BRIEF REPORT

AN ANALYSIS OF INDIVIDUAL ELEMENTS OF COMPOUND STIMULI

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Compound stimuli consist of two or more elements that can be separated and potentially control behavior individually (Stromer, McIlvane, & Serna, 1993). Even though multiple elements of stimuli are present in the environment when the three- or four-term contingencies are learned, not all aspects of the compound stimuli are necessarily a controlling part of the contingency. Lack of stimulus control by the different components of compound stimuli has been referred to as selective attention (e.g., Ploog, 2011; Ray, 1969), overselectivity (e.g., Dube & McIlvane, 1999; Schneider & Salzberg, 1982) or restricted stimulus control (e.g., Dube & McIlvane, 1997; Ribeiro et al., 2015; Stromer, McIlvane, & Serna, 1993). Experiments have shown that stimulus control often restricted in non-human animals (Born & Peterson, 1969; Reynolds, 1961) and humans diagnosed with developmental disabilities and autism (e.g., Dickson et al., 2006; Lovaas et al., 1971; Stromer, McIlvane, Dube, et al., 1993) when established with simple discrimination training. Lovaas et al. (1971) found that in children without developmental disabilities and autism, all aspects of the compound stimuli controlled responding when tested separately in a simple successive discrimination training procedure. Perez et al. (2015) found similar results in a simple simultaneous discrimination procedure with college students. Whereas, restricted stimulus control has been shown after conditional stimulus control has been established in matching-to-sample (MTS) training procedure in the same population (Braaten & Arntzen, 2019; Stromer & Stromer, 1990a).

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MTS training is an efficient procedure to establish conditional discriminations among stimuli. In this procedure, participants match one of several comparison stimuli to a sample stimulus. In MTS, the initial relation between the sample stimulus and the comparison stimuli can either be identical or arbitrary. In identity MTS, participants match stimuli that are identical or have a physical resemblance to each other. Whereas, in arbitrary MTS, the stimuli are different and do not have physical similarities. Based on the programmed consequences given in the arbitrary MTS procedure, participants learn specific four-term contingencies between stimuli, defined by the experimenter.

Braaten and Arntzen (2019) tested the preference for the individual elements of four different compound stimuli in adult participants after an identity MTS procedure. The compound stimuli in these experiments were made up of simple shapes superimposed on a colored background. In both experiments, many participants repeatedly responded, in a forced-choice test, to only one aspect of the compound stimuli. The element from the compound stimuli that controlled responding (color or shape) varied across participants. The uniform responding to one element might reflect that the chosen stimulus had acquired stimulus control and not both elements of the compound stimulus. A limitation in this study was the forced-choice set-up where participants had to choose between the two correct comparison stimuli. Hence, the authors suggested as a future experiment to establish conditional discriminations with abstract and compound stimuli in an arbitrary MTS format and to test each element of the compound stimuli individually. Such an experiment would test if adults show restricted stimulus control in MTS or if the result of the Braaten and Arntzen study was an artifact of the procedure (forced-choice).

In an MTS procedure, once participants have learned several arbitrarily related stimulus-stimulus relations, one can test for the formation of stimulus equivalence classes. Stimulus equivalence is verified by the emergence of novel relations between the sample and comparison stimuli. Sidman and Tailby (1982) described that when participants relationally respond to three untrained properties: reflexivity, symmetry, and transitivity, stimulus equivalence classes have emerged. Some experiments have used compound stimuli in arbitrary MTS procedures. These experiments have tested for emergent relations by separating and rearranging the compound stimuli in different ways (e.g., Stromer & Stromer, 1990a, 1990b). Stromer and Stromer (1990a) trained 18 college students in an MTS procedure using compound stimuli and tested for equivalence relations. The compound stimuli used in the experiment were tone and color stimuli presented at the same time. Stromer and Stromer reported that 14 out of 18 participants responded consistently with the two 5-member equivalence classes and four participants that did not. These results suggest that both elements of the compound stimuli do not control responding in arbitrary MTS for some participants. Stromer and Stromer (1990b) extended their procedure by training each component of the compound stimuli (tone and color) to abstract stimuli first, before training compound stimuli to a new abstract stimulus. The results showed that stimulus control by all elements of the compound stimuli was established for a higher number of participants (13 out of 14). Hence, these results might indicate that different manipulations of the MTS arrangement can affect stimulus control to compound stimuli.

