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Stimulus Equivalence and Supplemental Measures on Equivalence relations

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Summary

The stimulus equivalence paradigm has shown to be amenable to experimental simulations of generative behavior such as problem-solving, remembering, language, and concept formation. This experimental approach investigates how novel behavior can generate from something that has never been directly taught. In specific, data from equivalence studies has repeatedly shown that unreinforced relations among physically arbitrary stimuli can emerge following the acquisition of some stimulus relations. Article 1 introduces stimulus equivalence as a research strategy that typically administrates conditional discrimination procedures and evaluates responding according to a descriptive system that is identified by a set accuracy criterion. Variables shown to affect stimulus equivalence will be discussed, as well as future directions on potential relevant measures will be proposed. Article II presents an empirical study on the effects of discriminative functions by stimuli as independent variables through the acquisition of conditional relations, response time to novel stimulus relations during test trials, and outcome on equivalence class formation in conditional discrimination testing. Additionally, a stimulus sorting test is explored by means of an alternative test on class formation.

Stimulus Equivalence and Supplemental Measures on Equivalence Relations

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Abstract

The present article introduces stimulus equivalence research as an experimental analysis on how previously unrelated stimuli can generate a specific pattern of responding without being directly taught. Murray Sidman and colleagues set forth that stimulus equivalence should be considered as a basic process in line with other behavioral processes such as reinforcement, discrimination, or generalization. In specific, a direct outcome of the reinforcement contingencies that have previously been in effect during the establishing of some stimulus relations. Stimulus equivalence entail that physically arbitrary stimuli within a class is functionally substitutable to one another, and their relations are defined as equivalent only after the occurrence of a specific pattern of responding. Studies on stimulus equivalence have traditionally focused on accuracy scores after exposure to the required testing contingencies. However, a number of studies have reported that equivalence relations do not always reliably emerge. Data have shown that different experimental parameters can be used to systematically manipulate the likelihood of equivalence class formation. Thus, indicating that the current theoretical and methodological account is fairly limited with respect to the prediction and control of the relevant variables influencing equivalence relations. Consequently, the present article will emphasize on potential supplemental measures on equivalence relations that might enable further elaboration and directions within stimulus equivalence research.

Keywords: complex stimulus control, conditional discrimination, stimulus equivalence, parameters, measures

Stimulus Equivalence and Supplemental Measures on Equivalence Relations

In our everyday speech, we say that one has a concept and that certain things or words appear meaningful, familiar, or less understandable to one. We often respond appropriate to both similarities and arbitrary events in our surroundings. We frequently adapt to new situations, compose utterances, solve problems, and identify items without previously having emitted the behavior. The underlying processes of these repertoires have been debated among philosophers, psychologists, and scientists for numerous of decades. There seems to be a divergence not only because of different connotations in our vocabulary, but also what the actual subject matter of study is (e.g., Murphy, 2002; Palmer, 2002; Sidman, 1994).

Within behavior analytic terms, one does not possess a concept, one act in a certain way to specific stimuli (Keller & Schoenfeld, 1950). That is, a given class of stimuli will generate the same response or alternatively occasion responding to other stimuli within the same class. For instance, the sight of a car, its sound or smell, a Duplo car, Ford, or a Bentley may all produce the verbal response “car” even though they do not share common modalities or formal properties. As words and symbols enter into classes, we may even sometimes react to them as if they were equivalent to the actual things they refer to. Stimulus classes are continuously altered and expanded, and class members will simultaneously belong to more than one class. The present paper will introduce a research strategy of studying complex stimulus control among physically arbitrary stimuli that appears as equivalent to one another. Namely, conceptualized by Sidman and colleagues (e.g., Sidman & Tailby, 1982), stimulus equivalence as a specific pattern of responding originated from the reinforcement contingencies. Nevertheless, questions derived from their analysis will be described due to a number of studies showing that these patterns of responding can be systematically manipulated with different procedural variations. The conditions under which these behavior-environment relations occur are regarded as important both for the general concern of the phenomena as well as by how these functional relationships can be specified through careful experimental manipulations. Lastly, future directions on the study of equivalence relations will be proposed as this may facilitate a comprehensive account on stimulus equivalence. That is, both in the guidance of research questions as well as instructional programs operating with an effective technology of teaching educational skills.

Stimulus equivalence

The stimulus equivalence paradigm refers to the study of untaught behavior derived from directly taught relations among some stimuli in a class. A great curiosity of basic research in the field of stimulus equivalence and conditional discrimination learning experiments was shown after Sidman (1971) published an article from a behavioral study of language. The results demonstrated how unreinforced behavior could derive under new contextual cues. The experiment was conducted with a conditional discrimination procedure, and the participant was a 17-year-old boy with developmental disabilities. He was earlier known to match spoken words to pictures and naming of visually presented pictures. The participant was not capable of oral reading and showed no comprehension of written words. After training conditional relations between dictated words to corresponding written words and dictated words to corresponding visual pictures, correct matching of pictures to words and words to pictures emerged. Additionally, he named written words without being directly taught to do so. These previously arbitrary stimulus relations were described as to be equivalent to one another, and later redefined as stimuli being substitutable for each other (Sidman, 1971, 1994). That is, distinguishable from similarity based classes as they are not a product of primary stimulus generalization or required to share physical attributes. Moreover, different from functional stimulus classes as they necessarily do not possess identical behavioral functions (Green & Saunders, 1998).

The methodology of studying equivalence relations in behavior is normally conducted with conditional discrimination procedures, also named matching-to-sample. This has mainly been done with computers automatically presenting stimuli in training and test trials of at least two or more predefined classes. For example, an equivalence class with three class members can be established by training conditional relations of A to B, and B to C (A→B→C). Tests for derived relations would then be presented as BA, CB, AC, and CA. With three potential equivalence classes, all training and test trials begins with a sample stimulus (e.g., A1) followed by presentations of comparison stimuli (e.g., B1, B2, and B3) and choice requirement of an appropriate stimulus (e.g., B1). For descriptive purposes, the designated letters are typically symbols for distinctive class members and the numbers signify class membership. Programmed consequences of a 100% are given during the establishing of conditional relations, and the maintenance of the directly trained relations is ensured with a gradual fading of consequences. A potential equivalence class must consist of at least three or more stimuli, and is further inferred after testing properties of reflexivity, symmetry, and transitivity without differential reinforcement (Sidman & Tailby, 1982). Reflexivity is demonstrated if the participant matches a comparison identical to the sample stimulus. Each stimulus must bear a relation to itself (e.g., if A1 then A1, and not A2 or A3). This has also been described as identity matching. Symmetry is demonstrated if responding to the conditional relation between sample and comparison stimuli is reversed (e.g., if A1B1, then B1A1, and not B1A2 or B1A3). That is, the discriminative functions of the stimuli are bidirectional. Transitivity is demonstrated if the linkage of directly trained relations results in correct matching of a comparison that has never been concurrently presented with a sample during training (e.g., if A1B1 and B1C1, then A1C1, and not A1C2 or A1C3). A combined test of equivalence may also be done by testing for symmetry and transitivity simultaneously (e.g., if A1B1 and B1C1, then C1A1, and not C1A2 or C1A3).

Equivalence relations are merely inferred after positive tests of reflexive, symmetrical, and transitive properties, as in the mathematical definition of equivalence. This account encloses the term *relation* as an empirical concept based on patterns of responding to stimuli in potential classes. A restricted behavioral definition of equivalence may thereby avoid hypothetical constructs of some unobservable entities such as knowledge, memory, intention, and so forth. Sidman (1994, 2000) has argued that equivalence relations derive as a direct outcome of the reinforcement contingencies. That is, the reinforcement contingency establishes prerequisites for the properties that entail stimulus equivalence responding. Equivalence relations do not consist of components from basic units, but is rather analogous to other fundamental behavioral processes such as reinforcement, discrimination or generalization. According to Sidman (1994), potential equivalence classes can be further partitioned by a participants learning history, contextual control established during training contingencies, or test conditions. There are, however, other views on stimulus equivalence and its origins (see e.g., Hayes, Barnes-Holmes, & Roche, 2001; Horne & Lowe, 1996). Contrary to seeing stimulus equivalence as a basic process, equivalence relations are predicted to emerge as a product of particular learning histories. For instance, issues have been raised whether equivalence relations exist before verbal behavior, or if verbal behavior might be a necessary prerequisite for equivalence relations. In parallel, Sidman (1992, 1994) have implied that individual learning histories such as verbal behavior may break down equivalence relations into new classes. Even though equivalence classes are facilitated by verbal behavior, there are still no conclusive data on its origins (e.g., Moore, 2009; Sidman, 2000; Stromer & Mackay, 1996). Other accounts, however, have proposed that equivalence relations may derive from stimulus pairings or environmental stimulus correlations independently of the reinforcement contingencies (e.g., Minster, Elliffe, & Muthukumaraswamy, 2011; Tonneau, 2001).

In general, research has shown that the descriptive system of stimulus equivalence can be a valuable predictor. On the other hand, several experiments have also revealed that predefined equivalence classes not reliably emerge as initially suggested. Procedural variations have demonstrated that likelihood of equivalence class formation can be systematically manipulated (e.g., Arntzen, 2012). These findings have further led to questions of whether the properties of reflexivity, symmetry, and transitivity entail equivalence relations, or if the derived relations may be separable component processes that must be analyzed in its own right (e.g., Pilgrim & Galizio, 1996). Correspondingly, a closer examination on the variables affecting stimulus equivalence may provide a more molecular analysis on equivalence relations, as well as to clarify the generality of the phenomena. The following section will emphasize some of the different variables shown to influence equivalence class formation, and potential relevant aspects on equivalence relations will finally be proposed.

Variables and likelihood of stimulus equivalence

Various experimental approaches have been outlined to examine variables that either prohibit or enhance equivalence class formation. In specific, experimental manipulations have been done with reinforcement contingencies, response requirement to sample, sample and comparison introductions (i.e., simultaneous or delayed matching-to-sample), instructions, time restrictions, stimuli of different modalities and attributes, expansion of classes and members, training structures and nodal numbers, as well as how training and test trials are introduced (see Arntzen, 2012; Fields & Moss, 2007; Sidman, 1994, for an overview). These variables have more or less been shown to influence the acquisition of conditional relations and outcome on equivalence tests. However, the effects also seem to depend on population and age differences (see e.g., Fields, Adams, & Verhave, 1993).

Training arrangements. The training and test blocks can be arranged in three different sequences: simple-to-complex, complex-to-simple, and the simultaneous protocol. Each of these protocols is distinct in regard to when training and test trials are introduced, and will consequently generate a different outcome (Imam, 2006). For instance, several studies have shown that the simultaneous protocol, which requires acquisition of conditional relations prior to the introduction of test blocks, is less likely to establish equivalence relations (Fields, Landon-Jimenez, Buffington, & Adams, 1995; Fields et al., 1997). Furthermore, the main three training structures used in conditional discrimination procedures are one-to-many (OTM), many-to-one (MTO), and linear series (LS). In OTM, also named sample-as-node, a sample stimulus is trained to two or more comparison stimuli. The MTO structure is arranged with at least two or more sample stimuli trained to one comparison stimulus, hence the name comparison-as-node. In LS, one sample stimulus is trained to a comparison stimulus, and then the same comparison stimulus is used as a sample for a new comparison.

According to earlier papers by Sidman and colleagues (1994), temporal or structural aspects such as the arrangement or training order should not affect the likelihood of outcome on stimulus equivalence. Their analysis implies that a proper training contingency that excludes competing stimulus control repertoires will establish the predefined conditional relations, and further lead to the formation of equivalence classes. However, obtained data have shown that retention of directly taught relations during training and test trials not always lead to predicted derivative relations among stimuli (Arntzen & Haugland, 2012; Eilifsen & Arntzen, 2009). Others have reported data on consistent, but incorrect responding according to the experimenter defined classes although conditional relations had been established in training (Arntzen & Holth, 2000; Holth & Arntzen, 1998, 2000). A number of studies have also demonstrated differential probabilities of stimulus equivalence with different training arrangements. For instance, the use of a LS structure under a simultaneous protocol has consistently been reported as the least effective when compared to OTM and MTO (Arntzen, Grondahl, & Eilifsen, 2010; Arntzen & Holth, 1997, 2000; Saunders, Chaney, & Marquis, 2005). Obtained results on the differences between OTM and MTO have been diverse (e.g., Arntzen & Holth, 1997, 2000; Saunders et al., 2005; Saunders, Drake, & Spradlin, 1999), as well as relatively small differences between the two structures have been reported (Arntzen et al., 2010; Arntzen & Hansen, 2011; Arntzen & Nikolaisen, 2011; Smeets & Barnes-Holmes, 2005).

Procedural variability across experiments makes it difficult to evaluate specific variables that are most effective in establishing equivalence classes. However, there have been several suggestions on the disparities found between these training structures. As proposed in Saunders and Green's (1999) discrimination analysis, differential outcomes can be influenced by how simple discriminations are embedded in conditional discriminations. All experimental stimuli must be discriminated from every other stimulus during training, and the authors predict that only the MTO structure can establish basic component skills of successive and simultaneous discriminations among stimuli. That is, in a MTO structure with AC and BC training, both successive discriminations among sample stimuli (i.e., A1 from A2, or B1 from B2) and simultaneous discriminations between comparison stimuli (i.e., C1 vs. C2) are presented. According to Saunders and Green (1999), simultaneous discriminations are more easily acquired than successive. Successive discrimination training is further assumed to automatically lead to simultaneous discriminations. Accordingly, when equivalence tests of AB and BA are introduced in a MTO structure, the prior successively discrimination trained A and B as samples will be less difficult to acquire when presented concurrently as comparisons in tests. The LS and OTM structures does not involve all necessary simple discriminations in training, and will therefore decrease likelihood of class consistent responding. Differences between the training structures are expected to be more pronounced as a function of additional untrained simple discriminations when class size or number of classes expands (Saunders & Green, 1999). However, recent studies have shown divergent results when training structures have been compared. In a single-subject design, participants were made to subsequently form three 4-member classes after establishing three 3-member classes (Arntzen et al., 2010). Obtained data showed no significant differences between OTM and MTO. The same trend was observed when class members increased from three to six in three potential equivalence classes in a between-subject design (Arntzen & Hansen, 2011). Thus, signifying that other variables than the number of simple discriminations could be relevant. Furthermore, Arntzen (2011) questioned whether different processes should be associated with the three different training structures. Such as in the LS structure, where nodal stimuli function both as sample and comparisons in several conditional relations prior to testing.

