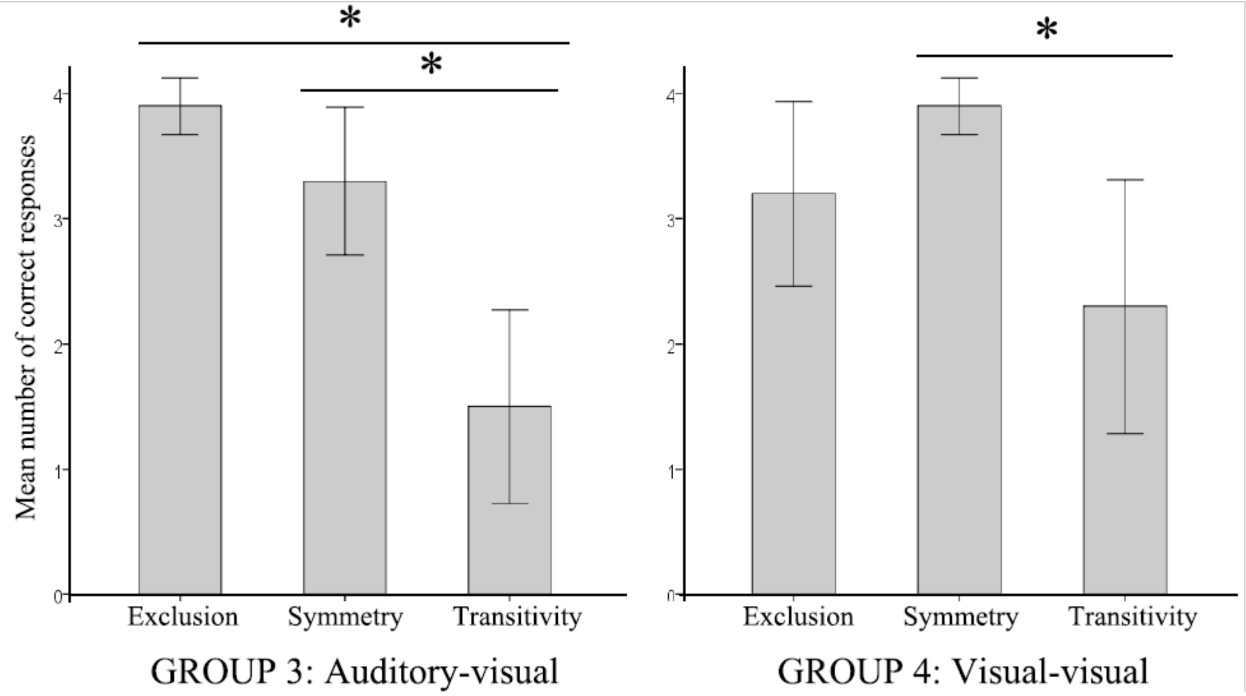

Figure 3. **Mean number of correct responses in test trials for groups 3 and 4**. Confidence intervals of error bars are 95%. * $p \leq 0.05$. ** $p \leq 0.01$. Participants of Group 3, trained with an auditory-visual baseline, showed exclusion and symmetry scores higher than those in transitivity. Participants of Group 4, who had the visual-visual baseline, also had symmetry scores higher than those in transitivity. Exclusion was higher for participants of Group 3, but symmetry was higher for Group 4.

In general, results of this experiment replicate those of Experiment 1, despite the fact that the exclusion performance was assessed independently from symmetry and transitivity. Accurate exclusion performance was more reliable in the auditory-visual modality, while accurate symmetry performance was more reliable in the visual-visual modality. Accurate transitivity performance appears to be a type of accuracy that occurs later developmentally and seems to depend on the other ones, especially symmetry.