The studies mentioned have investigated compound stimuli in arbitrary MTS in humans with compound sample stimuli and simple (one element) comparison stimuli. Hayashi and Vaidya (2008) investigated the effect of establishing control with compound stimuli as a sample stimuli, comparison stimuli, or both in an MTS procedure. In their conclusion, they suggested that conditional discriminations might be easier to establish if the sample stimulus is a simple stimulus and comparison stimuli are compound stimuli than the other way around. One way to investigate the compound stimuli's function as sample or comparison stimuli and test for emergent responding can be done by comparing One-to-Many (OTM) and Many-to-One (MTO) training structures. For example, in a three-member stimulus class where the compound stimulus is the nodal stimulus, the compound stimulus would be the sample stimulus in an OTM training structure. In the MTO training structure, the compound stimulus would be the comparison stimuli.

Investigating restricted stimulus control to elements of compound stimuli in arbitrary MTS and testing for emergent responding with an additional manipulation of the training structure in adult participants has, as far as the authors know, not yet been studied. Hayashi and Vaidya's (2008) results may predict that participants trained with an MTO training structure will use fewer training trials to learn conditional discriminations. However, they did not test for emergent relations, so we do not know how such manipulation would affect emergent responding. Saunders and Green (1999) argue that the number of simple discriminations learned in conditional discrimination training predicts the outcome of a test for stimulus equivalence relations. In an MTS procedure, participants are exposed to simple discrimination when learning conditional discriminations. Based on their analysis, the MTO training structure presents all simple discriminations between all stimuli in training, whereas the OTM structure does not. This discrepancy between the number of simple discriminations presented in training might result in higher yields in stimulus equivalence tests following the MTO training structure than the OTM training structure. Saunders and Green's assumption is based on single element stimuli and not compound stimuli.

The present experiment's primary purpose is to investigate restricted stimulus control with compound stimuli in adult participants in arbitrary MTS and emergent responding. To do so, participants will learn conditional discriminations with some compound stimuli in an arbitrary MTS procedure with a 0-s delay, followed by a test for equivalence class formation with elements of the compound stimuli tested individually. A secondary purpose is to investigate if the function of the compound stimuli either as a sample stimulus or comparison stimulus in the MTS procedure would affect potential restricted stimulus control. For this purpose, two groups, one trained with OTM training structures and one with MTO, will be compared.

METHOD

Participants

Twenty-six female and four male (age 19–53) university students participated in the experiment. Participants signed a consent form where they were informed in general terms about the experimental situation, their rights, and the experiment's approximated duration (one hour). All participants were shown their data and thoroughly debriefed about the research.

Setting

Two rooms were used to conduct the experiment. One room was $13m^2$, had two windows covered with blinds, and furnished with chairs and tables. The second room was without windows and organized with dividing walls creating two small cubicles. Each cubical was 2.7 m^2 and equipped with one table and one chair

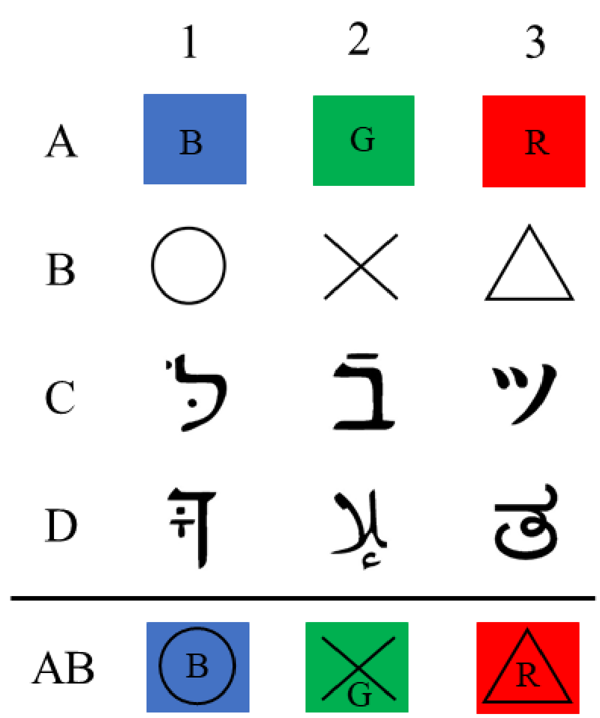
Apparatus and Stimuli

Participants were trained and tested on laptop computers with Windows 8 operating system and connected with an external mouse. One computer had a 15.6-inch screen, and the other one had a 17-inch screen. Custom-made matching-to-sample software ran the training and testing, controlled stimuli presentation, and registered participants' responses.

