Symmetry and Stimulus Class Formation in Humans: Control by Temporal Location in a Successive Matching Task

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Abstract

Symmetry refers to the observation that subjects will derive B-A (e.g., in the presence of B, select A) after being trained on A-B (e.g., in the presence of A, select B). Whereas symmetry is readily shown by most humans, it has been difficult to demonstrate in nonhuman animals. This difficulty, at least in pigeons, might result from responding to specific stimulus properties that change when sample and comparison stimuli switch roles between training and testing. In three experiments, we investigated to what extent human responding is influenced by the temporal location of stimuli using a successive MTS procedure. Our results indicate that temporal location does not spontaneously control responding in humans, while it does in pigeons. Therefore, the number of functional stimuli that humans respond to in this procedure might be half of the number of functional stimuli that the pigeons respond to. In a fourth experiment, we tested this assumption by doubling the number of functional stimuli controlling responding in human participants in an attempt to make the test more comparable to symmetry tests with pigeons. Here, we found that humans responded according to indirect class formation in the same manner as pigeons did. In sum, our results indicate that functional symmetry is readily observed in humans, even in cases where the temporal features of the stimuli prevent functional symmetry in pigeons. We argue that this difference in behavior between the two species does not necessarily reflect a difference in capacity to show functional symmetry between both species, but could also reflect a difference in the functional stimuli each species responds to.

Keywords: stimulus equivalence, associative symmetry, successive matching-to-sample, stimulus class formation, stimulus control, antisymmetry, functional stimulus

Symmetry and Stimulus Class Formation in Humans: Control by Temporal Location in a Successive Matching Task

Stimulus equivalence is an empirical phenomenon that was formally conceptualized by Sidman (1990) and has been described as a set of three characteristics that are assumed to play a critical role in language and cognition (Horowitz & Gordon, 1972; Kahana, 2002). Symmetry is one of those characteristics (alongside of reflexivity and transitivity); it entails that a subject can match stimulus A to B after successfully learning to match B to A. This thus implies a bidirectional relation between two stimuli, such that the two stimuli can be used interchangeably. In contrast to reflexivity and transitivity, symmetry has proven difficult to obtain in nonhuman animals (Lionello-DeNolf, 2009), in apparent violation of the assumption that there is continuity in behavior between humans and nonhuman species (Greenwood, 2016).

It has been argued that the difficulty of obtaining symmetry in nonhuman animals might be related to the typical use of a two-choice matching-to-sample (MTS) procedure (Zentall, Wasserman, & Urcuioli, 2014). In this procedure, first a sample is presented, typically in the middle of the apparatus, followed by two comparison stimuli, typically presented at the sides. The subject learns to respond to particular comparison stimuli in the presence of specific sample stimuli via reinforcement contingencies. During the symmetry test, the role of the stimuli as samples or comparisons is reversed. Symmetry is demonstrated if the subject chooses the comparison that was previously a sample in the presence of a sample that was previously the correct comparison. Crucially, in the two-choice MTS procedure, the sample and comparison stimuli are presented at different locations during acquisition, and these locations change during the symmetry test. Because the spatial location of a stimulus exerts strong control over the behavior of nonhumans (Iversen, 1997; Iversen, Sidman, & Carrigan, 1986; Lionello & Urcuioli, 1998), the shift in location when comparisons become samples and samples become comparisons might have precluded the observation of symmetry.

More recently, a successive go/no-go MTS procedure has been used to avoid problems associated with control by the spatial location of stimuli in nonhuman animals. In this procedure, a sample is followed by only one comparison, presented in the same spatial location as the sample. The subject can either respond (go) or not respond (no-go) to the comparison stimulus. When the two stimuli are defined as a match (i.e., a positive trial), responding to the comparison is reinforced. When the two stimuli are defined as a non-match (i.e., a negative trial), responding to the comparison stimulus is not reinforced (i.e., all non-match trials end in extinction). For example, subjects are trained to respond when A is followed by B (i.e., A-B), but to withhold responding when A is followed by C (i.e., A-C). To test for symmetry, B and C are presented as samples and A is presented as a comparison. Symmetry is demonstrated if the subjects respond similarly to the symmetrical relations as to the trained relations (i.e., there is more responding on B-A than C-A trials). With this procedure, evidence for symmetry was obtained in pigeons by Frank and Wasserman (2005) and Urcuioli (2008, Experiment 3). Importantly, to observe symmetry it was necessary to intermix reinforced identity matching trials (e.g., A-A; B-B) with training of the arbitrary relations (e.g., A-B; Frank & Wasserman, 2005; but see Campos, Urcuioli, & Swisher, 2014).

In contrast to nonhuman animals, human adults readily exhibit symmetry in the two-choice MTS procedure, even without explicit training on identity relations (e.g., Vervoort, Vervliet, Bennett, & Baeyens, 2014). Successive go/no-go MTS procedures can also establish symmetry in humans (Cullinan, Barnes, & Smeets, 1998; Debert, Matos, & McIlvane, 2007), although it seems that stimulus equivalence is obtained less readily in those procedures than in the two-choice MTS procedure (Smeets, van Wijngaarden, Barnes-Holmes, & Cullinan, 2004).

A critical difference between humans and nonhuman animals might be the functional stimulus to which the subjects respond (Zentall et al., 2014). The functional stimulus is defined by the characteristics of the stimulus that control the subject's behavior (Underwood, 1963). Whereas the functional stimulus might be determined purely by its physical characteristics (e.g., color or shape) for humans, it seems to be determined by a combination of the physical properties of that stimulus and its spatial and temporal location for nonhuman animals (Lionello & Urcuioli, 1998; Urcuioli, 2015). In particular, Urcuioli (2008) proposed that for pigeons the functional stimuli in a successive MTS task are compounds of the physical properties of the stimuli and their temporal location (i.e., the presentation order). This means that the animals respond differently to the same physical stimulus depending on when it is presented in the stimulus sequence. For example, stimulus A when presented as a sample (temporal location 1) or as a comparison (temporal location 2) would be treated by the pigeons as two different stimuli, denoted as A1 and A2. Table 1 shows the probable functional relations in Frank and Wasserman (2005, Experiment 1) according to this view.

Table 1

Positive training trials in Frank and Wasserman (2005, Experiment 1)

Training trials	Reinforced relation
A1–B2 D1–C2	Arbitrary training
A1–A2 B1–B2 C1–C2 D1–D2	Identity training

Note. Each stimulus is denoted by reference to its physical identity (denoted with a letter) and its temporal position (denoted with digits 1 and 2).

