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Stimulus Equivalence and Nodal Number

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Sammendrag

Den første artikkelen er en systematisk oppsummerende *review* av forskning på *nodal number* effekter innen stimulusekvivalens feltet. *Reviewen* har som utgangspunkt en oppsummerende artikkel skrevet av Fields og Moss i 2007. Denne artikkelen oppsummerer videre funn. Metoden for innhenting av data er systematiske søk utført ved bruk av databaser og elektroniske tidsskrift. Det er funnet 12 artikler som er inkludert. *Review* artikkelen oppsummerer eksperimentelle funn som har utvidet kunnskapen omkring effekt av node struktur resultater. Artikler som er inkludert er utvalgt gjennom ett sett med satte kriterier for inklusjon og informasjon er uthentet etter strukturerte punkter. Etter at resultater fra hver artikkel som er inkludert er presentert, oppsummeres og diskuteres resultatene opp mot tidligere funn og mulige fremtidige veier for forskning er foreslått.

Den andre artikkelen baserer seg på eksperimentell forskning innen feltet stimulusekvivalens. Eksperimentet hadde 20 deltakere, hvorav resultater fra 14 deltakere som fullførte trening og test er inkludert. Eksperimentets fokus er på hvordan ulike rekkefølger for presentasjon av relasjoner, og antall ganger relasjoner presenteres, påvirker utfallet av formasjonene av ekvivalens klasser, korrekt respondering sorter etter *nodal number* i emergente relasjoner, reaksjonstid sorter etter *nodal number* i emergente relasjoner, og innen-klasse preferanse tester. Resultatene er presentert i tekst og vist gjennom tabeller og figurer. Til slutt er resultatene oppsummert og diskutert i relasjon til tidligere forskning før muligheter for fremtidig forskning er diskutert.

Summary

The first article is a systematic summarizing review of research on nodal number effects within the field of stimulus equivalence. The starting point of the review is a previous summarizing article by Fields and Moss (2007). This present review summarizes how experimental findings have further elaborated on the nodal effects in stimulus equivalence research results. The method of data collection is systematic searches of databases and electronic scientific journals. A total of 12 articles have been included in the review as a result of the search. Articles are selected through set criteria and a set of relevant datapoints are collected from each experiment. After presenting each article, the results of the review are summarized and discussed in relation to previous research and possible future research is suggested.

The second article is based on experimental research in the field of stimulus equivalence. The experiment had 20 participants, where the results of the 14 participants that completed training and testing are included in the results of the experiment. The experiment is focusing on how alternations in presentation order of relations, and the number of times a relation is presented, affects the outcome of the equivalence test in terms of equivalence class formation, correct responding sorted by nodal number in emergent relations, reaction time sorted by nodal number in relations, and within class preference tests. The results are listed, showcased in tables and diagrams, and elaborated on. Finally, the results are summarized and relations to previous and possible future research discussed.

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Systematic Summarizing Review of Research on Nodal Number Effects

Abstract

The present review of results on nodal number effects starts where a summarizing overview on nodal number effects written by Fields and Moss (2007) left off. The starting point is chosen on the basis that no it is not possible to include all articles written on the topic, therefore a previous summary of results in the field is a good place to start to create an ordered overview. The objective of the current review is to provide a systematic overview and summarize further results produced on nodal number effects from 2007-2021. Systematic searches of databases and electronic journals were conducted. The eligibility criteria were that the articles were published after the summarizing article written by Fields and Moss in 2007, the articles had to be published in a peer reviewed journal, be based upon experimental research with human subjects, within the field of stimulus equivalence, include the term nodal or some approximation of this word in either the heading, key words or mentioned as a central result in the summary of the article, and be written in English or Norwegian. The systematic searches resulted in 12 articles being included that were in accordance with the set criteria. The results of these articles reported on data in some support of nodal number effects in terms of all showing indications in results. In the discussion section the articles limitations are discussed, and the general conclusion is that procedural issues must be resolved to confirm results reported on.