The same set of stimuli were used in both groups (see Figure 1) and consisted of 12 stimuli, potentially partitioned into three classes. The stimuli-set contained three color stimuli (A), three shape stimuli (B), and six abstract stimuli (C and D). In training, one compound stimulus was trained to two abstract stimuli. The compound stimuli consisted of shape stimuli superimposed on color stimuli AB (see Figure 1, the letters indicate which background color each stimulus had, and were not on the stimuli). The three compound stimuli were a circle on a blue (B) background, a cross on a green (G) background, and a triangle on a red (R) background. In the test, elements of each compound stimuli were separated and presented individually (stimuli A and B in Figure 1). All stimuli were approximately 5 cm x 5 cm on the screen.

The participants were asked to sort laminated printouts of the stimuli before training to ensure that they were not familiar with the experimenter-defined stimulus classes.

Figure 1
Experimental Stimuli in Both Conditions



Note. The stimuli used in training and testing. The letters on the left side denote class members, and the number on the top denotes the class. AB stimuli on the bottom are the compound stimuli made up of A and B stimuli merged on top of each other. The letters on the A and AB stimuli represents the color of the stimuli, and were not on the stimuli used in the experiment. B=blue, G=green, and R=red.

Design

Participants were randomly assigned into two groups. In one group, participants were trained with an OTM training structure, hereafter called OTM-group. Here, the compound stimuli were the nodal stimuli, always presented as sample stimuli. Participants in the other group were trained with an MTO training structure, hereafter called MTO-group. Again, the compound stimuli were nodal stimuli, but the compound stimuli served as comparison stimuli in this condition.

Procedure

Instruction

Participants were seated in front of a computer and presented with the following instruction on the screen (translated from Norwegian):

"A stimulus will appear on the screen. You must click on this with the mouse. Three stimuli will appear. Select one of these by clicking the mouse. If you choose the one we have defined as correct, words like "good," "super," etc., will appear on the screen. If you press incorrectly, "wrong" will display on the screen. During the experiment, the computer will not provide feedback on whether your choices are correct or incorrect, but based on what you've learned, you can get all the tasks right. Do your best to get everything correct. Good luck!"

To advance to training, participants had to press the "START" button below the instruction.

Training

The purpose of the training phases was to establish six conditional discriminations. Participants in the OTM-group were taught A1B1-C1, A2B2-C2, A3B3-C3, A1B1-D1, A2B2-D2, A3B3-D3 relations, whereas participants in the MTO-group learned C1-A1B1, C2-A2B2, C3-A3B3, D1-A1B1, D2-A2B2, D3-A3B3 relations. Each trial began with a sample stimulus in the middle of the screen, and after a mouse click on the sample stimulus, it disappeared, and three comparison stimuli appeared on the screen with a 0-s delay. Here, participants had to choose one of three comparison stimuli. If they chose the experimenter-defined correct comparison, words like "correct," "good," etc., appeared in the middle of the screen. If they chose the experimenter-defined wrong comparison, the word "wrong" appeared on the screen. The programmed consequences were on the screen for 1 s, followed by a 0.5 s intertrial interval before the next trial. For each trial, the three comparison stimuli appeared randomly in the four corners of the screen. The baseline relations were established concurrently in blocks of 30 trials. Each relation was presented five times in a block and in random order. After one block with 90% correct or more, the probability of programmed consequences was reduced to 75%, 25%, and then 0% in the consecutive blocks. If the mastery criterion of 90% correct was not reached, the last block was repeated.