Importantly, if for pigeons the functional stimuli in a successive MTS task are compounds of both the physical properties and the temporal location of the stimulus, then at a functional level, any observed behavior that looks like symmetry is not an instance of symmetry between sample and comparison stimuli as defined by Sidman (1990). Despite looking like functional symmetry to a human observer, the functional stimuli involved in training (e.g., A1-B2) are different from those involved in testing (e.g., B1-A2). To test for *functional symmetry* between the sample and comparison, the symmetry test should consist of B2-A1. This is physically impossible because the temporal feature of B2 mandates that it is presented as the second stimulus in a trial, whereas the temporal feature of A1 mandates that it is presented as the first stimulus in a trial (Urcuioli, 2008, p. 278).

Urcuioli (2008) explained how reinforced identity trials can allow for the indirect formation of stimulus classes and how this can result in *apparent symmetry* (as in Frank & Wasserman, 2005). Urcuioli (2008) argued that functional stimuli that are presented together within a reinforced trial become members of the same stimulus class. The top part of Figure 1 depicts the stimulus classes predicted to emerge according to this hypothesis based on the relations trained in Frank and Wasserman (2005). In addition, Urcuioli (2008) assumed that elements that appear in multiple stimulus classes will cause class merger (cf. Sidman, 1994). As a result, stimulus classes should emerge as depicted at the bottom of Figure 1. Crucially, the application of these hypothesis to the procedure in Frank and Wasserman (2005) results in stimulus classes in which physically identical stimuli presented at the two temporal locations are contained within the same class, due to class merger. According to Urcuioli (2008), this is exactly why apparent symmetry emerged in Frank and Wasserman (2005).

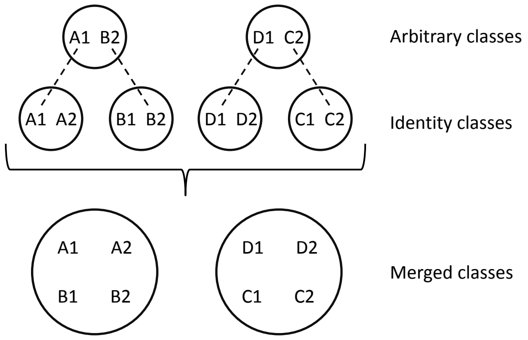

Figure 1. The circles depict the stimulus classes predicted to emerge in Frank and Wasserman (2005) according to Urcuioli's (2008) theory of indirect stimulus class formation. The top panel shows the stimulus classes predicted to form based on reinforced sample-comparison pairs. Dashed lines connect elements common to different classes. The bottom panel shows the resulting merged stimulus classes.

To provide support for his theory, Urcuioli (2008, Experiment 4) conducted a particularly elegant experiment that evaluated a strong and counterintuitive prediction. By changing the reinforcement contingencies described above such that half of the trained relations were identity (i.e., B1-B2 and C1-C2) and the remaining half were oddity (i.e., A1-D2 and D1-A2), different stimulus classes should arise (see the bottom panel of Figure 2). On the basis of Urcuioli's theory, class merger between these elements and the reinforced arbitrary relations A1-B2 and D1-C2, would result in two stimulus classes: one containing B1, B2, A1, and D2, and the other one containing C1, C2, D1, and A2. During the test phase, one should expect the subjects to respond more on B1-D2 than B1-A2 trials and to respond more on C1-A2 than C1-D2 trials (as depicted in the bottom panel of Figure 2). This is exactly what was observed (Urcuioli, 2008, Experiment 4). Urcuioli termed this emergent effect *antisymmetry* because at the surface level the observed response is the opposite of what would be expected based on functional symmetry (i.e., symmetry between sample and comparison stimuli when the functional stimuli do not alter based on the temporal location of the stimuli; Urcuioli, 2015).

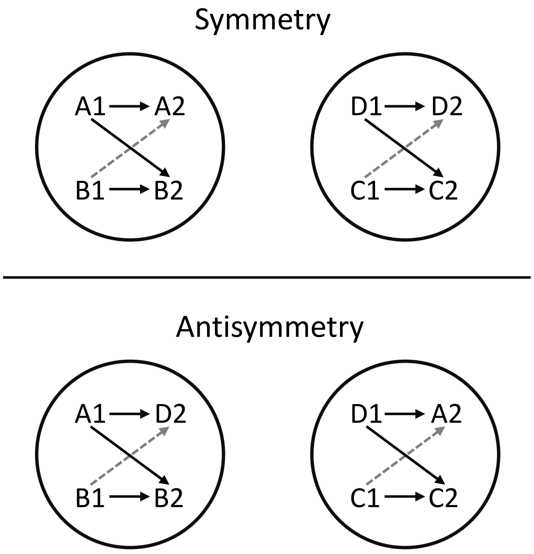

Figure 2. The top panel depicts a schematic overview of the positive training trials in Frank and Wasserman (2005, Experiment 1). The bottom panel depicts the positive training trials in Urcuioli (2008, Experiment 4). Solid black arrows denote all explicitly trained relations. Dashed arrows indicate observable emergent relations.

Because the functional stimuli are not the same for humans and nonhuman animals given a similar learning experience, one should not expect that the same relations would emerge. Therefore, the question arises whether the difficulty to observe functional symmetry in nonhuman animals (Lionello-DeNolf, 2009) reflects a fundamental limitation in the capacity to show functional symmetry or whether nonhumans respond to different functional stimuli than humans (McIlvane, 2014). The present paper explored this issue. In the first three experiments, we assessed the extent to which human responding is controlled by the temporal location of stimuli in successive MTS procedures similar to those used by Urcuioli (2008) with pigeons. We found that the functional stimuli for humans did not include the temporal location of the stimulus. Moreover, we argue that the number of functional stimuli that the pigeons respond to doubles when a stimulus is both presented first and second in a trial sequence within the same experiment, but that the number of functional stimuli does not change in humans trained on the same procedure. In a fourth experiment, we tested this hypothesis by replacing every stimulus with two different stimuli, one for each temporal location (i.e., either first or second in the trial sequence). For example, in Experiment 1-3, stimulus A could appear at both temporal locations (i.e., A1 or A2), whereas in Experiment 4 each stimulus could only appear at one temporal location (i.e., A1 and A2 were replaced by A and E, see Table 2). Hence, this increased the number of functional stimuli controlling responding in humans by a factor of two. Apart from that, all other design aspects were kept the same. We believe that this change made the task more comparable to symmetry tests with pigeons because the number of functional stimuli that each species responded to was equated. With this modification, we found that humans responded according to indirect class formation, which is equivalent to the results obtained in pigeons.