Nodal stimuli. One can only study the effects of nodal stimuli with the use of a LS training structure, whereas increasing class members in OTM and MTO are not affected by the number of nodes (Arntzen et al., 2010; Arntzen & Hansen, 2011; Saunders & Green, 1999). Nodal stimuli are conditionally related to two or more stimuli, and singles are stimuli trained in relation to one stimulus. For instance, a 5-member class with AB, BC, CD, and DE as directly trained relations comprises three nodal stimuli. The 1-node relations will then be presented as AC, CA, BD, DB, CE, and EC, 2-nodes as AD, DA, BE, and EB, and 3-nodes as AE and EA. The stimuli A and E are defined as singles, and the B, C, and D stimuli as nodes included in potential transitive and equivalence relations. According to Fields and colleagues (e.g., Fields, Adams, & Verhave, 1993; Fields & Verhave, 1987), stimuli within a class are inversely related by the number of nodes that separates them in training. This account questions the relational strength among stimuli contrary to seeing them as equally substitutable within a class. Data have shown a positive relation between accuracy and the number of nodes. In particular, accuracy of responding have been demonstrated to decrease as a function of number of nodes in the absence of class formation, as well as for those showing improved responding during repeated test blocks (e.g., Bentall, Jones, & Dickins, 1998; Fields, Adams, Verhave, & Newman, 1990; Kennedy, 1991; Spencer & Chase, 1996). In addition, the behavioral functions trained to stimuli within potential equivalence classes may also be inversely related by the numbers of nodes that separated them in training (e.g., de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; Fields, Adams, Verhave, & Newman, 1993; Fields et al., 1995). By contrast, one might question whether demonstrated effects of nodal numbers can be due to some methodological artifacts. As discussed by Imam (2006), there will be an unbalanced number of training trials when trial types are trained in a serial manner. That is, first AB, then BC, CD, and lastly DE. The conditional relations introduced in the beginning (i.e., AB) may possibly be overtrained when compared to the ones introduced at the end of training (i.e., DE). An unequal reinforcement history could therefore influence nodal effects unless the trial types are automatically equalized or trained concurrently. Even though some studies (Fields et al., 1995; Fields & Watanabe-Rose, 2008) have demonstrated nodal effects with the abovementioned precautions, a possible confound will still exist with the use of two potential equivalence classes. That is, extraneous stimulus control might be established by two instead of three comparisons during conditional discrimination training. Carrigan and Sidman (1992) questioned whether this may increase the possibility of rejecting comparisons instead of observing the sample and consequently selecting the correct comparison. Similarly, discriminative control of a particular stimulus or an attribute within the stimulus compound may also be present (e.g., Dube & McIlvane, 1996). In order to investigate whether participants attended to the predefined relations, Moss-Lourenco and Fields (2011, Experiment 3) employed a third null comparison with two potential 5-member classes in concurrent training of all trial types under a simultaneous protocol. Participants were then exposed to a within-class preference test that required them to choose among stimuli within the previously established equivalence classes. Results showed that participants preferred the comparisons that were approximately closer by the number of nodes during training. In addition, maintenance of the previously established equivalence classes was verified when participants were re-exposed to a between-class test. Thus, demonstrating the presence of two forms of contextual control during within- and between-class testing formats.

Stimuli attributes. In order to ensure valid inferences of independent variables, most basic research have focused on implementing stimuli sets that presumably prevent naming strategies or other influential factors such as pre-experimentally established stimulus relations. Commonly used stimuli have been supposed meaningless such as abstract figures, hard-to-name, and nonsense syllables. However, “meaningful” stimuli have also been implemented as independent variables. That is, familiar pictures, nameable, or experimentally established discriminative stimuli (S^Ds). A potential meaningful stimulus can be recognized by its dictionary description (denotative), attribute and emotional valence (connotative), or acquired behavioral functions (Fields, Arntzen, Nartey, & Eilifsen, 2012; Skinner, 1957). Stimuli may therefore be defined as meaningful when related to other stimuli within or between stimulus classes. Analogously, Bortoloti and de Rose (2009) have described meaningful stimuli as “referents”, and the stimuli belonging within the same class as “symbols” that can substitute the referent in certain contexts. Some studies have shown that potential equivalence class members which already belong to other stimulus classes may inhibit class formation (e.g., Leslie et al., 1993; Plaud, 1995; Plaud, Gaither, Franklin, Weller, & Barth, 1998). For example, Leslie et al. (1993) investigated the likelihood of class formation on clinically anxious and non-anxious participants. They found that aversive stimuli (i.e., threatening situations) such as *exams, job interview, and public speaking*, interfered with nonsense syllables and words with pleasant associations on class formation for participants who were defined as clinically anxious. However, the main findings have been that neutral functions of experimentally established S^Ds and familiar stimuli enhance equivalence class formation when compared to meaningless (e.g., Bentall, Dickins, & Fox, 1993; Fields et al., 2012; Tyndall, Roche, & James, 2004, 2009). Similarly, the speed of acquisition seems to be considerably enhanced by the inclusion of meaningful stimuli.

The effectiveness of meaningful stimuli has also been shown to vary depending on when it is introduced in training (Arntzen, 2004; Arntzen & Lian, 2010; Holth & Arntzen, 1998). Moreover, Fields et al. (2012) investigated the effects of one node as a meaningful, as an acquired function, and a meaningless stimulus within three larger nodal classes. Thirty participants attempted to form three 3-node 5-member classes in a LS training structure under the simultaneous protocol. The purpose of the training and testing protocol was to increase sensitivity of stimuli functions as independent variables on equivalence class formation. One group was exposed to all abstract stimuli (ABS group), and a second group with all abstract stimuli, but with the C-stimulus given preliminary successive and simultaneous discrimination training (ACQ group). The third group was exposed to abstract A, B, D, and E stimuli, and C-stimuli as familiar pictures (PIC group). The results showed that the latter group produced higher yields (80%) on equivalence class formation than participants given experimentally established S^Ds (50%) or abstract C-stimuli (0%) as nodes. These results signify that the acquired functions served by the C-stimuli in the ACQ group had some influence on class formation, but not as much as familiar pictures. The authors suggested that an additional type of stimulus control repertoire may have facilitated the moderate outcome for the participants exposed to simultaneous and successive discrimination training.

Measures on equivalence relations

Inferences on potential equivalence relations are merely done after exposure to the required testing contingencies. A common assessment method has been to look at the percentage correct responses in all test trials to determine whether the participant has established the predefined equivalence classes. However, it is important to point out that the set accuracy criterion is an arbitrary measure that helps the experimenter to easily recognize the predicted outcome. Hence, it does not reflect the actual pattern under study or other influencing variables because ceiling effects are present once the classes are formed. Correspondingly, Dymond and Rehfeldt (2001) have suggested supplemental measures that might give a more precise prediction and control on the emergence of untaught relations between stimuli. These have been measures such as verbal reports, stability over time, response time, and stimulus sorting. For example, some data have indicated that sorting tasks of stimuli cards after testing can display generalization and maintenance on established classes in a different format (Arntzen, Braaten, Lian, & Eilifsen, 2011; Fields et al., 2012; Pilgrim & Galizio, 1996). In the Fields et al. (2012) study, participants’ performances correlated perfectly with the conditional discrimination test and a following stimulus sorting test. There were also some participants that showed improved performance for one of the predefined classes. Thus, indicating that sorting also could be sensitive on improved performances. Even though stimulus sorting not explicitly assesses the properties of stimulus equivalence, these results imply that sorting might provide as a quick assessment on class formation. Additionally, this test can be valuable in applied settings as it appears as less time consuming than exposure to numerous trials in conditional discrimination testing. However, as suggested by Fields et al. (2012), future research should focus more on replications with respect to the potential and validity of implementing sorting as an alternative test on class formation.

The strongest index on stimulus equivalence is seen by its rapid emergence during test trials as this reveals the recent effects served by the training contingencies (Fields et al., 1997). Several experiments, however, have focused on other behavioral processes such as response time (i.e., reaction time or response speed) both as a dependent or an independent variable. Response time can be measured from the presentation of sample and comparisons to a choice of comparison, or from the onset of comparisons to the choice of a comparison. Data have repeatedly demonstrated a decrease in response speed from training to initial test trials across different trainings structures (e.g., Arntzen et al., 2010; Arntzen & Hansen, 2011; Bentall et al., 1993; Holth & Arntzen, 1998; Wulfert & Hayes, 1988). A common pattern has been shown with a decrease from baseline to symmetry, as well as from symmetry to trial types of transitivity and equivalence. Speed of responding also seems to even out in repeated test trials. Moreover, some studies have reported a positive relation between speed and the number of nodes (e.g., Bentall et al., 1998; Fields et al., 2012; Fields et al., 1995; Spencer & Chase, 1996). That is, a systematic decrease from baseline to symmetry, and further from symmetry to 1-, 2-, or 3-node relations and so forth. This has both been shown for those who establish and for those who do not establish equivalence classes. Thus, suggesting that response speed may differ as a function of test trial types. It must be noted, however, that temporal analyses might be sensitive to other events that are unrelated to the training and testing contingencies. It is also difficult to account for these patterns without proper observation, measurement tools, and control of the relevant variables affecting equivalence responding. Yet, data on response time may be considered as a fine grained analysis on potential variables influencing the formation of equivalence relations (Holth & Arntzen, 2000; Spencer & Chase, 1996). In particular, when accuracy is absent or when accuracy of responding is immediately consistent across all trial types.

Several interpretations have been put forward on these response patterns. For instance, Spencer and Chase (1996) have suggested that accuracy and response speed is inversely related by the number of nodes that separates the directly taught relations. Comparable results have been described in chronometric studies on semantic relatedness and associative strength (e.g., Collins & Quillan, 1969). Along with this notion, Fields and Moss (2007) have argued that the reported data reflects on the differential relatedness among stimuli in the class. That is, the number of nodes is regarded as a within-class variable that subsequently influences performance such as accuracy or response speed. Some studies have also indicated that stimuli within classes may differ in degrees of “meaningfulness” (Bortoloti & de Rose, 2009, 2012; Tyndall et al., 2004, 2009). Procedures such as the semantic differential or the implicit relational assessment procedure (IRAP) have been applied to evaluate quantitative degrees of relatedness among class members. The latter procedure measures responding to consistent or inconsistent blocks of trials that are based on class integrity between previously learned equivalence relations. A consistent trial refers to the established equivalence relations, and the inconsistent trials are presented as other stimulus relations. Specifically, participants are required to choose between “true” or “false” as response keys depending on consistent and inconsistent trials. Response time and accuracy are used as dependent measures, and may thus signify that fast and accurate responding reflects on stronger degrees of relatedness among stimuli than slow and accurate, or inaccurate responding (see e.g., Fields, Adams, Verhave, et al., 1993). Bortoloti and de Rose (2012) investigated the relational strength among class members previously established in a simultaneous and a delayed matching-to-sample format. Participants were given serialized training in an OTM and LS structure with conditional relations of AB, AC, and CD. The A stimuli contained two different sets of four happy and four angry human faces randomly presented, and the B, C, and D stimuli as nonsense syllables. The relational strength was tested between stimuli (i.e., A and D) never presented together during equivalence training and testing. Obtained results from the IRAP showed that accuracy and response speed increased for those who established classes in delayed matching than compared to those who were exposed to the simultaneous procedure. This is also similar to other findings on the enhancing function of increased delay values on class formation

(Arntzen, 2006; Vaidya & Smith, 2006). Thus, indicating that a delay during the establishing of conditional relations influence the maintenance and likelihood of fast and class consistent responding.

On the other hand, Arntzen (2006, Experiment 4) found that distracter tasks employed during delayed intervals reduced likelihood of outcome on class formation to a level of zero. Other studies have also shown that chances of a positive outcome decreases with time restrictions on responding (Arntzen & Haugland, 2012; Holth & Arntzen, 2000; Tomanari, Sidman, Rubio, & Dube, 2006). Time restrictions such as limited hold (LH) may be regarded as an opposite procedure with respect to increasing delays. Emission of responses after the time limit is not differentially reinforced. Thus, this procedure gives the possibility to investigate whether class consistent responding is dependent on any temporal aspects. Holth and Arntzen (2000), in their Experiment 3, found that none of 10 participants established three potential 3-member classes in an OTM structure with a LH of 2 s. to comparisons during tests. However, when LH to comparisons was removed in a second test, results revealed that three of the 10 participants formed classes. Thus, indicating that temporal variables may influence the formation of equivalence classes. Similarly, one might argue that discriminative responses to sample stimuli in the maintenance of conditional relations are a different type of behavior when compared to the behavior generated by novel stimuli compounds during initial testing. That is, the controlling variables for selecting a comparison are possibly not under direct stimulus control by the sample, and may thus evoke some additional behavior that is accounted by the typical decrease seen in response speed (Holth & Arntzen, 1998).

Inspired by neuroscientific methods, some experiments on stimulus equivalence have employed temporal measures such as event-related potentials (ERP) generated from averaged segments of electroencephalography (EEG). Electrodes are placed on the scalp, and ERP as a record of electrical activity is collected within a specific time frame between stimulus presentations and responses (e.g., Ortu, 2012). In specific, differences in continuous neural events are detected across experimental conditions. In contrast to a general approach of averaging data within groups of participants, some measures on ERP have shown to be amenable within single-subjects analyzes (Ortu, 2012). For instance, a component (i.e., waveform peak) named N400 is a negative ERP that occurs approximately at 400 ms after presentations of stimuli. The N400 have typically been seen after presentations of semantically unrelated stimuli (e.g., road-fork) and diminishes in amplitude when semantically related stimuli (e.g., knife-fork) are presented. This component has also been demonstrated as sensitive with respect to differences between established equivalence relations (i.e., previously arbitrary stimulus relations) and unrelated stimuli (Haimson, Wilkinson, Rosenquist, Ouimet, & McIlvane, 2009; Yorio, Tabullo, Wainselboim, Barttfeld, & Segura, 2008). Another positive ERP, named P3, occurs 300-400 ms after stimulus presentations. This component has repeatedly been observed following presentations of S^Ds, but not after S^Δs. For example, when participants were made to covertly count the number “2” (S^D) and ignore other numbers (S^Δs) presented successively on the screen, results indicated that the S^D evoked peaks of P3 as none occurred during presentations of S^Δs (Potts, 2004). These effects were also shown when participants were made to exhibit the same responses overtly. Similarly, increasing amplitudes of P3 correlates with decreases in reaction times to stimuli (e.g., Holm, Ranta-aho, Sallinen, Karjalainen, & Müller, 2006). That is, fast response speed to S^Ds corresponds with a larger P3 waveform peak. It is difficult to interpret these findings without making tentative suggestions. However, measures on ERP have subsequently been suggested to indicate the presence of covert behavior as these components might be indirect measures on response strength even if the threshold is below emission (Palmer, 2009). Future research should focus on whether these potential responses should be included in a functional relationship between the variables controlling behavior rather than single behavioral properties.