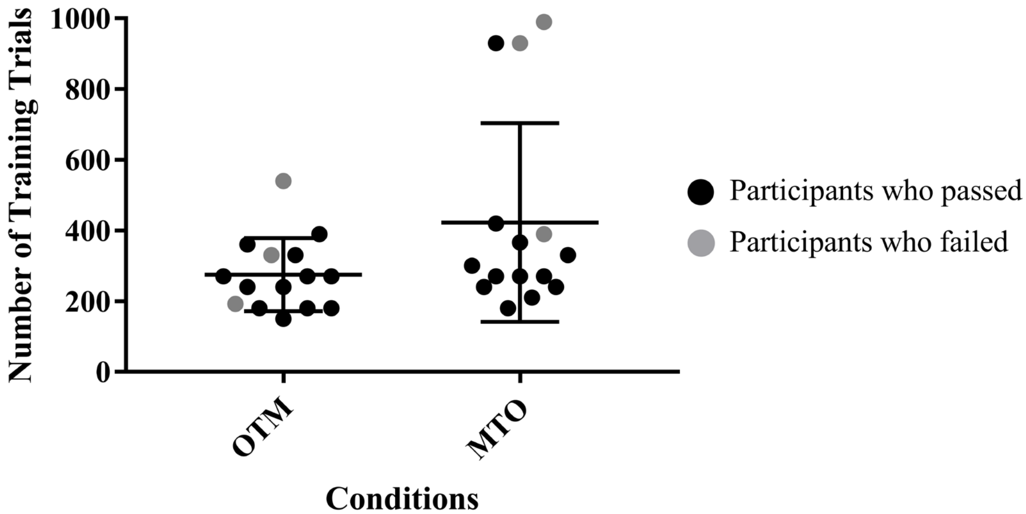
Testing

Testing Phase 1. The first testing phase's purpose was to test for baseline (BSL) and symmetry (SYM) relations with the compound stimuli. In this test, all compound stimuli were as in training, made up of shape and color. The test trials had the same set-up as in training. The test consisted of 60 trials: 30 BSL trials same as in training, and 30 SYM trials: C1-A1B1, C2-A2B2, C2-A3B3, D1-A1B2, D2-A2B2, D3-A3B3 for the OTM-group, and A1B1-C1, A2B2-C2, A3B3-C3, A1B1-D1, A2B2-D2, A3B3-D3 for the MTO-group. All trials were presented in random order.

Testing Phase 2. The purpose of the second testing phase was to test BSL, SYM, and equivalence (EQ) relations presenting each element of the compound stimuli at the time to evaluate if one part of the compound stimuli exerted more control of responding than the other. The second test phase started immediately after the first test, independently of the performance in Test 1. In Test 2, compound stimuli were separated, and each element was presented individually on the screen in each trial, shown as stimuli A and B in Figure 1. All participants, regardless of training structure, were tested for 30 trials similar to BSL relations with only color stimuli (BSL-C), 30 trials similar to BSL relations with only shape stimuli (BSL-S), 30 trials similar to SYM with only color stimuli (SYM-C), 30 trials similar to SYM with only shape stimuli (SYM-S), and 30 EQ trials: C1D1, C2D2, C3D3, D1C1, D2C2, D3C3 for both groups.

Figure 2

Number of Training Trials in Each Condition



Note. The black dots represent participants who passed Test 1, and the grey dots represent participants who failed Test 1 in the OTM and MTO condition. OTM=One-to-many, MTO=one-to-many.

In total, there were 150 test trials. The set-up was the same as in training and Test 1.

Mastery Criterion in Test 1 and Test 2. The mastery criterion for both tests was 95% correct for each relation. Participants with mastery below 95 percent in either baseline or symmetry relations on Test 1 were excluded from the experiment's last part. The criterion was set to exclude participants that did not establish the stimulus classes with the compound stimuli in Test 2. This way, to a higher degree of certainty, one could conclude that any incorrect responding in Test 2 was due to the separation of the compound stimuli.

RESULTS

Fifteen participants in each group finished the experiment with an average of 275 training trials in the OTM condition (range=150–540) and an average of 422 training trials in the MTO condition (range=180–990). Figure 2 displays the number of training trials for each participant. The black and grey circles denote those participants who passed and failed Test 1, respectively. An independent-samples t-test was conducted to compare the number of training trials in the OTM and MTO conditions. The test showed no significant difference in the number of training trials for the OTM (M=274.8, SD=103.1) and the MTO (M=422.4, SD=280.9) conditions; p=0.0664.