Experiment 1

In the current study, we conducted a successive MTS procedure with humans as subjects that replicated the pigeon procedure of Urcuioli (2008, Experiment 3) as closely as possible in order to ascertain that the procedure is suitable for investigating apparent symmetry in humans. In the original procedure, pigeons were tested in an experimental chamber containing a single response key. On this response key, four different stimuli could be projected. These stimuli could be divided into two categories: hue and form. The hue category consisted of a green (G) and a red (R) hue, and the form category consisted of an inverted white triangle (T) and three white horizontal lines (H) on a black background. During training, each trial began with the onset of a sample stimulus. A peck on this sample stimulus initiated a 5000-ms interval after which the stimulus disappeared. This was followed by a 500-ms blank interval, after which a comparison stimulus was presented. On positive trials, pecking the comparison resulted in the offset of that comparison and food delivery. On negative trials, the comparison disappeared after 5000 ms, and no food was delivered. During training, hue identity (i.e., R-R, and G-G), form identity (i.e., T-T, and H-H) and arbitrary relations (i.e., R-T, and G-H) were established. When the pigeons reached a discrimination ratio of .80 or higher on five consecutive training sessions, they proceeded to the test phase. During the test phase, in which no food was delivered, the pigeons were presented with trials that were the reverse of the arbitrary training trials (i.e., the sample and comparison stimuli switched roles). Pigeons pecked more on test trials that were the reverse of positive arbitrary training trials (i.e., T-R, and H-G) than on the reverse of negative arbitrary training trials (i.e., H-R, and T-G), indicating apparent symmetry.

Method

Participants. Twenty-four undergraduate students (M_{age} = 19.21 years, *SD* = 3.77), of which seven were men, participated in exchange for course credit and a chance to win two film vouchers. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The participants worked in soundproof rooms on a personal computer with a keyboard. The experiment was programmed in PsychoPy 1.81.00 (Peirce, 2007). Figure 3 shows the four stimuli that were used in the experiment. Like Urcuioli (2008), we divided the stimuli into two categories (checkerboards and Gabor patches), and we chose stimuli/categories that were unlikely to be part of pre-experimental categories and were not easily nameable. Stimuli were always presented in the center of the screen with a surface of 144 cm^2 on a black background.

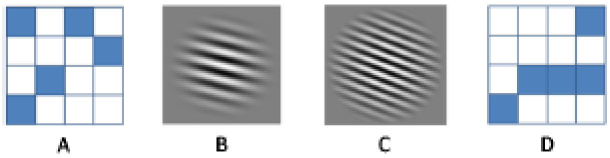

Figure 3. Stimuli used in Experiments 1, 2 and 3. Stimuli A and D were checkerboards, stimuli B and C were Gabor patches.

Design. We used a within-subjects design in which the specific sample-comparison combinations were counterbalanced across participants. The task consisted of a training phase and a test phase.

In the training phase, two arbitrary relations and four identity relations were trained. To this aim, 12 different trials were presented (see Table 2, Experiment 1): four identity, four oddity, and four arbitrary. On identity trials, the same stimulus was presented twice, as both a sample and a comparison. Oddity trials consisted of two different stimuli from the same category (i.e., checkerboards or Gabor patches), one presented as a sample and the other as a comparison. On arbitrary trials, two stimuli from different stimulus categories (i.e., checkerboards and Gabor patches) were presented. Whether the samples were checkerboards and the Gabor patches comparisons or vice versa was counterbalanced across participants. The four identity trials and two of the four arbitrary trials served as positive trials: a response to the comparison was reinforced. The four oddity trials and the two remaining arbitrary trials served as negative trials: a response to the comparison was punished (as described below).

In the test phase, four arbitrary trials were presented: two symmetry trials, in which the samples and comparisons from the two positive arbitrary training trials switched roles, and two non-symmetry trials, in which the samples and comparisons from the two negative arbitrary training trials switched roles.

Procedure. The ethical review board of KU Leuven approved all the procedures used in this and the following experiments. Upon arrival in the laboratory, participants gave their written informed consent to perform a computerized task with different visual stimuli, with the possibility of winning two film vouchers.

Training phase. The experiment began with on-screen instructions (translated from Dutch): *"In this experiment, you will be presented with images. When you see the first image, you need to press ENTER. If you press ENTER, the image will stay on the screen for one* *second. Then it will disappear and you will see a second image. Upon presentation of this second image, you must choose whether to press the SPACE BAR or WAIT until the image disappears. Depending on your response, you will earn or lose points. On some trials, you will HAVE TO press in order to earn points, whereas on other trials you CANNOT press in order to not lose any points. Try to use this feedback (points) to make the right choice the next time."* Thereafter, two example trials, with stimuli other than those used in the actual experiment, were shown in order to familiarize the participants with the task.

On every training trial, a sample stimulus appeared in the center of the screen. Participants were required to press the “return” key on the keyboard, and the sample remained on the screen for 1000 ms after the return key was pressed in order to increase the chance that the participants actually observed it. Sample offset was followed by an inter-stimulus interval of 500 ms and, subsequently, by a comparison stimulus that was presented in the same spatial location. From the onset of the comparison, participants had 5000 ms to either press the “spacebar” key or wait. When the spacebar was pressed, the stimulus disappeared immediately and feedback was presented. When the spacebar was not pressed within 5000 ms, the stimulus disappeared automatically and was followed by feedback. The feedback consisted of the number of points gained or lost. On positive trials, the participants earned 100 points by pressing the spacebar during the comparison presentation and 0 points when refraining from pressing the spacebar. On negative trials, they lost 100 points by pressing the spacebar during the comparison presentation and 0 points when refraining from pressing the spacebar. The feedback remained on the screen for 2000 ms and was then immediately followed by the next trial. One block consisted of the presentation of all 12 possible trials in random order.

When a block was finished, the participant’s score for that block was presented. This score could vary from -600 (everything wrong) to +600 (everything correct). Moreover, the participants were informed that they could proceed to the next phase when they reached the maximum score on two consecutive blocks. This instruction was presented with the general instructions on how to perform the task. When participants pressed the return key to indicate they had read the feedback, the next block started. As soon a participant reached the training criterion or completed a maximum of 11 blocks, they proceeded to the test phase.