Holth and Arntzen (2000) proposed that constrains on responding to comparisons could influence the probability of some type of precurrent responses that potentiates a “correct” choice. Other interpretations on changes in response time might be the role played by stimulus naming (Horne & Lowe, 1996) or by joint control of stimulus relations (Lowenkron, 1998). In an attempt to control for such plausible variables, an experiment was carried out with a LH titrated down to 1.2 s. during the last part of training, and a fixed LH of 2.5 s. in testing (Arntzen & Haugland, 2012). Five participants were exposed to OTM training of three 3-member classes in a simultaneous protocol with all abstract stimuli. One participant established the predicted classes, while none of the five exhibited any systematic decrease in response speed for either of the test trials. In particular, the speed of responding appeared to be similar throughout training and test trials. Arntzen and Haugland (2012) raised questions whether precurrent responses were suppressed as data showed that responding was most probably under control of the speed contingencies instead of contextual control served by the sample or the novel stimuli combinations. However, it must be noted that an OTM structure may not be as suitable as the LS structure to investigate differential speed to test trial types (Arntzen et al., 2010; Holth & Arntzen, 2000). Accordingly, an OTM structure establishes conditional relations between one sample and several comparisons, and may thus influence precurrent responses in relation to the common sample used in training. On the other hand, in LS training, the sample stimulus is merely related to one comparison, and will probably establish a different type of contextual control.

Future directions

As originally put forward by Sidman (1994, 2000), equivalence relations can be established by any events between stimuli or responses independently of physical similarities or behavioral functions. Furthermore, by definition, stimuli within an equivalence class are expected to be functionally substitutable for each other. On the basis of the abovementioned data, the trend seems to be somewhat different with respect to procedural variations of likelihood on class formation and the notion that stimuli within an equivalence class may differ in degrees of relatedness. As implied by Fields, Adams, Verhave, et al. (1993), accurate and equal response speed across trials types may, however, indicate that stimuli within a class are more equally substitutable or related. Bentall et al. (1993) attempted to address the issue between differential response speed and the effects of nameable “pre-associated”, nameable “non-associated”, and all abstract visual stimuli on class formation. Participants were given LS training with six 3-member classes under a simultaneous protocol in a simultaneous matching-to-sample (Experiment 1) and a zero delay (Experiment 2) procedure. Results showed that class consistent responding was considerably enhanced by the function of nameable and semantically related stimuli than with “non-associated” or abstract stimuli. The pre-associated group had less errors and numbers of trials during the acquisition of the conditional relations. Interestingly, response speed patterns during testing differed markedly across the groups. Participants who were exposed to semantically related stimuli showed no differences in speed of responding to different trials types. In contrast, a typical decrease in response speed from baseline, symmetry, and to 1-node trial types were reported for the two other groups. These results suggest that response speed could be more dependent on the type of stimuli used than by specific trial types. It is also reasonable to argue that the high outcome seen in the pre-associated condition was a product of class merger rather than the establishing of a new equivalence class per se (see e.g., Fields, 2009). Comparatively, the same issues were raised by Fields et al. (2012) with the participants who formed classes with meaningful stimuli as nodes among abstract stimuli. Furthermore, one should also question whether prior learning history influences accurate and consistent response speed to abstract stimuli that are conditionally related to meaningful stimuli in larger nodal classes. That is, a closer assessment on the properties of discriminative stimuli may possibly reflect a correspondence between speed patterns and equivalence class formation.

Although reinforcement contingencies during training typically generate an equivalence class, a potential differential relatedness cannot merely be measured by accuracy scores. A larger sample of a dependent variable might possibly enable a more precise prediction of the relevant controlling variables that are responsible for the establishing of equivalence relations. Similarly, a behavioral change, whether it is overt or covert, shown to be functionally related to particular environmental events should likewise be described within the three- or four-term contingency. As Palmer (2011) noted, “observability is not a property of a response but of the vantage point and tools of the observer” (p. 203). Even though the current methodology may lack the proper tools of investigating other measures on equivalence relations, plausible interpretations based on the currently available data may still seem to conform to behavioral principles as well as to guide further research questions. Moore (2009) proposed that the variables shown to affect stimulus equivalence responding should be understood as experimental tools rather than methodological deficiencies. The different accounts on stimulus equivalence and its origins should not be looked upon as contradictory on the basis of arguments, but one should rather focus on the induction and generality of collected data. An important future direction is to determine the extent of whether other analyzes than accuracy scores alone should be implemented on the investigation of equivalence relations.

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The Discriminative Functions of Stimuli and its Effects on Equivalence Relations and Response Time

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Abstract

The current experiment is a systematic replication and extension of Fields, Arntzen, Nartey, and Eilifsen (2012) study. The effects of meaningful, experimentally established S^Ds, and abstract C-stimuli as nodes were studied in potential three 5-member equivalence classes. Fifty participants were randomly assigned to one of five groups: (1) All Abstract (ABS), (2) Picture as C-stimuli (PIC), (3) Simultaneous and Successive discrimination training of abstract C-stimuli (SIM/SUCC), (4) Simultaneous discrimination training of abstract C-stimuli (SIM), and (5) Successive discrimination training of abstract C-stimuli (SUCC). Training and testing was arranged under a simultaneous protocol in a linear series structure. The discriminative functions served by the stimuli were observed through the acquisition of condition relations, response speed and accuracy during test for derived relations. A categorization task of stimuli cards was also explored as a potential test on class formation. Results showed that the inclusion of meaningful C-stimuli enhanced acquisition of conditional relations and class consistent responding when compared to the other groups. Thus, 5 of 10 participants in the PIC group, 4 of 10 participants in the SIM group, 3 of 10 participants in the SUCC group, 2 of 10 in the ABS group, and none out of 10 participants in the SIM/SUCC group. Main findings on speed of responding showed a typical pattern of decrease from training to initial test trials. However, response speed to trial types involving C-stimuli appeared stable for those who formed classes with meaningful stimuli (PIC group), and thus suggesting that speed and accuracy may be more dependent on stimulus familiarity than type of relation. Obtained data on stimulus sorting showed a perfect correspondence to the outcomes in conditional discrimination testing. Thus, indicating generalization and maintenance across test formats.

Keywords: Stimulus equivalence, meaningful stimuli, response speed, adults, linear series, simultaneous protocol, sorting test

The Discriminative Functions of Stimuli and its Effects on Equivalence Relations and Response Time

Research on equivalence relations typically involves conditional discrimination training of selected stimulus pairs followed by tests for derived relations among stimuli not presented together during training. Sidman (1971) described these stimulus relations to be equivalent to one another, and refined them later as stimuli being substitutable within a class (1994). Furthermore, stimulus equivalence can be regarded as a relevant method on experimental simulations of generative behavior such as problem-solving, remembering, language, and concept formation (e.g., Catania, 1986; Sidman, 1994).

An equivalence class must consist of at least three or more stimuli, and is merely inferred after testing properties of reflexivity, symmetry, and transitivity without differential reinforcement (Sidman & Tailby, 1982). For example, in a linear series (LS) training structure with three members in a class, a participant is taught to match A to B, and B to C (A→B→C). Reflexivity is demonstrated if the participant matches A to itself, B to itself, and C to itself. This has also been named identity matching, meaning that each stimulus must bear a relation to itself. Symmetry is shown if the participant can match B to A, when stimulus B is presented as a sample and stimulus A as a comparison during testing (if AB, then BA). Hence, the previously trained relations are bidirectional and the discriminative functions are reversed. Transitivity is demonstrated if the trained relations of A to B, and B to C produce comparison choice of stimulus C when A is presented as a sample (if AB and BC, then AC). Hence, correct responding to a comparison that has never been presented with the sample during training trials. Symmetry and transitivity can also be assessed together in a combined equivalence test (Sidman & Tailby, 1982). Specifically, when A is trained to B, and B is trained to C, correct matching would be shown if a participant matched the sample stimulus C to comparison stimulus A during testing (if AB and BC, then CA). A common assessment method on the formation of potential equivalence classes has been to look at the percentage correct responses after exposing participants to tests. Besides, other measures such as response time, stimulus sorting, stability over time, or verbal reports have been suggested as relevant aspects on equivalence relations (Dymond & Rehfeldt, 2001).

In an attempt to maximize experimental control and give a more molecular level of analysis, researchers have focused on identifying procedural variations that affect the formation of equivalence classes. Some of these experimental manipulations have been contingencies of reinforcement, time restrictions, instructions, stimuli sets of different attributes, training structures and nodal numbers, as well as how training and test trials are presented (see e.g., Arntzen, 2012, for an overview). For instance, the training and test blocks can be arranged differently with respect to when they are introduced. They are described as simple-to-complex, complex-to-simple, and the simultaneous protocol (Imam, 2006). Results have shown that the latter protocol, which requires all baseline relations to be established before testing begins, is less effective on equivalence class formation (e.g., Fields et al., 1997). The directionality of training is another structural variable that influence class formation (Fields & Verhave, 1987). The main three training structures used in conditional discrimination procedures are one-to-many (OTM), many-to-one (MTO), and LS. Prior research have found that the use of a LS structure combined with a simultaneous protocol generate the lowest probability on class formation (e.g., Arntzen, Grondahl, & Eilifsen, 2010; Arntzen & Holth, 1997, 2000). This structure also gives the opportunity to study effects of nodal stimuli, whereas increasing class members with OTM or MTO does not influence the number of nodes (Arntzen et al., 2010; Arntzen & Hansen, 2011; Saunders & Green, 1999). Moreover, Saunders and Green’s (1999) discrimination analysis predicts that dissimilarities between the training structures will be more pronounced as a function of additional untrained simple discriminations when class size or number of classes increase (see also Arntzen, 2011; Arntzen & Hansen, 2011, for a discussion on this issue).

According to Fields and Verhave (1987), likelihood of equivalence class formation is also influenced by its number of members and the arrangement of how stimuli are linked in training. Specifically, nodes are stimuli trained in relation to two or more stimuli, and singles are stimuli trained to one stimulus. For instance, after training a 5-member class with AB, BC, CD, and DE, test trial types of 1-node would be presented as AC, CA, BD, DB, CE, and EC, 2-nodes as AD, DA, BE, and EB, and 3-nodes as AE and EA. In this case, the A and E stimuli are defined as singles, while the B, C, and D stimuli as nodes conforming to transitive and equivalence relations. Some studies have shown that accuracy of responding decreases as a function of nodal numbers for those not forming classes, and likewise for those showing delayed emergence in repeated testing (e.g., Fields, Adams, Verhave, & Newman, 1990; see Fields & Moss, 2007, for an overview). Other studies have shown that a response (i.e., an acquired function) trained to one member in a class can be inversely related by the nodes that separated them in training (Fields, Landon-Jimenez, Buffington, & Adams, 1995; Moss-Lourenco & Fields, 2011).

Data have also indicated a positive relation between response time (i.e., response speed or reaction time) and numbers of nodal stimuli in a class (e.g., Arntzen & Holth, 2000; Bentall, Jones, & Dickins, 1998; Fields et al., 1995; Spencer & Chase, 1996). The main findings have been that speed of responding decreases when participants are introduced to test trials, as well as a further decrease is shown from symmetry to trial types of transitivity and equivalence. These patterns also seem to stabilize at the end of testing. Accordingly, Fields and colleagues have discussed that stimuli within an equivalence class are not mutually substitutable, but rather inversely related by the number of nodes. In contrast, Imam (2001, 2006) has found differing results when numbers of trials were equalized across all stimulus pairs. Imam raised questions whether reported patterns of accuracy and speed are due to procedural artifacts rather than the unequal relatedness among stimuli per se (see also Saunders & Green, 1999; Sidman, 1994; Tomanari, Sidman, Rubio, & Dube, 2006, for a discussion on these issues). In a study by Arntzen and Haugland (2012), response time was used as a dependent measure on potential three 3-member classes with a limited hold (LH) contingency. LH was titrated to 1.2 s. during training, and set to 2.5 s. in testing. One of the five participants established the predicted classes. Response time data revealed a mixed pattern of responding regardless of test trial types. Due to the fast responding contingencies in training, participants may have continued to respond fast during testing. The authors questioned whether participants acquired the new LH contingencies in testing that might have further led to poor discrimination of novel stimuli pairs or likewise not given an opportunity to engage in any precurrent responses. However, these response patterns may not be representative when taken in consideration that an OTM training structure was applied (Arntzen et al., 2010; Holth & Arntzen, 2000).

Other interpretations of response time patterns has been that responding during the establishing of equivalence relations may involve covert mediating behavior such as naming or other types of precurrent responses (e.g., Bentall, Dickins, & Fox, 1993; Holth & Arntzen, 1998; Holth & Arntzen, 2000; Lowenkron, 1998). Nevertheless, studies on response time present a scientific challenge for valid inferences on the dimensions of covert behavior. Presupposed meaningless stimuli such as abstract, hard-to-name, and nonsense syllables have therefore been traditionally employed to inhibit naming strategies or other extraneous variables. Several experiments, though, have investigated the effects of “meaningful” and experimentally established discriminative stimuli (S^Ds). A definition of a meaningful stimulus can be referred to on how it is described in the vocabulary (denotative), by its semantic attributes and emotional valence (connotative), or by its acquired functions (e.g., Fields, Arntzen, Nartey, & Eilifsen, 2012; Skinner, 1957). That is, meaningful as to how it is related to other stimuli. Meaningful stimuli can vary in degree (Bortoloti & de Rose, 2009, 2012; Tyndall, Roche, & James, 2004, 2009), and has likewise been shown to inhibit class formation when potential class members interfere with participants pre-experimental history (e.g., Leslie et al., 1993). However, main findings from experiments investigating the familiarity of stimuli have been that meaningful, but emotionally neutral, enhance equivalence class formation when compared to meaningless (e.g., Arntzen, 2004; Bentall et al., 1993; Fields et al., 2012; Holth & Arntzen, 1998). Some collected data on response time have also shown that speed of responding has been consistent to meaningful when compared to meaningless stimuli. For instance, Bentall et al. (1993) assigned participants to one of three conditions of nameable "pre-associated" stimuli, nameable but "non-associated" stimuli, and all abstract stimuli. Results demonstrated stable speed and accuracy within all test trials for participants given semantically related stimuli, while the other two groups of non-associated and abstract stimuli displayed similar response patterns with respect to nodal numbers. Thus, indicating that there is a difference between the relatedness among stimuli and response patterns of speed and accuracy.

A number of experiments have explored different functions of stimuli by using a single meaningful stimulus as a node among meaningless (Arntzen & Lian, 2010; Arntzen & Nikolaisen, 2011), or experimentally established S^Ds on equivalence class formation (Tyndall et al., 2004, 2009). Subsequently, Fields et al. (2012) conducted a parametric study on the effects of stimuli with discriminative functions in larger nodal classes. Thirty participants were randomized in three groups, and made to form three 3-node 5-member classes in a LS structure under a simultaneous protocol. Across groups, A, B, D, and E were all abstract stimuli, while the C-stimulus as a middle node was considered to be the independent variable. That is, the C-stimulus as a meaningful picture, an acquired function (i.e., successively and simultaneously discrimination trained), or an abstract meaningless stimulus. The training and test protocol was implemented for the purpose of increasing sensitivity of stimuli functions by decreasing chances of responding in accordance with stimulus equivalence. The effects of nodal stimuli were also possible to study within the LS structure. Lastly, a post-categorization task of stimuli cards was implemented to see whether card sorting could be a sensitive measure on class formation. Results showed that meaningful stimuli produced higher yields (80%) on equivalence class formation than experimentally established S^Ds (50%) and abstract stimuli (0%). Data also indicated that the speed of establishing baseline relations was modestly influenced by the inclusion of a familiar stimulus. Furthermore, response time during initial testing showed that speed decreased as a function of test trial types independently for those who formed or did not form classes. Lastly, card sorting showed that all participants who formed classes categorized the three experimenter defined classes correct. Sorting data also demonstrated delayed formation in one of the three experimenter defined classes for some participants.