Key words: stimulus equivalence, nodal number, nodal distance

From the mid 1960s and onwards, Sidman and his colleagues conducted experiments on reading and language. The techniques developed and the findings produced in these studies has laid the foundation for the field of investigating stimulus equivalence formation within behavioral science. In the results of these experiments, Sidman and his colleagues observed what we have now come to know as stimulus equivalence. They named and classified the phenomenon by lending terms from mathematical set theory, and they completed a range of additional experiments and papers on the topic (see Arntzen & Sætherbakken, 2021, for a comprehensive overview of the theoretical basis). Sidman elaborated and expanded on these findings in his book "Equivalence relations and behavior: A research story" (1994) where he extensively discusses findings and implications up to the point of the publication.

The procedure traditionally used in stimulus equivalence research is a conditional discrimination procedure where stimuli of predefined classes are related by presentation of sample and comparison stimuli. The participant chooses a comparison stimuli and programmed consequences follow the choice of comparison stimuli, as described by Sidman and Tailby (1982). By presentation of consequences upon choice behavior in repeated trials, participants learn to discriminate between the comparison stimuli conditional upon the sample stimuli. When the participants exhibit behavior in line with the process of conditionally discriminating between the stimuli, the training usually ends, and the testing begins. Participants are subjected to further tests of untrained relations. The test for untrained relations consists of all possible untrained relation in the predefined classes of stimuli (Sidman & Tailby, 1982). One example of the emergence of such untrained relations could be if we trained `if A then B`, we could test for the untrained relation of `if B then A`.

Equivalence relations are something we cannot directly observe but must infer from the results of the test. If we are to say that the stimuli of a predefined class have become equivalent, and that matching-to-sample has been generated, all the possible relations between stimuli within a predefined class that are not directly trained, must emerge in the test (Sidman, 1992). Sidman lends his terminology for classifying the observed phenomenon of stimulus equivalence from mathematical set theory and classifies the untrained relations by applying the terms reflexivity relations, symmetry relations and transitivity relations, to the untrained relations. The conditional relations must be reflexive, meaning that if the stimuli are related to each other, they must show the same kind of relation to themselves. If we then train \`if A then B\`, then \`if A then A\` must emerge. The relations must also show symmetry. If we train \`if A then B, \` then \`if B then A´ must emerge. The third requirement is that the relations must also be transitive, meaning that relations in the same class that have never been directly related in training, must emerge in the test.  If we train \`if A then B\` and \`if B then C, \` the relation \`if A then C\` must emerge. If all these possible relations emerge in testing, we say that the stimuli in the predefined class have become equivalent (Sidman, 1992).

Nodal Number and Nodal Distance

Through conditional discrimination training, relations in equivalence classes are formed between certain stimuli in certain ways. Fields and Verhave (1987) proposed a set of terms for classification of the structure of equivalence classes. Class size describes the number of stimuli that are in a class. Number of nodes describe the number of stimuli in a class that are connected to two or more other stimuli through training. Singles are stimuli that are only linked to one other stimuli in training. Directionality of training describes how stimuli are used as sample and comparison in training. One example is, if we train if \`A then B\` and \`if B then C\` the class would contain three stimuli, where the A and C stimuli are singles and the B stimuli is a node.

The training structure influences the number of nodes in a set of stimuli. A class of stimuli can be presented in different relations. The training structures are described as linear series (LS), many to one (MTO) and one to many (OTM) (see e.g., Arntzen, Grondahl, & Eilifsen, 2010 for a schematic setup of training structures) To exemplify: In LS the stimuli A, B, C and D are trained in pairs of `if A then B`, `if B then C` and `if C then D`. In MTO, the same stimuli are trained in pairs of `if A then D`, `if B then D` and if `C then D`. In OTM, the stimuli are trained in pairs of `if A then B`, `if A then C` and `if A then D`. The result is that the LS leaves us with two nodes, and the OTM and MTO leave us with one node. Both the MTO and OTM structure have been found to produce better outcomes in stimulus equivalence tests than the LS structure (e.g., Arntzen et al., 2010).