Test phase. The test phase started with the following on-screen instructions (translated from Dutch): *"We now proceed to the final stage. At this stage you will see new combinations. Despite the fact that these will be new combinations, try to press if you think you have to press and wait if you think that you have to wait. If you do this correctly, you can earn bonus points. These points will NOT be displayed on the screen. Try definitely to do your best because you are more likely to win cinema tickets if you press correctly in this round. This phase will not take long so just try to stay motivated! Good luck!"*

During the test phase, only the four remaining combinations were presented: two symmetry trials (i.e., B1-A2 and C1-D2), which were the reverse of the positive arbitrary relations, and two non-symmetry trials (i.e., B1-D2 and C1-A2), which were the reverse of the negative arbitrary relations. Participants were instructed that no feedback would be provided during this phase. On every trial, the message *"earned points are hidden"* appeared on the screen instead of the former feedback.

Each participant completed four blocks of four test trials, such that they each encountered eight symmetry and eight non-symmetry trials. If participants were responding according to symmetry on the test trials, they should press the spacebar on symmetry test trials but not press the spacebar on the non-symmetry test trials.

Table 2

Trials presented in Experiments 1-4

	Exp 1	Exp 2	Exp 3	Exp 4

Arbitrary training trials	**A1–B2 +** **D1–C2 +** A1–C2 - D1–B2 -	**A1–B2 +** **D1–C2 +** A1–C2 - D1–B2 -	**A1–B2 +** **D1–C2 +** A1–C2 - D1–B2 -	**A–G +** **B–H +** A–H - B–G -
Identity/Oddity training trials	**A1–A2 +** **D1–D2 +** A1–D2 - D1–A2 -	**A1–A2 +** **D1–D2 +** A1–D2 - D1–A2 -	A1–A2 - D1–D2 - **A1–D2 +** **D1–A2 +**	**A–E +** **B–F +** A–F - B–E -
Identity/Oddity training trials	**B1–B2 +** **C1–C2 +** B1–C2 - C1–B2 -	B1–B2 - C1–C2 - **B1–C2 +** **C1–B2 +**	**B1–B2 +** **C1–C2 +** B1–C2 - C1–B2 -	D–H - C–G - **D–G +** **C–H +**
Test trials		B1–A2 C1–D2 C1–A2 B1–D2		D–E C–F C–E D–F

Note. Responding on training trials denoted with a + was reinforced, whereas responding on trials denoted with a – was punished. Not responding was neither reinforced nor punished. Test trials were also neither reinforced nor punished.

Results

All the analyses were conducted in R (R Core Team, 2013). All Bayes factors were computed using the default settings in version 0.9.9 of the R package BayesFactor (Rouder, Morey, Speckman, & Province, 2012; Rouder, Speckman, Sun, Morey, & Iverson, 2009).

Training phase. Twenty of the 24 participants reached the training criterion (scoring the maximum on two consecutive blocks) in an average of six training blocks (*SD* = 2.03). The remaining four participants proceeded to the test phase after 11 blocks of training without reaching criterion. In the two last blocks, these participants responded correctly on 20, 22, 15, and 20 out of 24 trials.

Test phase. Figure 4 shows the responses (y-axis) made by each participant (x-axis) during the test phase. Black lines denote the number of symmetry trials on which the participant responded. Gray lines denote the number of non-symmetry trials on which the participant responded.

The number of symmetry trials on which participants responded was compared to the number of non-symmetry trials on which they responded. A paired-samples *t*-test revealed a significant difference, $t(23) = 8.37$, $p < .001$, indicating that participants responded more on symmetry ($M = 6.04$, $SD = 2.90$) than on non-symmetry trials ($M = 0.50$, $SD = 1.02$). The corresponding Bayes factor decisively supported the presence of a difference in responding between symmetry and non-symmetry trials, $\text{BF}_{10} = 686536$.

Of the 20 participants who reached the training criterion, 19 responded in line with symmetry, and one did not respond at all during the test phase (participant 20). Of the four participants who did not reach criterion in the training phase, two responded equally often on symmetry and non-symmetry trials (participants 21 and 22), and the other two did not respond at all (participants 23 and 24). That the participants who did not reach criterion in the training phase responded indifferently or not at all during the test phase probably reflects that they did not learn to do the task within the limited number of training trials. In general, we can conclude that participants responded significantly more on symmetry than on non-symmetry test trials, and, thus, that apparent symmetry emerged.

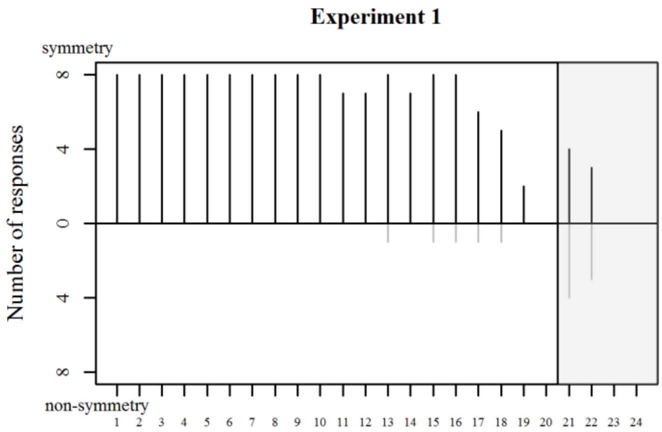

Figure 4. Experiment 1: Number of responses on test trials by participant, ordered from responding most to least in accordance with symmetry. The shaded area displays participants who did not achieve the training criterion. Black lines indicate the number of responses on

symmetry trials (i.e., the reverse of reinforced training trials), and gray lines indicate the number of responses on non-symmetry trials (i.e., the reverse of punished training trials). Note that it was possible to respond on both symmetry and non-symmetry trials.

Experiment 2

Experiment 2 assessed the prediction that apparent antisymmetry would emerge when both identity relations and oddity relations are reinforced in training. Here, we attempted to replicate Experiment 4 from Urcuioli (2008) in humans. In the original experiment, pigeons were trained in the same way as in Experiment 3 of Urcuioli (2008, which was replicated in our Experiment 1), except that they were trained to respond on hue oddity relations (i.e., R1-G2, and G1-R2, in which R stands for the red stimulus and G stands for the green stimulus) instead of hue identity relations. Pigeons were also trained on form identity matching (T1-T2 and H1-H2, in which T stands for the triangle shape and H stands for the horizontal lines) and the arbitrary training (R1-T2 and G1-H2), which leads to the counter-intuitive prediction that, during the test phase, pigeons would respond more on T1-G2 than T1-R2 trials (even though G1-T2 was not reinforced during training and R1-T2 was). The same applies for the second stimulus class, for which responding was expected to be stronger on H1-R2 than H1-G2 trials, even though responding on G1-H2 trials had been reinforced, and responding on R1-H2 had not been. This prediction was confirmed (Urcuioli, 2008, Experiment 4) and runs counter to what is expected if the functional stimulus were based solely on the physical identity of the stimuli (in which case, functional symmetry is expected).These findings indicate that T1 and T2 are functionally different stimuli for the pigeons, as are G1 and G2, and support the idea that both the apparent symmetry and the apparent antisymmetry effects observed by Urcuioli (2008) emerged through indirect stimulus class formation.