Results from Test 1 and 2 for participants in both groups are shown in Table 1. Here, performance above the criterion (95% correct) is written in bold. When presented with BSL and SYM test trials with the compound stimuli, three participants in each group did not reach criterion in one or both relations. These participants were excluded from further analysis. Eight participants in the OTM-group passed Test 2, and seven participants passed in the MTO-group. Fisher's Exact Test indicate a non-significant difference in test outcome on Test 2 between the groups (p=1). The four participants who did not reach the criterion in the OTM-group responded incorrectly on trials testing the color or the shape aspect of the compound stimuli. P17185 had incorrect responses when presented with the color stimuli in BSL trials, whereas P17171 responded incorrectly when the shape stimuli were presented in BSL trials. P17178 had a total of 42

Table 1

Overview of Results

OTM

Participant	Test 1 - Compound		Test 2 - Compund Separated				
#	BSL	SYM	BSL Color	BSL Shape	SYM color	SYM shape	EQ
17151	**30**	**30**	**30**	**29**	**29**	**30**	**30**
17159	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17160	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17162	**30**	**30**	**30**	**29**	**30**	**30**	**30**
17167	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17180	**29**	**30**	**30**	**30**	**30**	**30**	**30**
17181	**30**	**30**	**29**	**30**	**30**	**30**	**29**
17170	**30**	**30**	**30**	**29**	**30**	**30**	**29**
17158	**30**	**29**	28	**30**	**30**	**30**	**29**
17171	**29**	**30**	**30**	28	**30**	**30**	**30**
17178	**29**	**30**	8	**30**	10	**29**	**30**
17172	**29**	**30**	27	28	28	28	28
17154	**30**	27					
17175	**30**	27					
17164	28	28					

MTO

Participant	Test 1 - Compound		Test 2 - Compund Separated				
#	BSL	SYM	BSL Color	BSL Shape	SYM color	SYM shape	EQ
17152	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17163	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17166	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17177	**30**	**30**	**30**	**30**	**30**	**29**	**29**
17168	**30**	**30**	**30**	**30**	**29**	**30**	**30**
17173	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17179	**30**	**30**	**30**	**30**	**30**	**30**	**30**
17161	**30**	**29**	**30**	**30**	**30**	27	**30**
17169	**30**	**30**	**30**	27	**30**	28	**29**
17156	**29**	**30**	**29**	26	**29**	28	28
17165	**30**	**30**	**30**	10	**30**	10	**30**
17176	**29**	**29**	**30**	28	**30**	28	**30**
17157	28	**29**					
17153	26	25					
17155	24	19					

Note. The table shows the number of correct responses made in Test 1 and Test 2 for each relation. Performance above the mastery criterion (95%) is in bold. The three last participants in each group did not meet the criterion in Test 1 and did not advance to Test 2. BSL=baseline, SYM=symmetry, EQ=equivalence.

incorrect trials in Test 2. All incorrect trials were made regarding color stimuli, both in trials testing BSL and SYM relations. P17172 responded below the criterion in all relations tested, including EQ relations.

All five participants who did not reach the mastery criterion in the MTO group responded below the criterion in trials testing shape stimuli. P 17161 responded only incorrectly in SYM-S trials, where all the others did so in both BSL-S and SYM-S trials. All of those had two to four incorrect trials, whereas P17165 had 40 incorrect trials in both relations testing with shape stimuli. P17156 was the only participant that did not reach the criterion on EQ trials.