Upon the suggestion of the terms for describing how training structures establish relation between stimuli (Fields & Verhave, 1987), an effect of nodal distance, or number, separating the stimuli in equivalence classes is and examined through several studies. The results of such experiments are summarized by Fields and Moss (2007). In their article they find that data in support of relational strength of stimuli within a class being determined by the number of nodes separating the stimuli in the relations has been reported on in a variety of different experiments and tests (Fields & Moss, 2007).

Sidmans (1994, pp. 539) writing suggests some skepticism towards the idea of `nodal distance` as a term that is proposed by Fields and Verhave (1987) to describe the number of nodes separating the stimuli in a class and classify the apparent findings of nodal effects in experimental data. Sidman (1994, pp. 544-545) suggests there might be confounding variables at play. Variables such as reinforcement history, the need for derived relations in nodal relations, instructional issues, and procedural issues in comparison presentations. He suggests that the observed nodal results might say more about when a relation emerges rather than if it emerges, as repeated testing has produced equivalence relations (Sidman, 1994, pp. 541). To avoid hypothetical constructs being inserted into the terms, Sidman (1994, pp.539) suggests that the term nodal number could substitute the term nodal distance. As the term nodal number is referring to the number of nodes that must be involved in the conditional discriminations needed for a stimulus pair to be included in an equivalence relation, and this is directly observable. The possibility of procedural issues accounting for the observed nodal effects has also been supported in data from experiments conducted by e.g., Imam (2001, 2006). However, Fields and Moss (2007) argue that the procedure of these experiments might not be value neutral procedure and thus the results are questionable.

Fields and Moss (2007) find that experimental data in support of the `nodal distance` account has been found during delayed emergence, gradual transfer of functions after class formation, reinforcer presentations during derived relations probes, brain imaging studies, within class preference tests pitting different nodal relational types against each other and in results of response transfer tests that bifurcated multimodal equivalence classes. Upon summarizing these results, Fields and Moss (2007) conclude that the data suggests that stimuli in an equivalence class acquires both class-based, and nodal-based functions. When the test trials present within-class options, the responses are indicative of nodal effects. When the trials present between-class options, the responses are indicative of equal relatedness of the stimuli within the class. This is explained by suggesting that the reinforcement contingencies that establish the baseline relations of an equivalence class have three effects: imposing nodal structure on the stimuli in a class, establishing differential relations. Second the reinforcement contingencies establish relations among stimuli in a set. Third they establish discriminations between the stimuli in different sets. Depending on the emphasis of the tests, the results can point in the direction of class consistency and differential relations within a class (Fields & Moss, 2007).

Fields and Moss (2007) start their article by summarizing some experiments that show the emergence of untrained relations and transfer of function within an established equivalence class.

These test results demonstrate evidence of interchangeability of stimuli within an equivalence class. They go on to summarize experiments that show nodal effects in the delayed emergence of classes, the gradual transfer of function, exact measures during and after class formation, within class preference tests, brain imaging data and performances in emergent relations when classes are not formed. Fields and Moss (2007) argue that `nodal distance` is a structural variable that will not always be visible as the expression or non-expression of nodal effects will depend on the discriminative function served by the format of the test trail. It depends on whether within-class or between-class contingencies are signaled by test conditions.

Fields and Moss (2007) argument concludes that the results might not necessarily be in direct conflict with Sidmans (1994) account of equivalence, as the stimuli can still function as equivalent when across class testing is the trial format and that the nodal effects observed in studies listed in the article are owed to the fact that the stimuli acquire more functions than one (Fields & Moss, 2007). To avoid confusion of terms, the following paper will use the term nodal number to refer to the number of nodes separating the stimuli in a relation as the author finds it a more informative term than the nodal distance term. Nodal effect, or nodal number effect will be used to describe the results in the data that varies as an apparent function of number of nodes separating the stimuli.