In order to make the Urcuioli (2008, Experiment 4) procedure suitable for humans, we adopted the procedure from Experiment 1 but replaced identity training with oddity training for one of the two categories (i.e., B1-C2 and C1-B2 rather than B1-B2 and C1-C2). Table 2 (Experiment 2) depicts all the training trials, including the reinforced arbitrary trials A1-B2 and D1-C2. If the basis of apparent symmetry in humans is the same as in pigeons (i.e., indirect stimulus class formation), we should expect apparent antisymmetry to emerge here (see the top panel of Figure 5). This would result in participants pressing the space bar on B1-D2 and C1-A2 test trials but not responding on B1-A2 and C1-D2 trials. On the other hand, if human participants’ responding is not controlled by the temporal location of the stimuli, we should expect functional symmetry to emerge; participants should press the spacebar on B1-A2 and C1-D2 test trials, but not on B1-D2 and C1-A2 trials.

Figure 5. Trained (black arrows) and possible emergent (dashed arrows) relations in Experiments 2 and 3.

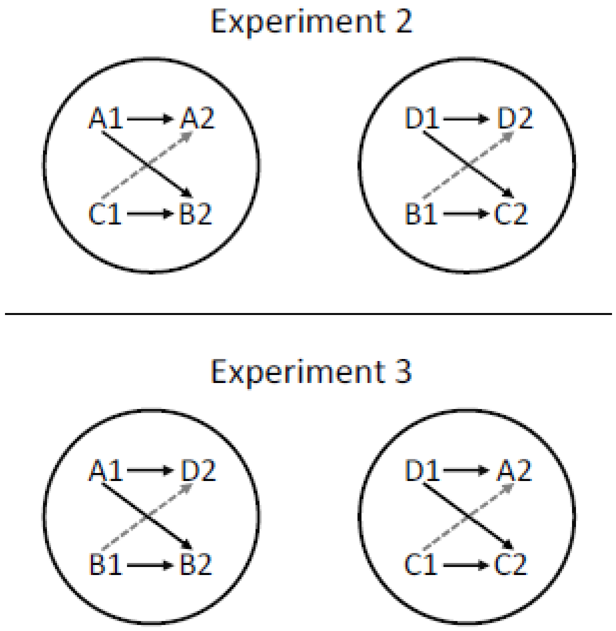

Figure 5. Trained (black arrows) and possible emergent (dashed arrows) relations in Experiments 2 and 3.

Method

Participants. Twenty-four undergraduate students (M_{age} = 21.13 years, *SD* = 5.39), of which seven were men, participated in exchange for course credit and a chance to win two film vouchers. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The same four stimuli were used as in Experiment 1 (see Figure 3).

Design. The design of Experiment 2 was the same as the design of Experiment 1, except that for one of the two stimulus categories responding to oddity relations rather than identity relations was reinforced.

Procedure. The procedure was the same as in Experiment 1, except that after training four participants, we increased the maximum number of training blocks to 14 because only one of the four reached criterion within the maximum 11 training blocks. The remaining participants proceeded to the test phase after meeting the training phase criterion or completing 14 blocks.

Results

Training phase. Sixteen participants reached criterion, in an average of 8.63 training blocks (*SD* = 2.83). Eight participants proceeded to the next phase without achieving criterion, three after 11 blocks of training and five after 14 blocks of training. The performance in the last two blocks for these participants was respectively 22, 12, and 18 correct out of 24 trials (for the participants who completed 11 training blocks) and 17, 23, 19, 23, and 21 correct out of 24 trials (for the participants who completed 14 training blocks).

Test phase. Figure 6 depicts the number of responses (y-axis) for each participant (x-axis) during the test phase in Experiment 2. Black lines indicate the number of symmetry trials on which a response was made, and gray lines indicate the number of antisymmetry trials on which a response was made.

A paired-samples *t*-test revealed a significantly larger number of responses on symmetry trials ($M = 6.75$, $SD = 1.75$) than antisymmetry trials ($M = 0.83$, $SD = 1.83$), $t(23) = 8.49$, $p < .001$. The corresponding Bayes factor provided decisive support for a difference in response levels on symmetry and antisymmetry trials, $BF_{10} = 873567$. Of the 16 participants who reached criterion, 15 responded in accordance with symmetry, and one responded in accordance with antisymmetry (participant 16). Of the eight participants who did not reach criterion, seven responded in accordance with symmetry (participants 17-23) and one responded more in accordance with apparent antisymmetry (participant 24). Overall, the human participants in our experiment exhibited apparent symmetry, in contrast to Urcuioli's (2008, Experiment 4) pigeons that displayed apparent antisymmetry. The presence of apparent symmetry and the absence of apparent antisymmetry is indicative of functional symmetry. This indicates that temporal location is not part of the functional stimulus for human participants and that the apparent symmetry observed here and in the previous experiment does not result from indirect stimulus class formation.

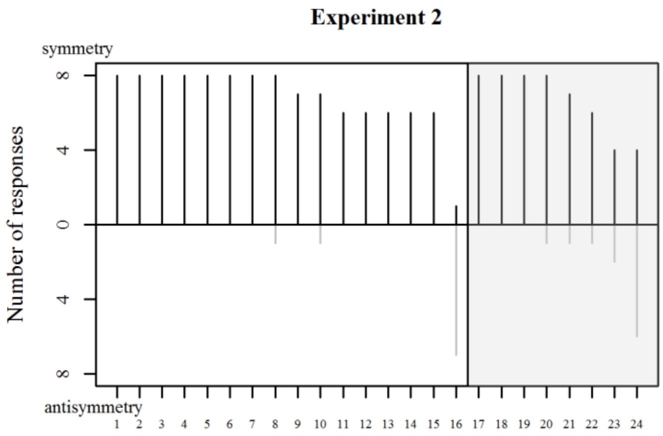

Figure 6. Experiment 2: Number of responses on test trials by participant, ordered from responding most in accordance with symmetry to responding most in accordance with antisymmetry. The shaded area displays participants who did not achieve the training criterion. Black lines indicate the number of responses on symmetry trials, and gray lines indicate the number of responses on antisymmetry trials. Note that it was possible to respond on both symmetry and antisymmetry trials.