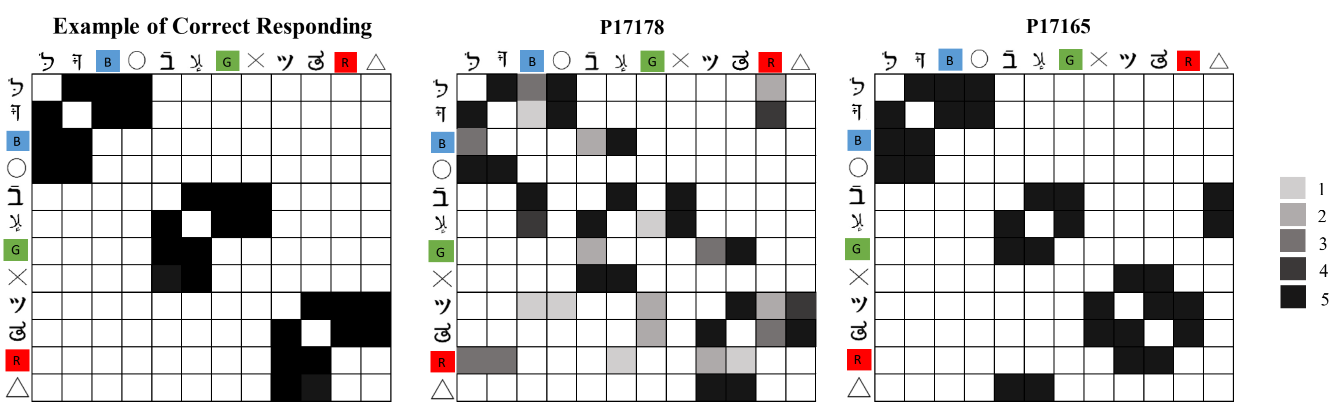
The test performance of the two participants with the most incorrect trials in Test 2 is displayed as a response matrix in Figure 3. Here, the vertical stimuli on the left side of the matrix represent sample stimuli, and the horizontal stimuli on the top of the matrix represent chosen compound stimuli. The different colors, from light grey to black, represent the number of responses illustrated on the right side of the figure. The left matrix exemplifies how the matrix would look if a participant responded correctly to all trials. The responses of P17178 in the OTM group are shown in the middle matrix. This participant had 22 incorrect test trials in BSL-C and 20 incorrect trials for SYM-C relations, and the incorrect responses to color stimuli were random without any pattern of responding. This response patten show a lack of stimulus control to all color stimuli. The right matrix shows responses of P17165 from the MTO group. This participant had 20 incorrect trials in both BSL-S and SYM-S relations, and systematically responded to the cross when the triangle was correct and vice versa. This response pattern shows participant-defined stimulus control.

DISCUSSION

In both groups, 12 out of 15 participants responded within the criterion on baseline and symmetry relations in Test 1. Thought, when exposed to Test 2, where the compound stimuli were separated, 33.3% of participants in the OTM-group and 42% in the MTO-group did not reach the test's mastery criterion (95%). For these participants, both elements of the compound stimuli did not control responding.

Figure 3

Response Matrix for Two Participants



Note. The response matrix display responses made in Test 2. Stimuli on the left side of each matrix represent sample stimuli, and the stimuli on the top represent the comparison stimuli chosen by the participants. The matrix on the left is an example of 100 % correct responding. The different colors illustrate the number of responses made for each relation, labeled on the right side.

In this experiment, one might have expected a higher number of participants reaching the criterion in Test 2 for several reasons. Firstly, OTM and MTO training structures often result in high yields in stimulus equivalence relations (Arntzen, 2012). Also, variables such as small and few classes (Arntzen & Holth, 2000), meaningful stimuli (Fields & Arntzen, 2018), and training and testing with a 0-s delay (Arntzen, 2006; Bortoloti & de Rose, 2009) generally increase the probability of responding in accordance with stimulus equivalence. Lastly, stimuli used in the three compound stimuli are very familiar to the participants. Therefore, it is surprising and interesting that more than one-third of the total number of participants responded incorrectly when the compound was separated, and the elements were tested individually. The present experiment results differ from Lovaas et al. (1971) and Perez et al. (2015) that did not show restricted stimulus control in healthy children or adults, respectively. On the other side, the results support Braaten and Arntzen (2019) and Stromer and Stromer (1990a) that some adult participants show restricted stimulus control.

The present results show no statistical difference between the MTO and the OTM groups regarding equivalence class formation in Test 2. These results oppose Saunders and Green's simple discrimination analysis (1999), which predicts higher yields in equivalence class formation following training with an MTO training structure than an OTM training structure. Saunders and Green's discrimination analysis are based on simultaneous matching between sample and comparison stimuli. In the present experiment, a 0-s delay between the offset of the sample stimulus and the onset of the comparison stimuli was used. A delayed MTS procedure creates successive discriminations instead of simultaneous discrimination between the sample stimulus and the comparison stimuli. Saunders and Green do not discuss this variance of the procedure or how this would affect the outcome. Though, they do argue that simple successive discriminations are more difficult than simple simultaneous discrimination. Saunders and Green emphasize that the discrepancy between the number of simple discriminations embedded in the training structures increases when the class size and number of classes increase, leading to a greater difference in outcome between the two training structures. They also write that when training with few and small classes, differences between outcome might not be as evident (p.129), which might be the case for the present experiment.