Objective of Present Review

The objective of the present review is to summarize further experimental findings published since the Fields and Moss (2007) article, in terms of nodal number research. The importance of studying the subject is evident in the proposition that the number of nodes might be an important variable in influencing degree of transitive stimulus control, in that the number of intermediate stimuli in such a relation differs as a result of the training procedure. This might also influence the results in testing in that fewer relations might be established when the number of nodes separating the stimuli increases (Fields, Verhave & Faith, 1984).

During probe searches prior to the systematic process outlined in the method section of this paper, it became clear that the full body of articles on the topic of nodal number research in the field of stimulus equivalence was too extensive to properly review in an article with the set limitations of the present manuscript. A way to review papers without having to include all papers in the field of interest, is to start the review where a past review left off. The Fields and Moss (2007) article was the closest to such a review the author of this paper could find within the field. Based on these limitations, it was chosen as a starting point for the present review. The present review is focused on the methods of equivalence training applied in the different studies, and the results in terms of nodal number effects.

Method

In this section a detailed description of the methods applied for retrieving information for the review is outlined. The process of reviewing the literature was initiated by searching two databases: Psych Info, and Web of Science core collection in the categories of behavioral sciences, psychology multidisciplinary and psychology experimental. After searching the databases, archives of several electronic scientific journals were searched. The first journal was the European Journal of Behavior Analyses, then Journal of the Experimental Analyses of Behavior, The Psychological Record, Learning and Behavior and The Mexican journal of Behavior Analyses. All databases and journals were last searched on the 15.04.21. In the databases the search terms applied were equivalence, and node or nodes or nodal or nodality. In the database searches the nodality terms were parenthesized to indicate that one of them had to be present together with the word equivalence, in the heading, key words, or summary. In the journal search the option of including several different terms at once describing nodal terms was not applicable in the search-bar. In the journal searches, the words equivalence and nodal were applied, as the already included articles from the search of the databases largely seemed to include these terms.

The results are presented in a flow-chart (see Figure 1). The Psych Info search returned 109 results, the Web of Science search returned 82 results, The European Journal of Behavior Analyses returned 25 results, The European Journal of Behavior Analyses returned 72 results, The Psychological Record returned 76 results, Learning and Behavior returned 8 results and The Mexican Journal of Behavior Analyses returned 2 results. All the article's headings, keywords, and summaries were screened to exclude articles that did not meet the criteria or were duplicates of studies already included. The Psych Info search was the first one conducted, and 10 articles were included for further reading. The second search was the Web of Science, all 10 studies previously included came up in the results. No new studies were included from the search. Next a search of the journal European Journal of Behavior Analyses was conducted, and this search returned 25 results. No articles were previously included, and one new article was found to meet the criteria. Journal of The Experimental Analyses of Behavior was searched, and the return was 72 results, 4 were already included from previous search, and one additional article was included as a result of the search. The next search was conducted in the Psychological Record, where the return was 76 results. Three articles were already included from previous search and no new articles were included as a result of the search. The search of Learning and Behavior returned 8 results with one already included. No new articled were included. The Mexican Journal of Behavior Analyses was searched with a result of two articles, which did not meet the criteria. To summarize the returns, 12 studies were found to meet the criteria and was included for further reading and data collection in the present review. An overview of the included articles is presented in Table 1.

Each article was assessed for eligibility. Criteria for inclusion were that the articles had to be published in a peer reviewed journal to ensure the quality of the results included. The journals were checked for meeting this criterion in the databases of Norwegian Center for Research Data (NSD) where they have a Norwegian register for scientific journals (Norwegian Center for Research Data, 2020). The articles had to be based upon experimental research with human subjects, within the field of stimulus equivalence to be relevant for the topic in the present review. In addition, the article had to include the term nodal or some approximation of this word in either the heading, key words or mentioned as a central result in the summary of the article to ensure that the study was on topic for the present review. For accessibility, the article had to be in English or Norwegian for the author of the present study to be able to assess it.