General Discussion

The purpose of this study was to assess the hypothesis that exclusion performance could be a prerequisite for the establishment of stimulus equivalence relations measured by symmetry and transitivity performances. Thus, if the hypothesis is true, cases of symmetry or transitivity scores higher than scores in exclusion would not be observed. Results were different according to the sensorial modality of baseline relations. In the auditory-visual modality general results support the hypothesis of an apparent dependence between both kinds of performance. However, in the visual-visual modality results do not support this hypothesis. This is mainly due to the fact that with the auditory-visual modality results of almost all the participants in the exclusion trials were perfect. The sole exception came from participant 25 who also had a higher performance in symmetry over exclusion. This result is contrary to a dependence relation of symmetry on exclusion, but the dependence of transitivity on exclusion is still held up. High scores in exclusion in the auditory-visual modality are expected, given the broad evidence of this phenomenon in the field of fast mapping in toddlers before two years of age (e.g., Brady & Goodman, 2014; Markman et al., 2003).

In the case of the visual-visual modality, there were several cases of participants with higher scores in symmetry than in exclusion test trials in both experiments, and two cases of a higher score in transitivity than in exclusion test trials, one in each experiment. In consequence, it is possible to say that, at least in the visual-visual modality, exclusion performance is not a requisite for symmetry and for transitivity. The lower scores in exclusion in the visual-visual modality in comparison to the auditory-visual modality are remarkable. Given the early appearance of the exclusion performance in the auditory-visual modality in children, it would be expected to transfer to the visual-visual modality in children of about 5 years of age; but results show that this transfer in preschoolers has not happened. McIlvane, Gerard, Kledaras, Mackay, and Lionello-DeNolf (2016) report a case of a minimally verbal participant, who also shows high auditory-visual exclusion performance, but poorer visual-visual exclusion scores, which improved after a multiple-exemplar training. In the field of fast-mapping, some studies suggest that the skill to mapping novel word to novel objects developed with age (e.g., Gershkoff-Stowe & Hahn, 2007). For example, Halberda (2003) found that in fast-mapping test trials 14-month infants prefer the known object, but 17-month infants prefer the novel object. McIlvane and colleagues (McIlvane et al., 1987; McIlvane, Munson, & Stoddard, 1988; Wilkinson & McIlvane, 1997) proposed the stimulus class account of the exclusion, according to which "…exclusion performance results when subjects learn generalized rejection of any comparison that is not in the same experimentally defined stimulus class as the sample." (McIlvane et al., 1988, p. 492). This performance emerges as an effect of the multiple exposures to arbitrary S-S relations, as a way of generalized arbitrary association behavior. Early vocabulary learning could be the opportunity for multiple exposures to auditory-visual associations that enable the emergence of fast-mapping in toddlers. The lack of a reliable exclusion performance in the visual-visual modality in preschoolers could be a consequence of the absence of a history of arbitrary visual-visual associations. Data reported by McIlvane et al., (2016) seem to support this statement.

In the study of Plazas and Villamil (2017), adult human participants learned the conditional discriminations required for the establishment of two three-member classes (A1B1C1 and A2B2C2). Then they were exposed to some exclusion trials employing as defined stimuli those related in the baseline. For instance, participants had to select among comparison stimuli B1, B2, and B3, given the undefined stimulus A3 as sample, and they mostly selected B3, which was also undefined for the established baseline. These participants displayed accurate performances in test trials that assessed the symmetry and transitivity relations among the stimuli A3B3C3 that were previously related only by exclusion and not by direct feedback in the training. Results of this study suggest that exclusion performance could ground accurate performances in the baseline trials, and also in the transitivity test trials among the stimuli previously related only by exclusion and, in consequence, exclusion performance could be part of the repertory employed by participants in the establishment of stimulus equivalence classes. The Plazas and Villamil (2017) study was conducted with adults and in a visual-visual modality. It is possible that the integration of the exclusion performance in the establishment of stimulus class formation happens through ontogenetic development, later than preschool age.