The current experiment was inspired by Fields et al. (2012) study on the discriminative functions of stimuli as independent variables by employing identical parameters, stimuli sets, and experimental conditions. However, two additional groups were further given simple successive or simultaneous discrimination training of abstract C-stimuli. Hence, 50 participants were randomly assigned to one of five groups given one meaningful, one successively and/or simultaneously discrimination trained, or a meaningless stimulus as a node. A second research question was whether previous findings on response time patterns could be replicated. That is, a decrease in speed of responding from baseline to symmetry, and from symmetry to nodal trial types. Likewise, Bentall et al. (1993) reported results on accuracy and stable response speed to meaningful stimuli were explored by comparing these to abstract and experimentally established S^Ds. Finally, as employed by Fields et al. (2012), the current experiment examined participants’ categorization of stimuli cards as a possible measure on equivalence class formation.

Method

Participants

Fifty students and professionals were recruited through lectures and personal contacts. There were 22 males and 28 females aged between 19 and 62 (with the mean age of 27.8). None of the participants were familiar with the current research methodology or the field of stimulus equivalence. All participants were debriefed at the end of the experiment. Lastly, participants were given an article about stimulus equivalence.

Apparatus

Setting. The experiments were carried out in two different laboratories at Oslo and Akershus University College and Østfold University College. The experimental sessions were approximately 1.5 hr. to 3 hr. long. Cubicle number one was 1.3 m x 2.2 m, and furnished with one table and a chair. Cubicle number two was 2.5 m x 3.2 m, and furnished with two tables and three chairs. All participants were seated in neutral surroundings and blank walls.

Hardware and software. Two HP EliteBook 8740w laptop computers with Intel® Core ™ i5 CPU processors and 17-in. screens were utilized throughout the experiment. Both computers were equipped with a Dell mouse for the participants to use during all stages of the experiment. The conditional discrimination procedure was conducted with the software program MatchToSample, v. 3.12, written by Psych Fusion Software in collaboration with Professor Erik Arntzen. The software controlled the presentation of stimuli and automatically collected data such as number of incorrect/correct responses, train/test trials, train/test types, choice of comparison stimuli, reaction time (RT) to sample and comparison stimuli, and probability of feedback. Additionally, the software summated correct and incorrect baseline relations, properties of symmetry, 1-, 2-, and 3-nodes. Two other software programs from the

University of North Texas and the University of Sao Paulo were used for participants given preliminary simultaneous discrimination training and successive discrimination training, respectively. The presentation of stimuli was controlled by the software programs and data were automatically recorded.

Stimuli. The stimuli used in the conditional discrimination procedure were visual abstract and familiar stimuli (see Figure 1). For ease of viewing, stimuli were designated as letters for class members and numbers for the respective classes. Fifteen abstract stimuli were the same in four of the five stimuli sets, while the remaining stimulus set contained three meaningful pictures as C-stimuli as a substitution for abstract C-stimuli. All of the 18 experimental stimuli were printed on laminated cards (3.9 cm x 3.9 cm) for a pre- and post-categorization task. The background layout was white under stimuli presentations, whereas the abstract stimuli were displayed in black and the picture stimuli in colors. The invisible click-sensitive areas for the computer mouse were 9.4 cm (w) x 3.4 cm (h). During the feedback interval, at the right hand corner at the bottom, a numeral of ‘X’ correct responses was displayed in blue color. Additionally, 21 abstract stimuli were used for participants given preliminary discrimination training (see Figure 2).

Design

The experimental design was a between-subject design. All participants were randomly assigned to one of five groups: (1) All Abstract (ABS), (2) Picture as C-stimuli (PIC), (3) Simultaneous and Successive discrimination training of abstract C-stimuli (SIM/SUCC), (4) Simultaneous discrimination training of abstract C-stimuli (SIM), and (5) Successive discrimination training of abstract C-stimuli (SUCC).

Participants in the ABS group were given all abstract stimuli attempted to be formed in equivalence classes. Participants in the PIC group were given abstract A, B, D and E stimuli, but with the C-stimuli as familiar pictures. For the SIM/SUCC group, participants were given all abstract stimuli, but with both preliminary simultaneous and successive discrimination training of C-stimuli. Participants in both the SIM and SUCC groups were exposed to all abstract stimuli, but given separate preliminary simultaneous or successive discrimination training of C-stimuli. All participants completed the conditional discrimination procedure in a simultaneous protocol, and attempted to form three 5-member equivalence classes from twelve sets of conditional relations. In addition, a pre- and post-categorization task of the experimental stimuli was implemented for all participants.

Procedure

Information. Participants were asked to read and fill out a consent form before the experiment started. This document declared that the experiment was within the field of stimulus equivalence and that they were to do tasks on a computer for approximately one to three hours. They were informed that their participation was anonymous and that the purpose of the experiment was strictly for research. Participants were told that they could choose to withdraw from the experiment at any time without consequences, and that a debriefing session would be given after completion of the experiment.

Categorization task. Before assigned to preliminary training and test, a total set of 15 stimuli cards were given to be categorized (15 abstract stimuli for the ABS, SIM/SUCC, SIM and SUCC groups, and 12 abstract and three stimuli as familiar pictures for the PIC group). The Norwegian equivalent of the phrase was given: “Place the stimuli in groups, and let me know when you are finished”. If participants had any questions, the experimenter replied that he/she could not give additional information about the task. When finished, the experimenter collected the categorized stimuli and instructed the participant to be seated in front of the computer. Completion of the conditional discrimination procedure was followed by a post-categorization task with the same instructions and identical stimuli given in the pre-categorization task.

Simple discrimination. Participants in the SIM/SUCC, SIM, and SUCC groups were given simultaneous and/or successive discrimination training of abstract C-stimuli before the conditional discrimination procedure was introduced.

Participants exposed to simultaneous discrimination training were instructed to choose between two stimuli appearing on the screen. They were informed that the computer would not tell if their choices were correct during some stages. This procedure established the C-stimuli as S^Ds among other stimuli. The training protocol consisted of five phases with randomized trials per block in a concurrent training format. Phases 1−3 established C1, C2, and C3 as S^Ds from X's, Y's, and Z's as delta stimuli (S^Δ), respectively. Phase 4 included all the previous CX, CY, and CZ trials mixed together in one block. Correct responding to C-stimuli during Phases 1−4 produced the word “Correct”, while incorrect responses to X's, Y's, and Z's were followed by a blank screen. Programmed consequences and the inter-trial interval (ITI) were 1 s. Phase 5 tested assessed preferences for C1, C2, and C3 as familiar stimuli among P, R, and S as unfamiliar stimuli. This phase did not provide any corrective feedback. Neither of the X, Y, and Z stimuli nor the P, R, and, S stimuli were used in conditional discrimination. All blocks were repeated until 10 consecutive correct responses occurred in each block, and further to continue on either successive discrimination training or conditional discrimination training.

Participants exposed to successive discrimination training were instructed to click three, six, or nine times at the stimuli being singly presented on the screen, and further to terminate responses by pushing the “END” button at the computer keyboard. This procedure established discriminability among the C-stimuli with a three-ply multiple schedule. Correct responses were defined as FR-3 for C1, FR-6 for C2 and FR-9 for C3. Correct responding according to the FR-schedules produced the word “Correct”, while erroneous responses produced the word “Incorrect”. Stimulus presentations were randomized, and 10 consecutive correct responses were required to proceed to conditional discrimination training.

Instructions. Prior to the conditional discrimination procedure, the following text equivalent in Norwegian was presented on the computer screen:

A stimulus will appear in the middle of the screen. Click on this by using the computer mouse. Three other stimuli will then appear. Choose one of these by using the computer mouse. If you choose the stimulus we have defined as correct, words like “very good”, “excellent”, and so on will appear on the screen. If you press a wrong stimulus, the word “wrong” will appear on the screen. At the bottom of the screen, the number of correct responses you have made will be counted. During some stages of the experiment, the computer will not tell you if your choices are correct or wrong. However, based on what you have learned, you can get all the tasks correct. Please do your best to get everything right. Good luck!

If participants had any questions, the experimenter would not provide any other cues than already given in the instruction text or the consent form.

Conditional discrimination. All training and test trials started with the presentation of a sample stimulus, and required an observing response to sample stimulus in the middle of the screen. Next, three comparison stimuli would immediately display randomly in three of the four screen corners. Sample stimulus and comparison stimuli remained on the screen until a selection response of one comparison stimulus occurred. Responding to comparison stimuli was recorded as RT in seconds, and inversed RT was later converted to response speed (see Baron, 1985, on this issue). Programmed consequences appeared in the middle of the screen, and were presented for 500 ms with an ITI of 1 s. Correct responding to comparison produced Norwegian words like *correct*, *good* and *excellent* etc., while choice of incorrect comparison was followed by the word *wrong*. The mouse position was reset to the middle-top of the screen in each trial.

Training. Twelve sets of conditional relations were trained and tested in a simultaneous protocol. That is, all baseline relations were presented in blocks of trials and established before randomized test probes of symmetry, 1-, 2-, and 3-nodes were introduced. Conditional discrimination training occurred in a LS structure, A→B→C→D→E, leading potentially to three 3-node 5-member classes. The training order was serialized, meaning that AB, BC, CD, and DE baseline relations were trained separately in blocks of the given order. Each training block consisted of nine trials, and all trial types were randomly presented three times each. The following trial types were given: A1B1B2B3, A2B1B2B3, A3B1B2B3, B1C1C2C3, B2C1C2C3, B3C1C2C3, C1D1D2D3, C2D1D2D3, C3D1D2D3, D1E1E2E3, D2E1E2E3, and D3E1E2E3. The first alphanumeric code is the sample, and the underlined alphanumeric code identifies the correct comparison. Selections of correct comparison were required on minimum 90% trials per block. Training blocks were repeated until participants reached the mastery defined criterion of at least 9 of 9 correct responses. In order to prevent overtraining of specific trial types, baseline relations were automatically equalized in succeeding blocks of trials. As shown in Table 1, programmed consequences of a 100% were given in Phases 1−5 (i.e., during the establishing of baseline relations and a mixed block of all trial types). Phases 6−9 assured maintenance of all baseline relations randomly mixed in a descending order of 75%, 50%, 25%, and 0% probability of consequences preliminary to testing. All mixed blocks required 33 of 36 correct responses.

Testing. Tests for derived relations were randomly interspersed with baseline relations in two separate test blocks of no programmed consequences. The second test block was introduced immediately without retraining. A minimum of 90% correct responses were required in order to be defined as responding in accordance with stimulus equivalence.

Specifically, 33 of 36 symmetry trials, 49 of 54 1-node trials, 33 of 36 2-nodes trials, and lastly 17 of 18 3-nodes trials for a total of 144 trials per block excluding baseline trials. All trial types were randomly presented three times in both blocks.

Results

All participants completed training and testing for derived relations, and were thus included in the data analyses. Individual data from participants are summarized in Table 2. The table shows number of training trials, errors, and summated test trial types of baseline, symmetry, and nodes. Transitivity and equivalence scores are summated as 1-, 2-, and 3-nodes. Performances in (a) acquisition and maintenance of baseline relations, (b) derived relations, (c) post-categorization, and (d) response time in test trials are considered below. Results from the first test block will mainly be focused on as these results reflect on the differences between training and initial testing. The number of training trials and speed of responding were computed by mean values as a few participants had very high scores.

Acquisition and maintenance

A descending order in median number of training trials were found with participants from the SUCC-, ABS-, SIM-, SIM/SUCC groups, and for the PIC group, respectively (see Table 2). Participants who formed classes in the first test block established the baseline relations in 31 % less trials than the participants who did not form classes. Acquisition of baseline relations for those who did not form equivalence classes in the first test was slowest starting with participants in the SUCC-, SIM-, ABS-, SIM/SUCC groups, and then fastest for the PIC group. Participants had fewest errors when C-stimuli were meaningful (group PIC). The same trend of corresponding errors and number of trials was obtained for the remaining groups.

Equivalence class formation

As shown in Table 2, fourteen of 50 participants formed classes in test block one. Across groups, the highest outcome on class formation was found for participants trained with meaningful pictures as C-stimuli (group PIC). Specifically, five of 10 participants established the predicted classes. Eight out of 10 acquired symmetry, and seven of 10 participants had the baseline relations intact. For the SIM group, four of 10 participants established equivalence classes. Moreover, nine of 10 had baseline relations intact, while symmetry was acquired by eight of the 10 participants. Three of 10 participants formed classes in the SUCC group. Baseline relations were intact for six of the 10 participants, and seven of 10 responded above the set criterion for symmetry. In the ABS group, two of 10 participants formed classes. Additionally, three participants maintained baseline relations, while two of these three individuals acquired symmetry. There were none participants who formed classes in the SIM/SUCC group. Baseline relations were maintained in five of the 10 participants, and two of 10 participants acquired symmetry.

Delayed emergence. Delayed emergence in the three experimenter defined equivalence classes was obtained for 10 additional participants (4307, 4320, 4322, 4327, 4337, 4348, 4349, 4354, 4359, and 4360) in the second test block. This effect was shown across groups. All, but one participant (4343), who immediately formed classes in the first test block, maintained the established equivalence relations in the second test block. However, participant 4343 sorted the post-categorization task correct.

Post-Categorization

Table 3 shows individual sorting in the pre- and post-categorization tasks on the left and right hand side, respectively. The left side of the table is separated into experimental groups, outcome on class formation in the conditional discrimination procedure, and participant numbers. Horizontally divided boxes in each row presents grouped stimuli for each participant, and are further separated into number of stimuli clustered from equivalence Classes 1, 2, and 3. For example, a number of 310 in one box indicates that a participant clustered three stimuli from Class 1, one stimulus from Class 2, and zero stimuli from Class 3 into one group. Hence, correct categorization according to the experimenter defined classes is presented as 500 for Class 1, 050 for Class 2, and 005 for Class 3 (i.e., three 5-member classes). For ease of viewing, correct sorting of all classes are marked by shaded boxes and the bold numbers identify correctly clustered stimuli in one of the experimenter defined classes. The left side of the table shows that participants sorted stimuli by chance as they knew nothing in advance in the pre-categorization task. Rather, all participants who responded in accordance with stimulus equivalence in the first test block sorted the entire stimuli array correct (see right side of Table 3). Ten additional participants (4307, 4316, 4320, 4322, 4327, 4337, 4348, 4349, 4354, and 4359) who did not form classes in test block one, sorted all stimuli correctly into the three experimenter defined classes. However, nine out of these 10 participants formed classes in the second test. Participant 4316, who did not form equivalence classes in the second test, did however respond correct when this test block was divided in two equal halves.