Experiment 3

In the previous experiment, we attempted to replicate the conditions under which Urcuioli (2008, Experiment 4) observed apparent antisymmetry in pigeons. In contrast to his results, we observed apparent symmetry in our participants. This indicates that our participants' behavior, in contrast to that of pigeons, was not mediated by indirect class formation and represents functional symmetry.

There was, however, a difference between our procedure and the one in Urcuioli (2008, Experiment 4). In Urcuioli (2008), the *samples* from the trained arbitrary relations (i.e., the hue stimuli R and G) were also presented on oddity training trials, which means that responding on R1-G2 and G1-R2 trials was reinforced, and responding on R1-R2 and G1-G2 trials was not. The *comparisons* from the trained arbitrary relations (i.e., the form stimuli T and H), however, were reinforced for identity matching. In the current Experiment 2, we did the reverse; that is, the samples included in the arbitrary relations (i.e., A1, and B1) were also presented on the identity trials and the comparisons were presented on the oddity relations (see Figure 5). Although this difference had no effect in pigeons (Urcuioli & Swisher, 2012), we believe that this subtle difference may have affected the formation of stimulus classes in humans. As a matter of fact, it is conceivable that what is learned about the arbitrary relations is dependent on what is learned about the sample stimuli. For example, if the sample stimuli of the arbitrary relations are also trained on identity, the participants might learn that the comparison stimuli that follow those sample stimuli are equivalent to them. If this assumption generalizes to the arbitrary relations, it could encourage treating the arbitrary relations as identity relations. As a consequence, indirect stimulus class formation as proposed by Urcuioli (2008) would perhaps be prevented. Experiment 3 evaluated this possibility by using the comparison stimuli from the reinforced arbitrary relations for identity training and the sample stimuli for oddity training (see Figure 5), as was done by Urcuioli (2008, Experiment 4).

Method

Participants. Of the 24 participants (M_{age} = 22.92 years, *SD* = 5.74), 11 were undergraduate students, seven were graduate students, and five were employed. Nine were men. The undergraduate students participated in exchange for course credit and the others on a voluntary basis. Each participant had a chance to win two film vouchers. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and the stimuli were the same as in the two previous experiments.

Design and Procedure. Table 2 (Experiment 3) shows the reinforcement contingencies for this experiment. A first difference from Experiment 2 was that the samples from the arbitrary relations were used in oddity instead of identity training and the comparisons from the arbitrary relations were used in identity instead of oddity training. Because only 16 participants reached criterion in the previous experiment, a second difference in this experiment was that we increased the maximum number of training blocks to 17.

Results

Training phase. Nineteen participants reached criterion in an average of 11 training blocks (*SD* = 3.46). Five participants proceeded to the test phase without reaching criterion after 17 blocks of training. In the last two blocks, the participants who did not reach criterion responded correctly on 15, 15, 16, 19 and 12 out of 24 trials.

Test phase. Figure 7 depicts the number of responses on test trials for each participant separately. Black lines indicate the number of symmetry trials on which a response was made, and gray lines indicate the number of antisymmetry trials on which a response was made.

A paired-samples *t*-test revealed a significant difference between the number of responses on symmetry ($M = 6.25$, $SD = 2.19$) and antisymmetry trials ($M = 1.33$, $SD = 2.21$), $t(23) = 7.08$, $p < .001$. The corresponding Bayes factor yielded decisive evidence in support of a difference in the number of responses to symmetry and antisymmetry trials, $BF_{10} = 50818$. The degree of symmetric responding (rate of symmetric versus antisymmetric responses) did not differ from that in Experiment 2, $t(46) = 1.017$, $p = 0.31$ ($BF_{10} = 0.44$).

Of the 19 participants who reached criterion, 18 responded in accordance with symmetry and one did not respond at all (participant 19) during the test phase. Of the five participants who did not reach criterion, none responded in accordance with symmetry; four responded equally on symmetry and antisymmetry trials (participants 20, 21, 22 and 23) and one (participant 24) responded more in accordance with antisymmetry. In sum, our results show that despite using the samples from the arbitrary trials in oddity training, humans display apparent symmetry rather than apparent antisymmetry, unlike pigeons. This suggests that the emergent behavior displayed by humans in this task likely represents functional symmetry rather than indirect stimulus class formation.

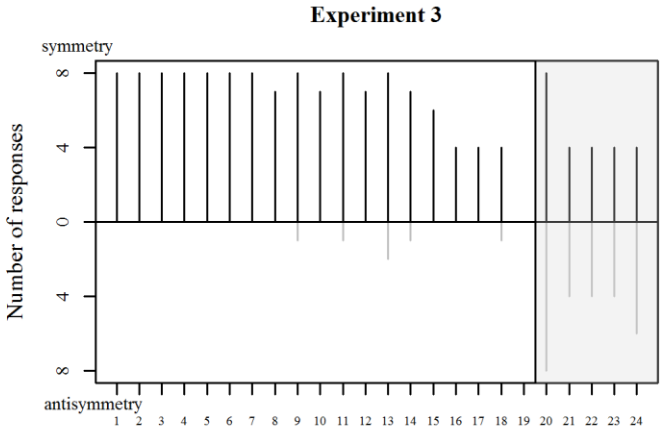

Figure 7. Experiment 3: Number of responses on test trials by participant, ordered from responding most in accordance with symmetry to responding most in accordance with antisymmetry. The shaded area displays participants who did not achieve the training criterion. Black lines indicate the number of responses on symmetry trials, and gray lines indicate the number of responses on antisymmetry trials. Note that it was possible to respond on both symmetry and non-symmetry trials.

Experiment 4

The previous three experiments assessed the similarity in behavior between pigeons and humans in relational responding in a successive MTS task. In two experiments that replicated conditions under which pigeons exhibit apparent antisymmetry (Urcuioli, 2008, Experiment 4), we found that humans exhibit apparent symmetry. We propose that the participants were not responding according to apparent antisymmetry in Experiments 2 and 3 because the relative temporal location of a stimulus in the trial sequence is not part of the functional stimulus for humans. If so, the number of functional stimuli the pigeons respond to doubles when a stimulus is presented both first and second in a trial sequence within an experiment. This would mean that in Urcuioli (2008) and in Urcuioli and Swisher (2012), there were eight functional stimuli, whereas in our experiments, there were only four. The goal of Experiment 4 was to investigate the occurrence of behavior indicative of indirect stimulus class formation in humans when the number of functional stimuli is increased to eight. To that end, we replicated our Experiment 2 with eight rather than four physical stimuli, thus substituting one physically unique stimulus for each of the eight functional stimuli that the pigeons allegedly responded to (see Figure 8). This resulted in four stimuli that were only presented as sample stimuli (i.e., A, B, C and D) and another four that were only presented as comparison stimuli (i.e., E, F, G and H). By using this procedure, we evaluated whether humans would form stimulus classes in a similar way as pigeons when the number of functional stimuli is equated.