Symmetry performance was higher in the visual-visual modality than in the auditory-visual modality in the Experiment 2. A possible factor associated with this result is the way in which symmetry was assessed in the auditory-visual procedure. Methodological issues associated with the implementation of matching to sample trials in which the comparison stimuli are auditory stimuli have been recognized (Dube, Green, & Serna, 1993). In studies in which auditory-visual baseline trials are taught to preschoolers, a naming test is often employed as a substitute of symmetry tests, generally with high scores (e.g., Sidman, Kirk, & Willson-Morris, 1985; Sidman & Tailby, 1982; Smeets & Barnes-Holmes, 2005). In the present study, we tried to implement a type of visual-auditory trial for symmetry testing, such that a visual stimulus had the function of sample, and when the children clicked on it, two written comparison stimuli appeared, but when the participant scrolled the mouse cursor over any of them the corresponding auditory stimulus was sounded. It is possible that this way of assessing symmetry might result in problems for the children. For instance, it is possible that in many cases children did not move the cursor mouse over the two visual comparison stimuli. Also, due to the programming of the task, it is possible that when the name of a comparison stimulus was being sounded, a child could have the cursor mouse over the other visual comparison stimulus. If this is the case, this would mean that the symmetry scores for Groups 1 and 3 were underrated. If the symmetry test trials that we employed were replaced by a naming test, these scores could be higher, and in consequence, the discrepancies in symmetry performance between auditory-visual or visual-visual baselines would be more apparent than actual. This possibility cannot be ruled out with the present data, and a systematic replication of this study would be necessary, comparing naming testing with the type of probe for symmetry that we employed here.

Symmetry had high scores across the modalities, and it was independent from the exclusion performance; whilst transitivity had more variable performance. It suggests an early development of symmetry in comparison with transitivity. Some developmental studies have showed the emergence of generalized symmetry at about the 17th month of age, followed by an explicit training in symmetry; and the emergence of transitivity performance occurring about 24-months of age (Lipkens et al., 1993; Luciano, Gómez, & Rodríguez, 2007). Other studies in adults have showed that transitivity is based on both the positive (sample-S+) relations and the negative relations (sample-S-) established in the baseline, whilst symmetry seems to depend mostly on the positive (sample-S+ relations) baseline relations (Plazas & Peña, 2016; Plazas & Villamil, 2016, 2017). In consequence, symmetry and transitivity performances could be grounded in different kinds of stimulus control. McIlvane et al. (1987, p. 205) suggested that exclusion performance emerges from the negative relations involved in the conditional S-S baseline relations. If symmetry is only based on the positive baseline relations, this could account for its independence from the exclusion performance. Exclusion and transitivity would have a common base on the negative relations involved in the multiple-expossures to arbitrary S-S relations. However, transitivity also requires that these negative relations should be among stimuli from alternative experimentally predefined equivalence classes (Plazas & Villamil, 2016). This does not need to be prerequisite for the exclusion performance to emerge as a generalized behavior. But although exclusion is a simpler performance than transitivity, the latter could develop through a direct route without the former, as results of participants 15 and 39 suggest.

Contrary to some studies showing an apparent advantage of the auditory-visual modality over the visual-visual modality for the establishment of equivalence relations (e.g., Green, 1990; Smeets & Barnes-Holmes, 2005), in this study the symmetry and transitivity scores were higher for the visual-visual groups. In this study, several preschoolers about 5-years old showed low performance in transitivity test trials. Our test for transitivity responding consisted of only four test trials, intermixed with symmetry trials. Some studies have showed more reliable emergence of transitivity performance following independent assessment of symmetry (Adams, Fields, & Verhave, 1993; Fields, Adams, Newman, & Verhave, 1992; Smeets, Barnes, & Roche, 1997; Smeets, Dymond, & Barnes-Holmes, 2000), and following a re-exposure to the baseline training and testing conditions (e.g., Sidman et al., 1985). In consequence, if children who had low scores in transitivity test trials were first tested for symmetry and/or were retrained and retested, it is likely that their scores would be higher. However, for the purposes of this study, an assessment based on only four trials for each test type was enough to discriminate the mastery of this performance criterion in these subjects.

Acknowledgments

Elberto A. Plazas, Facultad de Psicología, Fundación Universitaria Konrad Lorenz, Bogotá, Colombia; Deby Cortés, Facultad de Psicología, Fundación Universitaria Konrad Lorenz, Bogotá, Colombia. This study was conducted as part of the professional practicum of the second author's degree in psychology, under the supervision of the first author.

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Financial conflict of interest: No stated conflicts.
Conflict of interest: No stated conflicts.

Submitted: *August 31st, 2016*

Resubmitted: *March 3rd, 2017*

Accepted: *March 5th, 2017*