There are differences between the two groups in the present experiment regarding participants' responding to the compound stimuli' elements for those who failed Test 2. Participants in the MTO-group only responded incorrectly to shape stimuli, not color. Whereas in the OTM-group, participants responded incorrectly to both color and shape stimuli. The main difference between the two conditions is that the compound stimuli serve as sample stimuli in the OTM training structure and as comparison stimuli in the MTO training structure. Thus, the compound sample stimuli are successively discriminated from each other in OTM, and the compound comparison stimuli are simultaneously discriminated from each other in MTO. Arguably, presenting all the compound stimuli on the screen together, the color stimuli are the most immediate visually discriminable feature of the compound stimuli. All the shape stimuli are black and, though familiar, maybe not visually impactful. The present results indicate that simultaneous discrimination of the compound stimuli might have resulted in an increased probability of stimulus control to the more outstanding or salient part of the compound stimuli, the color. Contrary, when compound stimuli are successively discriminated as sample stimuli, the compound stimuli are not pitted against one another. Hence, whether participants responding are under control of the shape or color might be the result of participants' preference (learning history) for the color or shape of that particular compound stimuli and not because of a comparison of the compound stimuli as sample stimuli, resulting in more variation in what aspect of the compound stimuli controlled behavior. Future research could vary the compound stimuli functions and the stimuli that compose the compound stimuli to investigate this potential effect of simultaneous and successive discrimination on restricted stimulus control. Also, one could include more complex or unfamiliar stimuli as the compound stimuli.

The BSL and SYM relations in Test 2 are of most interest in terms of evaluating restricted stimulus control. However, the equivalence trials are interesting to assess whether participants fully formed equivalence classes. Only P17172 in OTM-group and P17156 in MTO-group did not reach the criterion in EQ trials. They had incorrect trials in other relations tested, see Table 1. Both responded correctly in Test 1, which shows that the separation of the compound stimuli disrupted class formation. All the other participants establish 3 three- or four-member equivalence classes with one or both aspects of the compound stimuli, respectively, as a part of the class.

Two participants stand out due to a high number of incorrect trials in Test 2, illustrated in Figure 3. P17165, in the MTO group, had 20 incorrect trials. This participant systematically responded to the cross when the triangle was correct and the triangle when the cross was correct. Such a pattern of responding is an example of participant-defined classes as opposed to experimenter-defined classes. The participant responded correctly to the circle stimuli, as defined by the experimenter. In the OTM-group, P17178 had 23 incorrect trials, mostly to color stimuli. This participant responded incorrectly to all colors indicating a general lack of stimulus control and not participant-defined class formation. Individual differences as to what aspect of the compound controls responding have been shown in pigeons (Reynolds, 1961) and humans (Braaten & Arntzen, 2019).

The results from this experiment show that participants used, on average, approximately 50% more training trials to learn the six conditional discriminations with an MTO training structure compared to the OTM training structure. This result was not significant, though it might indicate that learning conditional discriminations with an MTO training structure with compound stimuli as comparison stimuli were more challenging. Hayashi and Vaidya (2008) argued that discriminability is a more critical feature then complexity. "…(T)he stimuli that are more readily discriminated should be positioned as the sample and those less readily discriminated as the comparison stimuli" (p.182). In the present experiment, the simple stimuli were abstract shapes unfamiliar to the participants (see Figure 1), and the compound stimuli were well-known shapes and colors. In terms of discriminability, it is difficult to conclude that the compound stimuli in the present experiment are more difficult to discriminate than the abstract, unfamiliar shape; actually, it might be the opposite. Participants have a long history with squares, triangles, and circles and the colors; blue, green, and red, making those stimuli potentially easier to discriminate than the abstract stimuli. Therefore, it is challenging to draw any conclusions on whether current results support or oppose Hayashi and Vaidya.

Finally, the present results have valuable contributions by elucidating that restricted stimulus control occurs under specific conditions in conditional discrimination procedures in adult humans without a diagnosis, which has practical implications that should be considered when establishing stimulus control to complex stimuli. Simultaneously, this experiment shows that small manipulations of the MTS procedure and a fine-grained analysis can increase knowledge regarding the stimulus function in a four-term contingency and the role of simple simultaneous and successive discriminations in conditioned discriminations and stimulus equivalence class formation.

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