There were five participants (4319, 4321, 4329, 4355, and 4358) who did not show evidence of established classes in the conditional discrimination test procedure, but did however categorize one of the five-member equivalence classes correct. As shown in Figure 3, a closer assessment on the correlation between performances in card sorting and class formation testing was done by separating all test trials for Classes 1, 2, and 3. The shaded boxes presents a maximum of three numerals per test trial type in each class, and all blank boxes with numerals are defined as wrong responses. For instance, participants 4321, 4355, and 4358 had already established one of the experimenter defined classes in the first test block, meaning that responses to all trial types in one of the three classes were correct.

Interestingly, participant 4355 showed a gradual change from the first to the second test block of consistent, but incorrect, responding on the same trial types for Classes 1 and 2. This participant’s card sorting indicated a corresponding partition between the two classes, and the intactness of Class 3. The same trend was observed for participants 4358 and 4321. Participant 4319 showed a different pattern on card sorting than in equivalence class formation testing. Class consistent responding improved during the first to the second test block, and delayed emergence was shown for Class 3 in the last test block. The sorting test merely revealed correct sorting of Class 2. However, the remaining stimuli were separately clustered by class membership. Participant 4329 showed similar improvement in equivalence class testing, but only the intactness of Class 1 in card sorting. Moreover, categorization data implied a gradual emergence of equivalence Classes 2 and 3 with only one stimulus card incorrectly grouped.

Speed of responding

Speed of responding was defined as inversed RT in seconds, and calculated as 1/the mean of median reaction times from the onset to choice of comparison. As can be seen in Figure 4, response speed decreased across groups from the last five training trials of no programmed consequences to the first five test trials of each trial type. This was a consistent pattern equally for those who did and did not form equivalence classes. A further reduction in response speed was shown as a function of trial types. In general, speed of responding declined from test trials of baseline to symmetry, and from symmetry to nodal trials for the ABS-, SIM/SUCC-, SIM-, and SUCC groups. Decline of speed was more apparent in test trials of baseline to symmetry for participants in the ABS group. In contrast, data obtained for the PIC group shows that speed was faster and more stable in the last five training and test trials of baseline and symmetry for those who formed classes. For all groups, 1-, 2-, and 3-

node trials occasioned stable and slow responding compared to baseline and symmetry trials. This was most pronounced for the participants who passed equivalence formation testing.

As presented in Figure 5, a further analysis was done by separating trial types of C-stimuli as samples and comparisons from all other trial types to see if the functions of C-stimuli had any effect on speed during testing. Results from the PIC group revealed that speed of responding to baseline trials of BC and CD, symmetry trials of CB and DC, 1-node trials of AC, CA, CE, and EC was equal independent of trial types for those who formed classes, but not for those who did not (see top panel in Figure 5) When trial types of C-stimuli were separated for the other groups, results showed a decrease in responding as a function of trial types independently of class formation (see four lower panels in Figure 5). That is, speed of responding decreased steadily from baseline to symmetry, and from symmetry to 1-node trials.

Discussion

The purpose of the present experiment was to replicate and extend Fields et al. (2012) findings. In specific, the discriminative functions of stimuli were examined through the establishing of baseline relations, outcome of class formation, and response time to comparison stimuli. A post-categorization task was implemented for the purpose to see if equivalence classes would maintain in a different testing format. The main findings were that (1) the PIC group required the least median number of training trials and errors to proceed in testing, (2) the inclusion of a meaningful C-stimulus enhanced class consistent responding when compared to meaningless and experimentally established S^Ds, (3) a decrease in response speed was shown during initial testing, and (4) post-categorization data corresponded to the outcomes in conditional discrimination testing.

Acquisition and maintenance of baseline relations with the least errors were most rapidly gained by participants in the PIC group. This is comparable to other studies of both within- and between-subject design (Arntzen & Lian, 2010; Bentall et al., 1993; Fields et al., 2012). An increasing number of trials and errors were found with the SIM/SUCC-, SIM-, ABS-, and SUCC group, respectively. The highest yields on equivalence class formation in the first test block were shown for 50% of participants in the PIC group, and by 80% of them in the second test block. This is in accord with earlier findings on the enhancing effects of meaningful stimuli as nodes on class formation (Arntzen & Lian, 2010; Arntzen & Nikolaisen, 2011; Fields et al., 2012). Furthermore, likelihood of class formation was shown for 40% of participants in the SIM group, 30% in the SUCC group, 20% in the ABS group, and 0% in the SIM/SUCC in the first test block. Overall, there were 10 participants who demonstrated delayed emergence of all three classes in the second test block. According to Sidman (1994), delayed emergence in repeated testing is mainly due to a pre-experimental or an experimental history of several stimulus-stimulus relations other than the designated ones during training. Proper contextual control will eventually form equivalence classes. Dube and McIlvane (1996) extended this analysis by proposing that the controlling stimuli attributes not always correspond to the experimenter defined ones. Hence, suggesting that emergence will occur more rapidly if consistent responding is shown during the end of baseline maintenance phases. This analysis might be comparable for nine of these 10 participants as the maintenance of baseline relations were intact during both test blocks. Delayed emergence was shown across groups and thus indicating that it occurred independently of the functions served by the C-stimuli. In addition, results revealed that the participants who formed classes in the first test block acquired baseline relations in 31% less trials than those who did not. Further research should focus on a possible correspondence by the occurrence of delayed emergence and other variables such as training trials and errors.

Obtained yields for the ABS group replicates previous findings on the difficulty of acquiring baseline and equivalence relations with abstract stimuli in larger nodal classes with a LS structure under the simultaneous protocol (Arntzen et al., 2010; Arntzen & Holth, 1997; Fields et al., 2012). In consideration of Saunders and Greens' (1999) discrimination analysis, the results from the SIM and SUCC groups may reveal that prior discrimination training of C-stimuli had some facilitating effects on class formation. This analysis predicts that simple discriminations establish necessary repertoires (i.e., successive and simultaneous) on the formation of conditional relations and equivalence classes. According to Saunders and Green (1999), successive discrimination is presupposed to automatically advance simultaneous discrimination repertoires as they are more easily acquired than the former. The current results showed that the establishing of conditional relations and equivalence classes were more difficult for the participants given preliminary successive discrimination training than for the participants given simultaneous training. Even though little difference is seen between the two groups, one might argue that participants given successive discrimination training should have been better prepared than participants in the SIM group. As noted by Fields et al. (2012), however, only part of this enhancement effect can depend on these repertoires. The authors discussed that an additional type of stimulus control repertoire might have been responsible for the intermediate outcome on class formation (50%) in their group given preliminary simultaneous and successive discrimination training (group ACQ). However, current results for the SIM/SUCC group differed markedly from Fields et al. (2012) identical condition as the SIM/SUCC group had none who formed classes in the first test block. A consideration in interpreting these results could be that the baseline relations were not intact for 50% of participants in the SIM/SUCC group. Saunders and Green (1999) proposed that retention of baseline relations influence outcomes of equivalence class formation. In contrast, other studies have shown divergent results on this issue (e.g., Arntzen & Haugland, 2012; Eilifsen & Arntzen, 2009). Comparable to these studies, 19 participants (3, 3, 5, 5, and 3 participants in the ABS-, PIC-, SIM/SUCC-, SIM-, and SUCC groups, respectively) in the current experiment showed maintenance of baseline relations in the absence of class formation in test block one. Interestingly, one participant from the SIM/SUCC group showed delayed emergence in the second test block even though poor retention of baseline relations was shown in the first test block. Furthermore, the current experiment required maintenance of baseline relations before test trials were randomly interspersed with directly trained relations. Although the SIM/SUCC group had lower median number of training trials than the other two groups given simple discrimination training, the current disparities cannot be fully clarified. One can also speculate whether a recent history of simple discrimination training may inhibit the transformation from simple discrimination to the control by conditional relations. An eye-tracking experiment conducted by Dube et al. (2006), showed that participants with low accuracy on multiple sample tasks had problems with shift of stimulus control when sample stimuli increased from two to four per trial in a delayed matching-to-sample format. The authors suggested that the observing behavior might have been under control of some other aspects than conditional stimulus control.

An analysis of why the SIM and SUCC groups had higher accuracy in equivalence than the SIM/SUCC group seems complex. It is also difficult to account for the dissimilar results found between the present SIM/SUCC group and Fields et al. ACQ group. However, an extended replication was carried out with ten participants given identical training and testing procedures as the SIM/SUCC and ACQ group. These results showed that five participants established the predicted classes. Thus, indicating that the present findings might be related to the differences among enrolled participants in these experiments. Future replications should therefore focus on both single-subject and between-subject designs.

During the last part of conditional discrimination training, sample stimuli are assumed to function as S^Ds upon selections of specific comparison stimuli. In test trials, though, participants are introduced to novel combinations of stimuli relative to the baseline contingencies. Accordingly, speed of responding to comparison stimuli generally tend to decrease in testing. The present data are in accord with prior findings on the decrease in response speed from training to initial test trials of baseline to symmetry, and from symmetry to transitivity and equivalence trials (e.g., Arntzen & Holth, 2000; Holth & Arntzen, 1998; Wulfert & Hayes, 1988). This was observed across groups and independently of class formation. However, response speed patterns in training and test trials of baseline and symmetry appeared more stable for those who formed classes in the PIC group. Somewhat different from earlier findings (e.g., Bentall et al., 1998; Spencer & Chase, 1996), the current results did not show a positive relation between nodal numbers and speed of responding. Response patterns appeared slow and steady in 1-, 2-, and 3-nodes trials, and were most pronounced by those who formed classes.

As noted in the introduction, decrease in speed of responding during initial test trials may indicate some kind of precurrent behavior. Yet, there have been other studies (Arntzen & Haugland, 2012; Tomanari et al., 2006) not showing obvious systematic patterns when LH contingencies have been applied. However, these findings have mainly been demonstrated with participants not forming equivalence classes. Arntzen and Haugland (2012) discussed that when participants are forced to respond fast during training and testing, a possible side effect might be that precurrent responses are suppressed. In a study by Bortoloti and de Rose (2012), participants were given either simultaneous or delayed matching followed by the implicit relational assessment procedure (IRAP). This methodology measures responding under time restrictions between stimuli in consistent or inconsistent trials based on prior equivalence training. The authors implied that the relational strength among stimuli should be more evident when responding is fast and accurate. Results from the IRAP procedure revealed fast response speed and accuracy for those who formed classes in delayed matching, than compared to those who generated classes in the simultaneous procedure. Thus, showing that the relatedness among stimuli could be a function of delay values. Furthermore, differences in response speed during initial tests may also signify varying degrees of relatedness among stimuli in a class. Fields et al. (1993) suggested that the more equal speed is to accurate responding, the more substitutable stimuli are within a class. Correspondingly, when response speed to trial types of C-stimuli was analyzed in the current experiment, interesting results were found for participants forming classes in the PIC group. In particular, no differences were seen in speed of responding to trial types including meaningful C-stimuli (i.e., baseline, symmetry, and 1-node). However, distinct patterns were shown for the participants failing to establish equivalence classes in the PIC group. Their response patterns were comparable to the remaining groups demonstrating a systematic decrease from baseline to symmetry, and from symmetry to 1-node trials independently of class formation. These results are similar to Bentall et al. (1993) findings were speed and accuracy was steady in their nameable “pre-associated” group, but not for the groups exposed to nameable “non-associated” and all abstract stimuli. Thus, indicating that responding could be influenced by a participant’s familiarity to stimuli, and not specifically by trial types when classes are formed. Further research should explore the effects of meaningful stimuli by presenting new tests of semantically related stimuli after the formation of equivalence classes with meaningful pictures as nodes. One prediction might be that participants should respond equally fast and accurate to these stimuli. In addition, it would be interesting to see whether similar effects of meaningful stimuli can be shown by varying the degrees of meaningfulness by morphed pictures.

The current findings of stable response speed to trial types of C-stimuli for those who formed classes in the PIC group might be a case of equal substitutability among baseline, symmetry, and 1-node relations. However, even though response speeds to these trial types appeared stable for participants forming classes in the PIC group, stable speed of responding was not evident when all test trial types were analyzed. Imam (2006) argued that the observed differences in response speed during tests are due to serialized introductions of the conditional relations in training. That is, participants will have less experience to presented stimuli at the end of training than the ones introduced first. The nodal numbers are not considered as important variables as there is an unequal reinforcement history between the stimulus pairs. Although the current experiment used serialized training, overtraining of specific trial types was still prevented by automatically equalizing training trials across trial types. In addition, a simultaneous protocol ensured that all baseline relations were acquired before tests were introduced. A possible limitation, however, might have been for the groups given additional exposure to C-stimuli during preliminary simple discrimination training. This may have caused an unequal reinforcement history when compared to the PIC and ABS groups that were only given conditional discrimination training with C-stimuli. Further experiments should therefore focus on controlling the number of trials, as well as training baseline relations concurrently.

An accurate correspondence was found between performances in conditional discrimination testing and the post-categorization test. All participants who formed the three experimenter defined classes in test block one equally sorted all stimuli cards correct. This was shown across groups and thus indicating that the functions of C-stimuli did not affect card sorting performance. Maintenance of the established equivalence relations in the sorting task implies that the two different tests could function in the same manner of demonstrating derived relations, as well as showing generalization across test formats. Similar results have been observed in other studies (Arntzen, Braaten, Lian, & Eilifsen, 2011; Fields et al., 2012; Pilgrim & Galizio, 1996). The current experiment did also show that those who did not form classes in the first test, but did so in the second, sorted all stimuli correct. Thus, indicating maintenance of equivalence classes even though they did not immediately emerge.

Furthermore, interesting results were found for five participants who showed negative outcomes of class formation in both tests, but rather showed intactness for one of the three predefined classes in sorting. One might assume that delayed emergence could be indicated for two of these five participants as their performance during testing improved, and thus showing the intactness of one class in the second test block. However, different results were obtained for the three remaining participants. In particular, even though they had one class intact, a gradually consistent, but incorrect, responding was shown for the two other classes during the test blocks. Their card sorting data did also correspond to this pattern. Similar results on consistent nonequivalence responding have been reported by others (Arntzen & Holth, 2000; Holth & Arntzen, 1998).

Overall, the present post-categorization data showed that card sorting corresponded to the outcome in class formation testing. In addition, sorting may be sensitive on measuring whether participants base their sorting selections on one or more of the potential equivalence classes. However, a note should be taken on the differences between the conditional discrimination procedure and categorization testing. The latter test does not specifically examine properties of equivalence, but rather the presence of a stimulus class. The tests will therefore differ in several ways. First, in conditional discrimination, a participant is made to choose a comparison dependent upon the sample stimulus that is presented on a trial-by-trial basis (i.e., simultaneous presentation of one sample and three comparisons). In the sorting task, however, a participant is made to choose concurrently between the entire stimuli array. As discussed by Arntzen et al. (2011), one might ask whether the latter task appears more easy as it is possible to discriminate all the stimuli at once. Second, the sorting task is completed within one trial, while conditional discrimination testing is conducted over successive trials. These results may signify card sorting to be suitable for educational settings as conditional discrimination testing can be time consuming. However, further research should focus on whether participants show similar performances in repeated sorting, as well as retention over time. A possible limitation in the current study would be whether the given instructions in the pre-categorization task influenced participants' responding in conditional discrimination training and testing. Future replications could assess this matter by excluding initial instructions and pre-categorization, and rather expose participants to sorting either before or after testing in a conditional discrimination format.