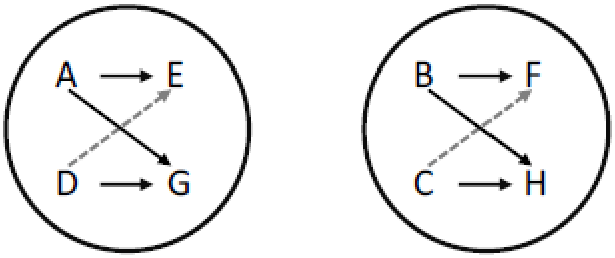

Figure 8. The merged stimulus classes formed by reinforced training trials (solid black arrows) and possible emergent relations (dashed arrows) in Experiment 4. Each character denotes a unique physical stimulus.

Method

Participants. Twenty-four undergraduate students (M_{age} = 18.75 years, *SD* = 1.26), of which three were men, participated in exchange for course credit and a chance to win two film vouchers. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. Eight symbols from the font style “wingdings” were used as stimuli, shown in white on a black background (see Figure 9). We abandoned the use of categories (i.e., checkerboards and Gabor patches) because the use of categories could make the task unnecessarily complex and was not included in Urcuioli’s (2008) theory; moreover, in Frank and Wasserman (2005), categories were not used.

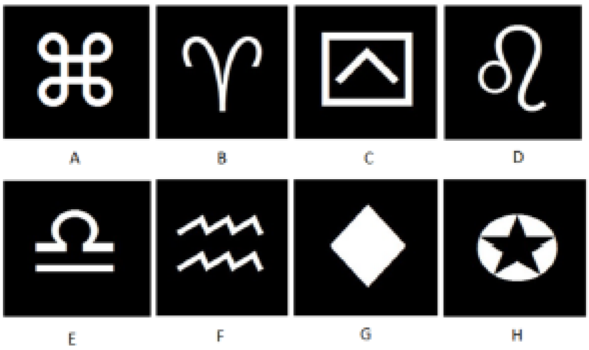

Figure 9. The stimuli used in Experiment 4.

Design. The design was the same as in Experiment 2, except for the use of eight, instead of four, physically different stimuli. Table 2 (Experiment 4) denotes all the trained relations in this experiment, which were six positive arbitrary relations and six negative arbitrary relations. There were four random assignments of stimuli to letters, and participants were randomly assigned to one of those four stimulus assignment groups.

Procedure. The computer task remained the same as in the previous experiments. Because we expected the task to be more difficult than in previous experiments as a result of the increased number of stimuli, we observed whether the first three participants reached criterion within a maximum of 17 training blocks. Because one of the three did not, we increased the maximum number of training blocks to 25 for the remaining participants.

Results

Training phase. Twenty-two participants reached criterion in an average of 11.14 training blocks (*SD* = 4.19). Two participants proceeded to the test phase without achieving criterion, one after 17 blocks (participant 23) and one after 25 blocks (participant 24). In the last two blocks, the participants who did not reach criterion responded correctly on 20 and 19 out of 24 trials.

Test phase. Figure 10 depicts the number of responses on test trials by each participant. Black lines indicate the number of class-consistent trials on which a response was made, and gray lines indicate the number of class-inconsistent trials on which a response was made.

A paired-samples *t*-test revealed a significant difference between the number of responses on consistent (M = 5.63, SD = 2.92) and inconsistent trials (M = 2.46, SD = 2.81), $t(23) = -3.03$, $p = .006$. The Bayes factor supported this difference in responding across trial types, $BF_{10} = 7.49$. Of the 22 participants who reached criterion, 14 responded in accordance with indirect stimulus class formation (participants 9-22), one participant did not respond at all during the test phase (participant 8), and the remaining seven participants responded more on trials inconsistent with the indirectly established classes than on consistent trials (participants 1-7). Of note, all the latter participants belonged to two of the four counterbalancing groups. It may be that in those groups, the stimulus classes that were predicted via indirect class formation were counterintuitive to prior beliefs the participants may have held, for example that stimuli with similar shapes belong together. Of the two participants who did not reach criterion, one participant showed more class-consistent responding (participant 24) and the other showed more class-inconsistent responding (participant 23).

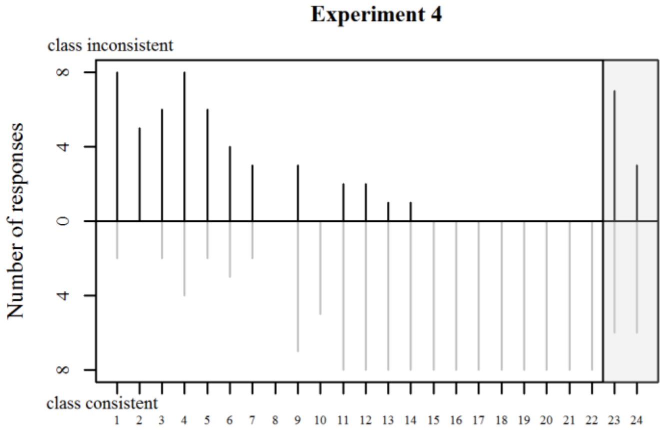

Figure 10. Experiment 4: Number of responses on test trials by participant, ordered from responding least to most class consistent. The shaded area displays participants who did not achieve the training criterion. Black lines indicate the number of responses on trials containing stimuli from different stimulus classes (class inconsistent). Gray lines indicate the number of responses on trials containing stimuli from the same merged class (class consistent).