To conclude, meaningful pictures as nodes were found to be more effective with respect to number of training trials and probability of class formation than meaningless and experimentally established S^Ds. Furthermore, obtained data on response speed shows a systematic decrease in responding from training to initial test trials. However, a fined-grained analysis on the trials involving C-stimuli may indicate that speed and accuracy are dependent on the type of stimuli presented, rather than the relations between test trial types. Lastly, post-categorization data shows that card sorting can be used as an alternative test for class formation.

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Table 1.
Experimental phases of training and test trials in the conditional discrimination procedure

Phases	Trial types	Programmed consequences (%)	Minimum trials	Criterion
Acquisition				
1. Serialized trials	A1B1, A2B2, A3B3	100	9	9
2. Serialized trials	B1C1, B2C2, B3C3	100	9	9
3. Serialized trials	C1D1, C2D2, C3D3	100	9	9
4. Serialized trials	D1E1, D2E2, D3E3	100	9	9
5. Mixed trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3	100	36	9
Maintenance				
6. Mixed trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3	75	36	33
7. Mixed trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3	50	36	33
8. Mixed trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3	25	36	33
9. Mixed trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3	0	36	33
Testing				
1. Randomized test block of baseline, symmetry, 1-, 2-, and 3-node trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3 B1A1, B2A2, B3A3, C1B1, C2B2, C3B3 D1C1, D2C2, D3C3, E1D1, E2D2, E3D3 A1C1, A2C2, A3C3, C1A1, C2A2, C3A3 B1D1, B2D2, B3D3, D1B1, D2B2, D3B3 C1E1, C2E2, C3E3, E1C1, E2C2, E3C3 A1D1, A2D2, A3D3, D1A1, D2A2, D3A3 B1E1, B2E2, B3E3, E1B1, E2B2, E3B3 A1E1, A2E2, A3E3, E1A1, E2A2, E3A3	0		
2. Randomized test block of baseline, symmetry, 1-, 2-, and 3-node trials	A1B1, A2B2, A3B3, B1C1, B2C2, B3C3 C1D1, C2D2, C3D3, D1E1, D2E2, D3E3 B1A1, B2A2, B3A3, C1B1, C2B2, C3B3 D1C1, D2C2, D3C3, E1D1, E2D2, E3D3 A1C1, A2C2, A3C3, C1A1, C2A2, C3A3 B1D1, B2D2, B3D3, D1B1, D2B2, D3B3 C1E1, C2E2, C3E3, E1C1, E2C2, E3C3 A1D1, A2D2, A3D3, D1A1, D2A2, D3A3 B1E1, B2E2, B3E3, E1B1, E2B2, E3B3 A1E1, A2E2, A3E3, E1A1, E2A2, E3A3	0		

Note. The directly taught relations are presented in sequences of acquisition and maintenance trials. Both test blocks were interspersed with baseline relations. The set criterion of correct responses was 9 of 9 in serialized trials, and 33 of 36 in mixed trials.

Table 2.

Individual data from conditional discrimination training, both test blocks, and outcome on equivalence class sorting test

			Acquisition		Maintenance		1. test						2. test						ECF sorting
P #	Condition	# of training trials	Total	Error	Total	Error	BSL	SYM	1N	2N	3N	ECF	BSL	SYM	1N	2N	3N	ECF	
4345	Abs	540	324	81	216	7	**36**	**36**	**52**	**34**	16/18	**138**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4346	Abs	576	432	70	**144**	1	**35**	**35**	**53**	**34**	**17**	**139**	**36**	**36**	**54**	**35**	**18**	**143**	**YES**
4320	Abs	504	360	66	**144**	4	**36**	**33**	44/54	24/36	12/18	113/144	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4321	Abs	576	432	62	**144**	2	**34**	**34**	44/54	28/36	9/18	115/144	**34**	32/36	35/54	17/36	7/18	91/144	NO
4331	Abs	792	648	99	**144**	1	**33**	29/36	18/54	7/36	7/16	61/144	32/36	32/36	16/54	13/36	7/18	68/144	NO
4350	Abs	1044	900	186	**144**	5	31/36	29/36	14/54	17/36	9/18	69/144	31/36	28/36	14/54	18/36	10/18	70/144	NO
4340	Abs	324	180	19	**144**	0	30/36	28/36	23/54	13/36	3/18	67/144	29/36	28/36	20/54	10/36	9/18	67/144	NO
4305	Abs	468	324	22	**144**	0	30/36	27/36	14/54	5/36	6/18	52/144	25/36	26/36	22/54	11/36	2/18	61/144	NO
4336	Abs	900	756	125	**144**	1	29/36	27/36	19/54	6/36	1/18	53/144	25/36	25/36	19/54	6/36	0/18	50/144	NO
4308	Abs	684	360	69	324	21	26/36	26/36	16/54	17/36	5/18	64/144	NOT AVAILABLE						NO
4333	Pic	324	180	20	**144**	0	**36**	**36**	**54**	**36**	**17**	**143**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4334	Pic	324	180	23	**144**	1	**36**	**34**	**52**	**34**	16/18	**136**	NOT AVAILABLE						**YES**
4309	Pic	324	180	17	**144**	0	**35**	**35**	**54**	**36**	**18**	**143**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4344	Pic	324	180	23	**144**	3	**35**	**36**	**51**	32/36	**17**	**136**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4343	Pic	468	252	34	216	28	32/36	**34**	**53**	**35**	**18**	**138**	25/36	22/36	29/54	23/36	11/18	85/144	**YES**
4307	Pic	288	144	14	**144**	3	**36**	**35**	48/54	30/36	16/18	129/144	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4348	Pic	324	180	34	**144**	4	**36**	**36**	48/54	27/36	10/18	121/144	**36**	**36**	**53**	**36**	**18**	**143**	**YES**
4359	Pic	576	432	69	**144**	0	**34**	31/36	40/54	27/36	11/18	109/144	**36**	**35**	**54**	**36**	**18**	**143**	**YES**
4355	Pic	360	216	26	**144**	1	32/36	**34**	36/54	19/36	8/18	97/144	30/36	30/36	30/54	12/36	6/18	78/144	NO
4315	Pic	432	288	59	**144**	2	29/36	29/36	24/54	18/36	4/18	75/144	26/36	31/36	30/54	14/36	7/18	82/144	NO
4327	Sim/Succ	1584	1440	241	**144**	0	**36**	**34**	48/54	29/36	11/18	122/144	**36**	**36**	**53**	**36**	**17**	**142**	**YES**
4342	Sim/Succ	468	324	29	**144**	1	**35**	30/36	17/54	9/36	8/18	64/144	**36**	32/36	21/54	16/36	6/18	75/144	NO
4319	Sim/Succ	468	324	48	**144**	0	**35**	31/36	35/54	19/36	6/18	91/144	**36**	**36**	47/54	28/36	15/18	126/144	NO
4351	Sim/Succ	540	396	69	**144**	0	**34**	13/36	19/54	12/36	6/18	50/144	**35**	20/36	16/54	14/36	6/18	56/144	NO
4328	Sim/Succ	468	252	54	216	7	**33**	27/36	23/54	7/36	5/18	62/144	29/36	27/36	23/54	4/36	0/18	54/144	NO
4337	Sim/Succ	900	576	99	324	25	32/36	**33**	42/54	25/36	6/18	106/144	**36**	**36**	**53**	**35**	**18**	**142**	**YES**
4338	Sim/Succ	360	180	28	180	4	32/36	29/36	15/54	13/36	5/18	62/144	26/36	26/36	28/54	20/36	1/18	75/144	NO
4341	Sim/Succ	1188	756	168	432	50	30/36	23/36	20/54	21/36	8/18	72/144	30/36	28/36	17/54	16/36	8/18	69/144	NO
4356	Sim/Succ	360	216	37	**144**	0	28/36	28/36	12/54	13/36	9/18	62/144	24/36	23/36	9/54	14/36	12/18	58/144	NO
4335	Sim/Succ	396	252	21	**144**	0	15/36	11/36	13/54	9/36	9/18	42/144	14/36	9/36	18/54	10/36	5/18	42/144	NO
4330	Sim	468	324	47	**144**	2	**36**	**36**	**54**	**33**	**18**	**141**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4332	Sim	540	396	75	**144**	1	**36**	**36**	**53**	**35**	**17**	**141**	**36**	**36**	**52**	**35**	16/18	**139**	**YES**
4347	Sim	432	288	39	**144**	1	**36**	**36**	**52**	**35**	**18**	**141**	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4326	Sim	396	252	23	**144**	1	**35**	**36**	**53**	**35**	**17**	**141**	**36**	**36**	**53**	**36**	**17**	**142**	**YES**
4339	Sim	828	648	93	180	4	**36**	31/36	28/54	8/36	4/18	71/144	**35**	26/36	27/54	6/36	4/18	63/144	NO
4358	Sim	360	216	53	**144**	0	**35**	**36**	46/54	27/36	10/18	119/144	31/36	21/36	43/54	24/36	7/18	95/144	NO
4324	Sim	612	396	50	216	7	**35**	**34**	43/54	25/36	11/18	113/144	21/36	19/36	31/54	22/36	9/18	81/144	NO
4322	Sim	504	360	73	**144**	0	**35**	**35**	48/54	29/36	10/18	122/144	**36**	**36**	**54**	**36**	**18**	**144**	**YES**
4349	Sim	684	540	91	**144**	0	**35**	**34**	39/54	25/36	11/18	109/144	**36**	**36**	**53**	**36**	**18**	**143**	**YES**
4313	Sim	936	756	194	180	9	26/36	28/36	20/54	11/36	6/18	65/144	29/36	25/36	19/54	10/36	5/18	59/144	NO
4312	Succ	252	108	10	**144**	0	**36**	**36**	**53**	**36**	**17**	**142**	**36**	**36**	**54**	**35**	**18**	**143**	**YES**
4323	Succ	396	252	23	**144**	1	**36**	**36**	**52**	**36**	**17**	**141**	**36**	**36**	**53**	**36**	**18**	**144**	**YES**
4357	Succ	396	252	36	**144**	0	**36**	**36**	**52**	**34**	**17**	**139**	NOT AVAILABLE						**YES**
4360	Succ	576	432	81	**144**	0	**35**	**35**	**50**	27/36	12/18	124/144	**36**	**36**	**54**	**34**	**17**	**141**	NO
4329	Succ	792	612	164	180	4	**34**	30/36	30/54	14/36	5/18	79/144	**35**	**35**	42/54	23/36	8/18	108/144	NO
4354	Succ	756	612	149	**144**	1	**33**	**33**	45/54	27/36	10/18	115/144	**36**	**36**	**53**	**36**	**18**	**143**	**YES**
4316	Succ	576	432	55	**144**	0	32/36	**35**	40/54	21/36	8/18	104/144	**35**	**35**	46/54	30/36	8/18	119/144	**YES**
4325	Succ	684	540	129	**144**	0	32/36	29/36	18/54	9/36	4/18	60/144	**33**	32/36	18/54	10/36	12/18	72/144	NO
4352	Succ	612	432	105	180	5	31/36	**34**	36/54	19/36	10/18	99/144	**33**	**34**	43/54	22/36	14/18	113/144	NO
4353	Succ	972	792	191	180	7	24/36	13/36	17/54	15/36	6/18	51/144	NOT AVAILABLE						NO

Note. P # = participant number; ECF = Equivalence class formation. Participant 4351 was required to have 20 consecutive correct trials in both simultaneous and successive discrimination training. Due to an error, results from the second test block for participants 4308, 4334, 4357, and 4353 are not available.

Table 3 .

Individual pre- and post-categorization data

			Pre-categorization																					Post-categorization																							
Group	ECF	P #	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3	CL1	CL2	CL3
ABS	YES	4345	3	1	0	1	1	2	1	0	2	0	3	1										**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4346	3	1	0	1	0	1	1	1	0	0	1	1	0	2	1	**0**	**0**	**2**				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
ABS	NO	4320	3	2	0	1	1	4	1	2	1													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4321	1	2	2	2	1	2	2	2	1													**0**	**0**	**5**	2	3	0	3	2	0															
		4331	**3**	**0**	**0**	1	1	0	1	3	2	0	1	3										**3**	**0**	**0**	**2**	**0**	**0**	0	5	1	**0**	**0**	**2**	**0**	**0**	**2**									
		4350	4	2	0	1	2	2	0	1	3													3	1	0	1	0	1	0	1	1	**0**	**0**	**1**	0	1	2									
		4340	**1**	1	1	2	1	1	2	2	1	0	1	2										1	1	1	3	1	0	1	2	1	0	1	3												
		4305	3	1	1	1	3	1	1	1	2													5	2	1	0	3	4																		
		4336	3	1	1	0	2	2	1	1	1	1	1	1										3	2	0	2	2	1	0	2	4															
		4308	**2**	**0**	**0**	1	1	0	**1**	**0**	**0**	0	1	1	1	3	4							**2**	**0**	**0**	**2**	**0**	**0**	1	1	0	**0**	**2**	**0**	0	1	1	**0**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**2**
PIC	YES	4333	3	2	1	2	1	2	0	2	2													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4334	**1**	**0**	**0**	3	1	0	1	1	1	**0**	**2**	**0**	0	1	3	**0**	**0**	**1**				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4309	2	1	2	2	2	1	1	2	2													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4344	3	1	0	1	1	1	1	1	1	0	2	1	**0**	**0**	**2**							**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4343	**3**	**0**	**0**	1	1	1	1	1	1	0	2	1	0	1	2							**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
PIC	NO	4307	2	1	1	1	0	0	1	1	4	1	1	0	**0**	**2**	**0**							**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4348	2	0	1	1	0	2	1	1	0	1	2	0	**0**	**2**	**0**	**0**	**0**	**2**				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4359	3	0	2	1	1	1	1	2	2	0	2	0										**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4355	2	1	0	1	1	1	1	1	0	1	0	1	**0**	**2**	**0**	**0**	**0**	**3**				**0**	**0**	**5**	2	3	0	3	2	0															
		4315	4	1	0	1	0	1	0	2	3	0	2	1										4	1	0	1	1	2	0	2	1	0	1	2												
SIM/SUCC	NO	4327	3	3	2	2	2	3																**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4337	3	1	0	1	1	3	1	3	2													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4319	4	0	1	1	3	1	0	2	3													**0**	**5**	**0**	**3**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**3**									
		4342	1	2	0	2	2	1	1	1	2	1	0	2										**2**	**0**	**0**	3	0	2	0	2	2	0	3	1												
		4351	**3**	**0**	**0**	1	1	3	1	2	1	0	2	1										**2**	**0**	**0**	2	1	1	1	2	1	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**2**						
		4328	2	1	0	0	4	0	2	0	2	1	0	3										2	0	3	3	2	0	0	3	2															
		4338	3	2	0	1	1	3	**1**	**0**	**0**	0	2	1	**0**	**0**	**1**							**2**	**0**	**0**	**3**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**0**	**0**	**2**			
		4341	**3**	**0**	**0**	2	2	3	0	2	0	0	1	1	**0**	**0**	**1**							**3**	**0**	**0**	**1**	**0**	**0**	1	1	2	0	4	1	**0**	**0**	**2**									
		4356	3	1	1	1	0	1	1	2	1	0	1	0	0	1	2							3	1	0	2	1	1	0	2	1	0	1	1	**0**	**0**	**2**									
		4335	3	1	0	1	1	0	1	1	2	0	2	3										**1**	**0**	**0**	**3**	**0**	**0**	**0**	**2**	**0**	**0**	**3**	**0**	**0**	**0**	**2**	**0**	**0**	**3**						
SIM	YES	4330	1	1	0	2	0	1	1	2	1	1	1	0	0	1	2	**0**	**0**	**1**				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4332	3	2	0	1	2	2	1	1	3													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4347	3	1	0	1	1	0	1	1	0	0	1	1	0	1	2	**0**	**0**	**2**				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4326	3	1	0	2	2	2	0	2	3													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
SIM	NO	4322	4	1	2	1	1	0	0	3	1	**0**	**0**	**1**	**0**	**0**	**1**							**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4349	2	1	0	1	1	0	1	0	1	1	0	1	0	2	1	0	1	2				**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4358	3	1	0	1	0	1	1	1	1	0	2	1	0	1	2							**0**	**0**	**5**	1	4	0	4	1	0															
		4313	4	1	1	1	2	1	0	2	3													3	2	1	2	3	4																		
		4339	1	0	1	3	1	1	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	0	1	3	1	1	1	2	1	0	1	1	1	1	1	1	0	1	2									
		4324	3	0	0	1	1	0	1	1	0	0	1	1	**0**	**1**	**0**	0	1	4				5	5	5																					
SUCC	YES	4312	2	1	0	2	2	3	1	2	2													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4323	1	1	0	**1**	**0**	**0**	**1**	**0**	**0**	1	0	2	0	1	1	**0**	**1**	**0**	**0**	**1**	**0**	**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4357	2	1	1	2	0	2	1	2	1	0	2	1										**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
SUCC	NO	4354	2	3	1	2	1	2	1	1	2													**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4316	4	1	2	1	4	3																**5**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**5**															
		4329	3	1	1	1	2	1	1	2	3													**5**	**0**	**0**	0	5	1	**0**	**0**	**4**															
		4360	2	4	1	3	1	4																5	5	3	0	0	2																		
		4325	3	1	0	1	2	1	1	1	2	0	1	2										**2**	**0**	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**2**	1	1	1			
		4352	1	1	0	**2**	**0**	**0**	1	0	1	1	1	1	0	2	1	0	1	2				4	1	1	1	1	0	0	2	1	0	1	3												
		4353	4	2	1	1	3	4																4	1	2	1	4	3																		