General discussion

In four experiments, we assessed symmetry and antisymmetry in human participants using a successive MTS procedure that was modeled after previous experiments conducted in pigeons (Urcuioli, 2008). In Experiment 1, we investigated whether humans would show apparent symmetry using this procedure and found evidence for apparent symmetry, indicating that our procedural adaptations were successful. In Experiments 2 and 3, the reinforcement contingencies were altered such that apparent antisymmetry was predicted (cf. Urcuioli, 2008). In contrast to what was observed in pigeons, our human participants exhibited apparent symmetry, just as in Experiment 1. This suggests that the two species respond to different functional stimuli. For pigeons, the relative temporal location of the stimuli seems to be part of the functional stimulus (Urcuioli, 2015), effectively precluding the possibility of observing functional symmetry but allowing apparent symmetry via indirect stimulus class formation. For humans, the functional stimulus in the present procedure appears to be the physical identity of the stimuli, which allows for the observation of functional symmetry without the mediating role of indirect stimulus class formation.

Because the temporal component of stimuli is part of the functional stimulus for pigeons, there are twice as many functional stimuli in the successive MTS task for pigeons than there are for humans. This means that all the trained relations are functionally arbitrary for pigeons, which is not the case for humans (cf. Experiment 2 and 3). Experiment 4 increased the number of functional stimuli for humans by conducting MTS training with eight unique stimuli. With this procedure, humans showed the same response patterns as the pigeons (equivalent to the apparent symmetry and antisymmetry effects obtained in the pigeons), which is consistent with predictions of Urcuioli’s (2008) theory of indirect stimulus class formation.

The current results indicate that both humans (see Experiment 4) and pigeons (Campos et al., 2014; Urcuioli, 2008; Urcuioli & Swisher, 2012) can form associative classes via indirect class formation as described in Urcuioli (2008), but whether this also holds for other nonhuman animals remains to be determined (see Prichard, Panoz-Brown, Bruce, & Galizio, 2015). Humans, however, seem to be unique in demonstrating functional symmetry in successive MTS procedures without additional training (see Experiments 2 and 3). Additionally, the observed variability between participants’ scores in Experiments 1-3 was much lower than the variability in Experiment 4, indicating that functional symmetry (as observed in Experiments 1-3) is less complex for humans than indirect class formation (as observed in Experiment 4). This indicates that the functional stimulus for humans coincides with the physical identity of the stimulus, whereas for pigeons, and probably for other nonhuman animals as well, non-physical attributes such as spatial and temporal location are part of the functional stimulus (Swisher & Urcuioli, 2015). This analysis implies that it is impossible to present the same functional stimulus as both a sample and a comparison to nonhuman animals. Therefore, symmetry at the functional level is very hard to demonstrate in nonhuman animals. Moreover, it also implies that the absence of evidence for symmetry in nonhumans may not reflect a principled inability of nonhuman animals to exhibit symmetry, but merely a mismatch between the functional stimuli that actually control behavior and the functional stimuli intended by the experimenter (Zentall et al., 2014).

Humans seem to be able to respond solely to the physical attributes of a stimulus in this task. For humans, functional stimuli can thus contain only the physical characteristics (i.e., form or shape) independent of the spatial or temporal location at which they are presented. This ability might be beneficial for the development of verbal language, which emphasizes bidirectionality between two stimuli independent of spatial and temporal features (Horne & Lowe, 1996). Nonhumans, on the other hand, more readily display transitivity than symmetry (Lionello-DeNolf, 2009). This might be due to the control that the temporal and spatial features of the stimuli have over nonhumans' behavior in those sort of tasks. The antisymmetry paradigm developed by Urcuioli (2008) allows for responding based on the spatial and temporal location of stimuli and might therefore provide a fairer test of emergent relations, such as stimulus equivalence, in pigeons.

In order to further investigate the differences and similarities between humans and nonhuman animals regarding stimulus class formation, it would be interesting to train humans to respond based on the combination of both physical and temporal features. One possible way to do that is to use a set of stimuli that share some physical properties but vary on another relevant dimension, such as the same stimulus on different background colors. Based on the results of Experiment 4, we expect that humans would respond based on indirect class formation and consequently show antisymmetry when trained on procedures like those in our

Experiments 2 and 3, which would replicate the results of Urcuioli (2008, Experiment 4). Conversely, it would be interesting to see if nonhuman animals that are trained to disregard the relative temporal location of stimuli eventually come to respond in the same way as humans in the present procedure. One way to do this is to use multiple-exemplar training in which different exemplars of symmetrical relations are explicitly trained before the actual symmetry test (see Schusterman & Kastak, 1993 for the observation of functional symmetry in a sea lion after an extensive history of multiple-exemplar training).

To draw conclusions about the differences in behavior between humans and nonhuman animals on this task, we must be able to show that the differences are not due to differences in procedures. Although we based the current experiments on Urcuioli and colleagues' procedures (Urcuioli, 2008; Urcuioli & Swisher, 2012), some procedural modifications were necessary. However, these procedural differences do not prevent us from making comparisons between species for several reasons. First, the stimuli were different. In order to ensure that the participants did not have a pre-experimental history with the stimuli and that the stimuli were not easily nameable, we used checkerboards and Gabor patches rather than hues and forms. As in Urcuioli (2008), these stimuli belonged to two categories, although we do not think that this is a critical variable (as mentioned in Experiment 4, in which we abandoned the use of two categories). Second, both the sample and comparison durations could vary in our procedure, whereas they remained constant in the pigeon studies. Because we observed both functional symmetry (Experiments 1, 2 and 3) and behavior consistent with indirect stimulus class formation (Experiment 4), it seems likely that stimulus duration was not part of the functional stimulus for our participants. Third, we altered the reinforcement schedule. The pigeons in Urcuioli and colleagues' experiments experienced non-reinforcement (no food) on half of all the training trials independently of the accuracy of their responses because all negative trials (no match) ended in non-reinforcement, regardless of whether the birds pecked the comparison stimulus. In contrast, the feedback in our experiments consisted of three possibilities: a gain of points, a loss of points, or no change in points. On positive trials, responding resulted in a gain of points and not responding did not result in a gain or loss. On negative trials, responding resulted in a loss of points and not responding did not result in a gain or loss. We chose these contingencies because we expected that if responding on negative trials was not punished (i.e., response cost) participants would respond on every trial during testing. In addition, we choose to use different types of reinforcement on positive trials (gaining 100 points) and negative trials (avoiding a loss of 100 points) in order to prevent possible class merger based on the inclusion of a common reinforcer across classes.

In sum, our experiments suggest that both humans and pigeons can both respond based on indirect stimulus class formation, but only humans can readily show functional symmetry in a MTS procedure. The latter difference could be due to the fact that for pigeons but not humans, spatial and temporal features are automatically part of the functional stimuli they respond to. Future studies on stimulus equivalence in nonhuman animals should further focus on finding ways of minimizing control by the spatial and temporal properties of stimuli so that functional symmetry can be tested.

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