Note . Pre- and post-categorization data is presented on the left and right side, respectively. The left-most side shows experimental groups, outcome on equivalence class testing, and participant numbers. Data are separated within groups for those who formed and those who did not form equivalence classes (i.e., YES or NO). Categorization of stimuli are horizontally divided in boxes for all participants. Each box corresponds to the number of stimuli collected from equivalence Classes 1, 2, and 3. Correct sorting for one class is marked with shaded boxes, and bold numbers identify correctly grouped stimuli in one of the experimenter defined classes. See text for more details.

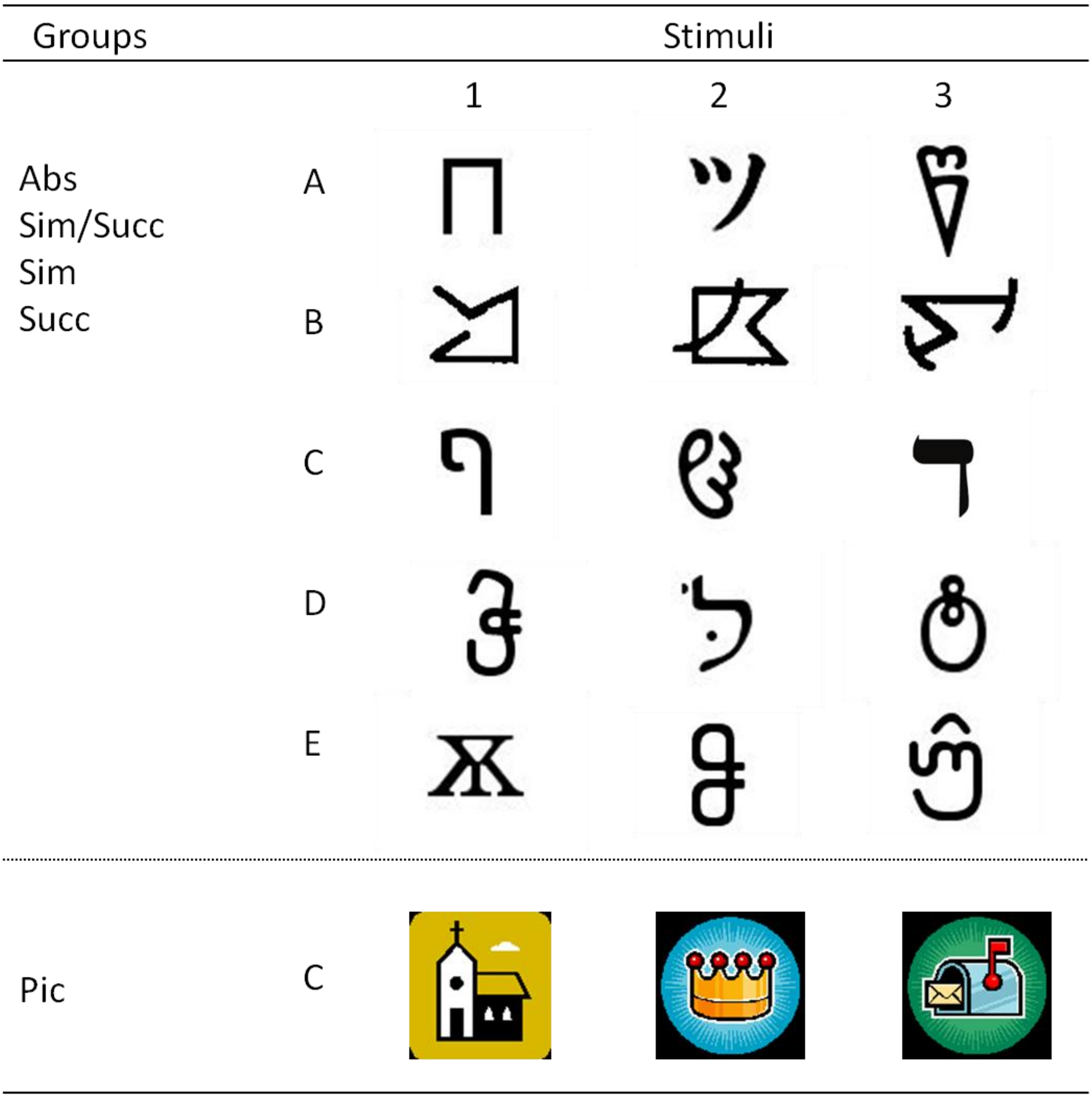


Figure 1. The figure shows the experimental stimuli used in the conditional discrimination procedure. See text for more details.

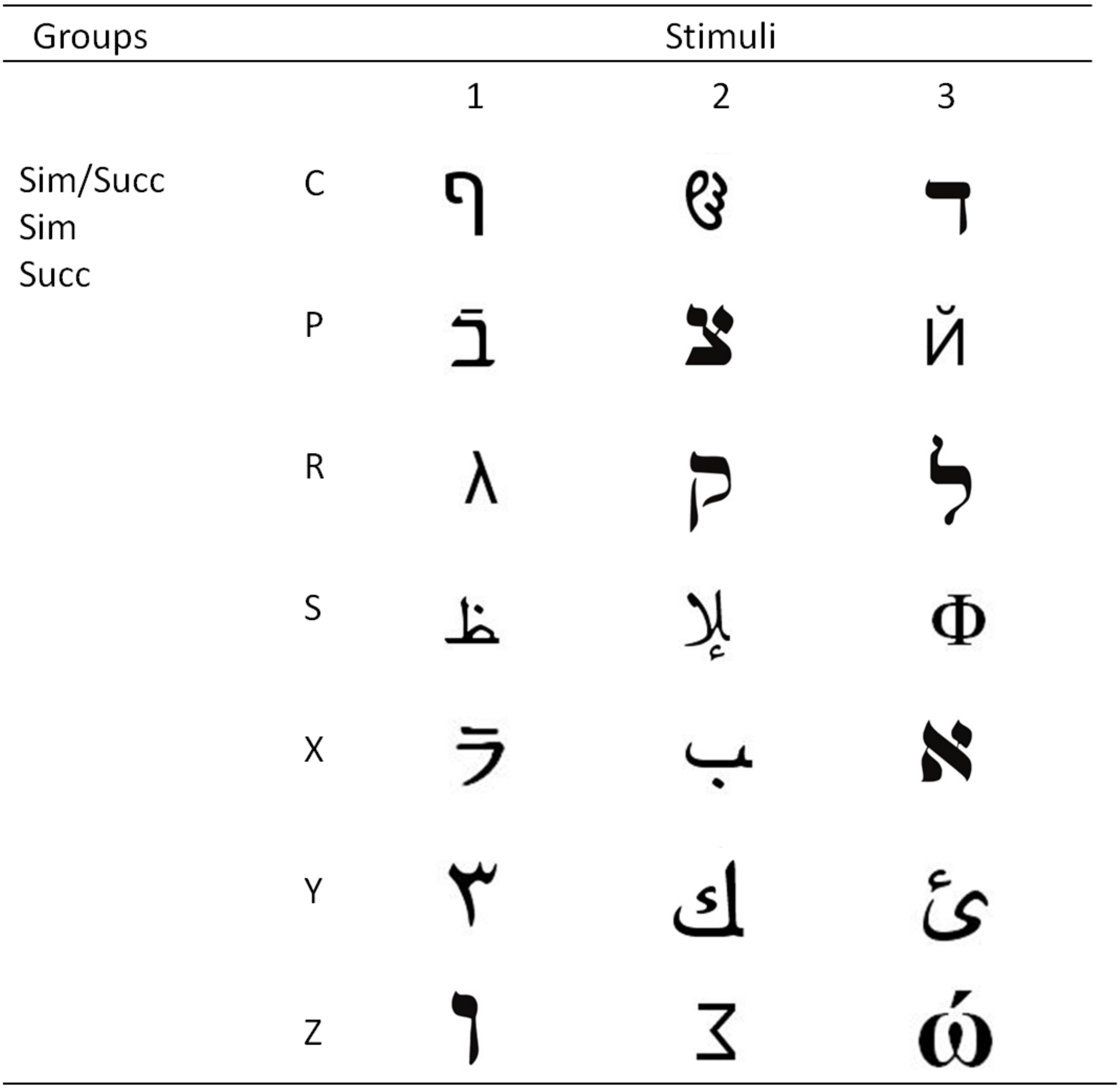
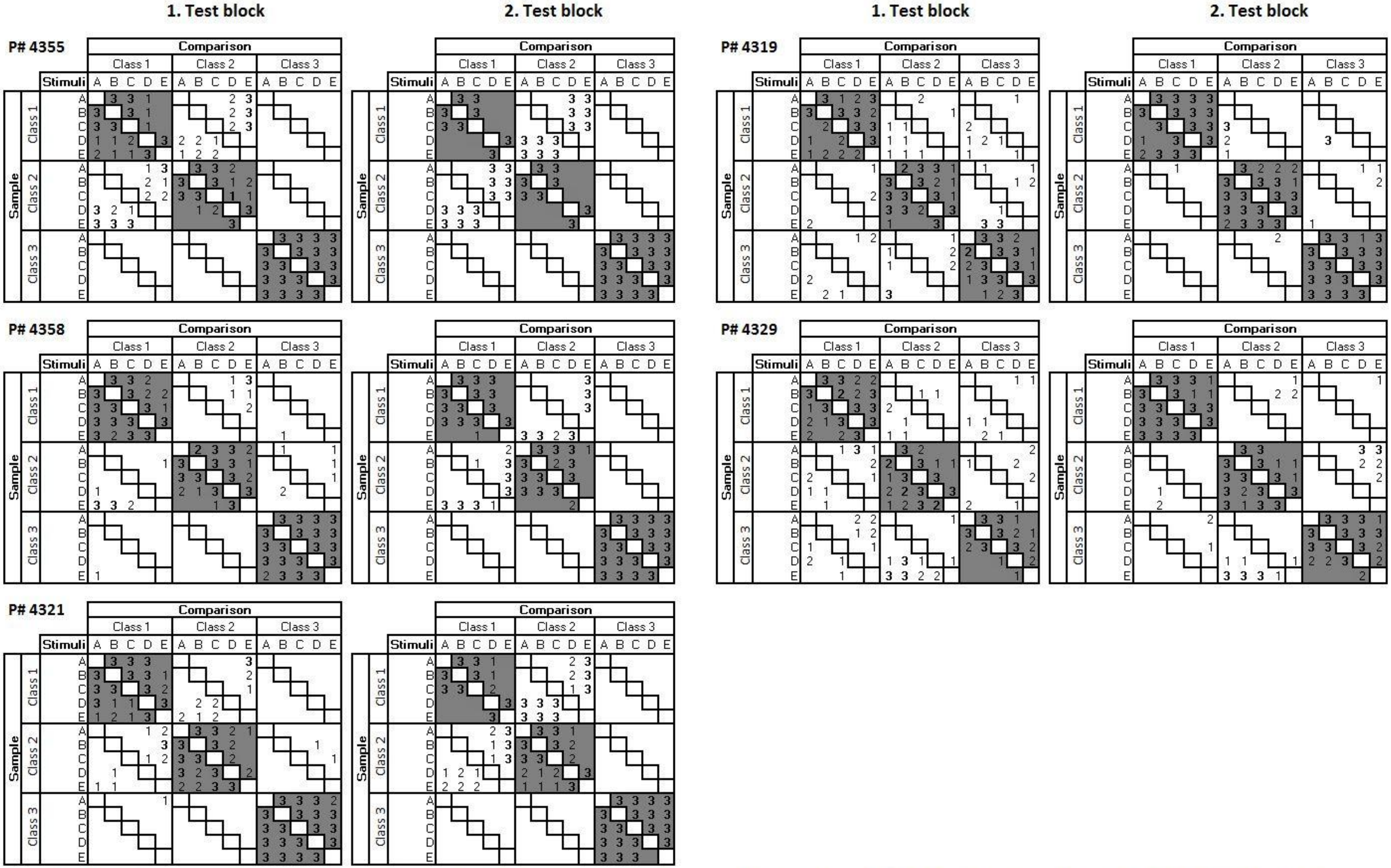


Figure 2. The figure shows the experimental stimuli used in the preliminary simple discrimination procedure. See text for more details.



P# 4355

1. Test block

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	1					2	**3**					
	B	**3**		**3**	1					2	**3**					
	C	**3**	**3**		1					2	**3**					
	D	1	1	2		**3**	2	2	1							
	E	2	1	1	**3**		1	2	2							
Class 2	A				1	**3**		**3**	**3**	2						
	B				2	1	**3**		**3**	1	2					
	C				2	2	**3**	**3**		1	1					
	D	**3**	2	1				1	2		**3**					
	E	**3**	**3**	**3**						**3**						
Class 3	A												**3**	**3**	**3**	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**	**3**	

2. Test block

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**						**3**	**3**					
	B	**3**		**3**						**3**	**3**					
	C	**3**	**3**							**3**	**3**					
	D					**3**	**3**	**3**	**3**							
	E				**3**		**3**	**3**	**3**							
Class 2	A				**3**	**3**		**3**	**3**							
	B				**3**	**3**	**3**		**3**							
	C				**3**	**3**	**3**	**3**								
	D	**3**	**3**	**3**							**3**					
	E	**3**	**3**	**3**						**3**						
Class 3	A												**3**	**3**	**3**	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**	**3**	

P# 4319

1. Test block

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	1	2	**3**			2						1	
	B	**3**		**3**	**3**	2					1					
	C		2		**3**	**3**	1	1				2				
	D	1		2		**3**	1	1				1	2	1		
	E	1	2	2	2		1	1	1			1			1	
Class 2	A					1		2	**3**	**3**	1		1			1
	B						**3**		**3**	2	1				1	2
	C					2	**3**	**3**		**3**	1					
	D						**3**	**3**	2		**3**			1		
	E	2					1			**3**			**3**	**3**		
Class 3	A				1	2					1		**3**	**3**	2	
	B						1				2	**2**		**3**	**3**	1
	C						1				2	2	**3**		**3**	1
	D	2										1	**3**	**3**		**3**
	E		2	1			**3**						1	2	**3**	

2. Test block

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	**3**	**3**										
	B	**3**		**3**	**3**	**3**										
	C		**3**		**3**	**3**	**3**									
	D	1		**3**		**3**	2						**3**			
	E	2	**3**	**3**	**3**		1									
Class 2	A			1				**3**	2	2	2				1	1
	B						**3**		**3**	**3**	1					2
	C						**3**	**3**		**3**	**3**					
	D						**3**	**3**	**3**		**3**					
	E						2	**3**	**3**	**3**		1				
Class 3	A									2			**3**	**3**	1	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**	**3**	

P# 4358

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	2					1	**3**					
	B	**3**		**3**	2	2				1	1					
	C	**3**	**3**		**3**	1					2					
	D	**3**	**3**	**3**		**3**										
	E	**3**	2	**3**	**3**								1			
Class 2	A							2	**3**	**3**	2		1			1
	B					1	**3**		**3**	**3**	1					1
	C						**3**	**3**		**3**	2					1
	D	1					2	1	**3**		**3**		2			
	E	**3**	**3**	2					1	**3**						
Class 3	A												**3**	**3**	**3**	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E	1										2	**3**	**3**	**3**	

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	**3**						**3**					
	B	**3**		**3**	**3**						**3**					
	C	**3**	**3**		**3**						**3**					
	D	**3**	**3**	**3**		**3**										
	E			1			**3**	**3**	2	**3**						
Class 2	A					2		**3**	**3**	**3**	1					
	B			1		**3**	**3**		2	**3**						
	C					**3**	**3**	**3**		**3**						
	D					**3**	**3**	**3**	**3**							
	E	**3**	**3**	**3**	1					2						
Class 3	A												**3**	**3**	**3**	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**	**3**	

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		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	2	2									1	1
	B	**3**		**2**	2	**3**			1	1						
	C	1	**3**		**3**	**3**	2									
	D	2	1	**3**		**3**		1				1	1			
	E	2		2	**3**		1	1					2	1		
Class 2	A			1	**3**	1		**3**	2							2
	B					2	**2**		**3**	1	1	1			2	
	C	2				1	1	**3**		**3**						2
	D	1	1				2	**2**	**3**		**3**					
	E		1				1	2	**3**	**2**		2			1	
Class 3	A				2	2					1		**3**	**3**	1	
	B				1	2						**3**		**3**	2	1
	C	1				1						2	**3**		**3**	2
	D	2		1			1	**3**	1		1			1		2
	E			1			**3**	**3**	2	2					1	

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	**3**	1					1					1
	B	**3**		**3**	1	1				2	2					
	C	**3**	**3**		**3**	**3**										
	D	**3**	**3**	**3**		**3**										
	E	**3**	**3**	**3**	**3**											
Class 2	A							**3**	**3**						**3**	**3**
	B						**3**		**3**	1	1				2	2
	C						**3**	**3**		**3**	1					2
	D		1				**3**	2	**3**		**3**					
	E		2				**3**	1	**3**	**3**						
Class 3	A					2							**3**	**3**	**3**	1
	B											**3**		**3**	**3**	**3**
	C					1						**3**	**3**		**3**	2
	D						1	1			1	2	2	**3**		2
	E						**3**	**3**	**3**	1					2	

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		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	**3**						**3**					
	B	**3**		**3**	**3**	1					2					
	C	**3**	**3**		**3**	2					1					
	D	**3**	1	1		**3**		2	2							
	E	1	2	1	**3**		2	1	2							
Class 2	A				1	2		**3**	**3**	2	1					
	B					**3**	**3**		**3**	2					1	
	C				1	2	**3**	**3**		2						1
	D		1				**3**	2	**3**		2					
	E	1	1				2	2	**3**	**3**						
Class 3	A					1							**3**	**3**	**3**	2
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**	**3**	

		Comparison														
		Class 1					Class 2					Class 3				
Sample	Stimuli	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Class 1	A		**3**	**3**	1					2	**3**					
	B	**3**		**3**	1					2	**3**					
	C	**3**	**3**		2					1	**3**					
	D					**3**	**3**	**3**	**3**							
	E				**3**		**3**	**3**	**3**							
Class 2	A				2	**3**		**3**	**3**	1						
	B				1	**3**	**3**		**3**	2						
	C				1	**3**	**3**	**3**		2						
	D	1	2	1			2	1	2		**3**					
	E	2	2	2			1	1	1	**3**						
Class 3	A												**3**	**3**	**3**	**3**
	B											**3**		**3**	**3**	**3**
	C											**3**	**3**		**3**	**3**
	D											**3**	**3**	**3**		**3**
	E											**3**	**3**	**3**		

Figure 3 . The matrices represents each of the two test blocks for five participants. The number of responses for each trial type is depicted for equivalence Classes 1, 2, and 3. All trial types were presented three times each. Correct responses are marked in the shaded boxes, and incorrect are shown in the blank boxes. The bold numbers identify whether participants responded consistently to a specific trial type. Presented sample stimuli are shown in rows, and comparisons in the columns. See text for more details.

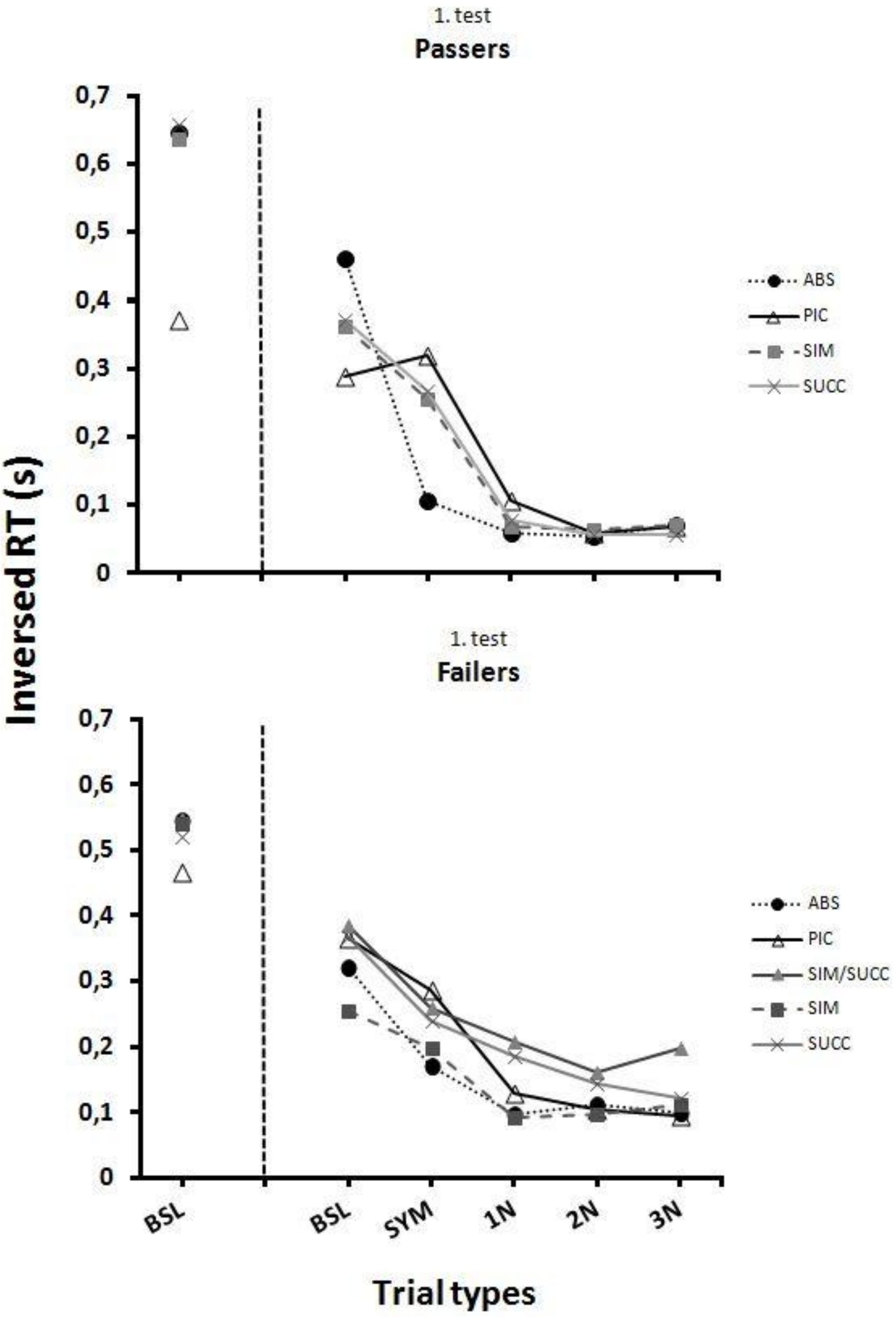

Figure 4. The figure shows inversed reaction time (i.e., speed) for the last five training trials of baseline relations, and first five test trial of baseline (BSL), symmetry (SYM), 1-, 2-, and 3-nodes. The upper panel "Passers" presents participants across groups who responded in accordance with stimulus equivalence. The lower panel "Failers" presents participants across groups who did not form the predicted equivalence classes.

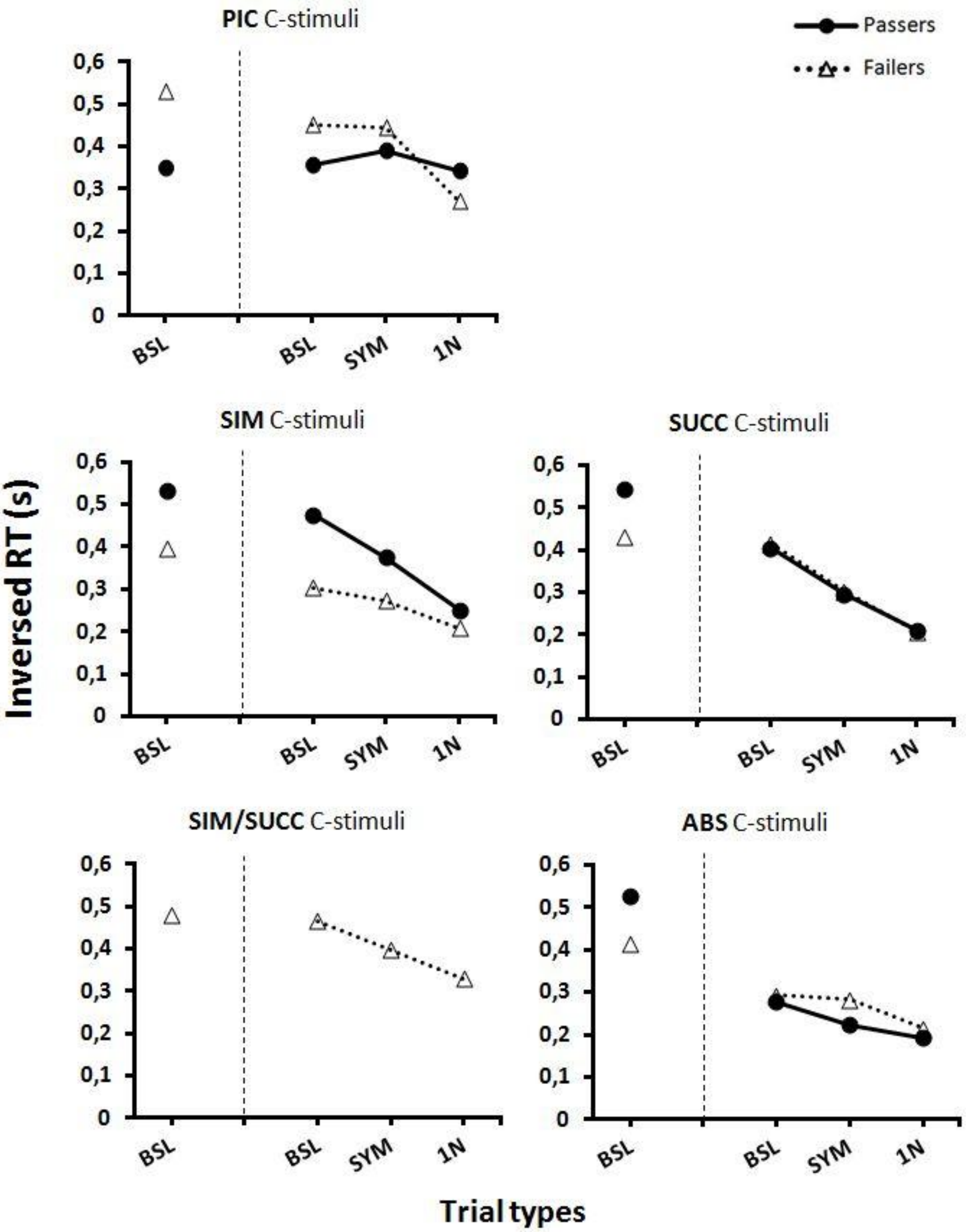

Figure 5. The figure shows inversed reaction time (i.e., speed) for separate trial types for C-stimuli as samples and comparison in the last five training trials, and all test trials of baseline (BSL), symmetry (SYM), and 1-node. Participants who formed classes are marked as "passers", and "failers" for those who did not establish the predicted classes.