To collect data from the articles, a table of key points within the field of study was established and the data from the article was added to the table. This method is a systematic approach for providing an overview of relevant similarities and differences in the experiments in question. The information extracted was on: Title of article, author names, yar of publication and journal of publication. This part of the results is presented in table 1. Further information on the study question and variables, descriptions of the participants in the study, the training procedure and design in the study, the general results and conclusions, number of trials, type of stimuli, number of stimuli and number of nodes, if the stimuli were familiar, if pretraining was conducted as this could have an effect, the criteria and structure of the test, if the instructions of "go together" or similar words were given prior to the experiment as this could be a confounding variable (see e.g., Sidman 1994, pp. 305-306), nodal effects, and strengths and weaknesses in the study. An abbreviated version of some of these results is presented in Table 2. The articles were summarized according to these points. Each article is described independently, followed by a summary of the results in the presented articles.

There is always a risk of being biased both in the summary of each article and in the final comparison and theoretical summary of the articles. Knowing this is a risk, the author has tried to be as impartial as possible and stay critical to the material in the studies conducted as well as the summaries in this review.

Results

In the following section a summary of all the relevant data extracted from each article will be presented individually, followed by a summary of the results (see tables 1 and 2). All experiments were conducted in experimental settings, using computers with specialized software.

Measuring Differential Nodal Distance Using the Function Acquisition Speed Test

Cummins and Roche (2020) investigated the effects of nodal number on stimulus relatedness within classes, using the function acquisition speed test (FAST). The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Mastery criterion of 15/16 correct responding was set for each block before introduction of new pairs, repeated maximum eight times. Participants were then automatically moved to a new block whether they had met the criteria or not. The criterion was 17/18 correct responding for the mixed blocks at the end of presentation of new relations to move on to the test.

Testing consisted of 3 different FAST assessing the relatedness of pairs that were varying in nodal number. The FAST was conducted by showing one stimulus on the screen, requiring a press of z or m key on the keyboard. In the first FAST, consistent response was trained with programmed consequences and 3s limited hold. The second FAST participants were to answer according to class consistence. The third FAST participants were again to answer class inconsistent. In between the FAST there was blocks of probes for emergent relations.

Findings indicate that directly related relations were more difficult to respond in opposition to than the ones separated by nodes. Group and individual level analyses broadly demonstrated that relatedness varied as a function of number of nodes separating the stimuli in the defined stimulus classes. On the individual level there are some limitations in that 6 participants show clear nodal effects while the other 10 have more unclear results. Further, significant difference was only seen between the 0-node and 2-node relations, not the 0- and 1-, and 1- and 2-node relations. The results are inconclusive, but some indications of nodal effects are apparent in the results.

On the Effectiveness of Including Meaningful Pictures in the Formation of Equivalence Classes

Arntzen and Mensah (2020) addressed questions on the inclusion of familiar stimuli in stimulus classes, that had not previously been answered. The article reports on three experiments addressing the difference between abstract shapes and pictures, the role of pictorial stimuli in test, and placement of familiar stimuli in class structure. In addition, they look at delayed emergence as a function of nodal number separating the stimuli in the different emergent relations.

The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). To move on from one block to the next, 90% correct responding was required. Thinning of consequences with a block of 75%, 50% and 0% programmed consequences was presented before initiation of testing. Depending on which groups and experimental conditions participants were assigned to, all stimuli could be abstract, one stimulus in each class could be familiar and colorful, one stimulus in each class could be black and white and familiar, or some stimuli but not in each class could be familiar. Testing was organized in two test blocks for all emergent relations, with interspersed baseline relations, consisting of 180 trials each. In experiment 1, all stimuli were included, in experiment 2 the familiar stimuli were excluded from test, and in experiment 3 all relations were included in test. In the end of the test, additional sorting tests were conducted.

Results in experiment 1 indicated that color of the familiar stimuli does not affect the formation of equivalence classes. Results in experiment 2 indicated that the familiar stimuli had effect in training, not in testing. In experiment 3, results indicated that the presence of a familiar stimuli in each class was more important than the placement in the structure of the class. The delayed emergence of equivalence classes was observed for some participants in all groups.

The findings are somewhat in support of the previous findings that the delayed emergence could be influenced by number of nodes separating the stimuli as the results are indicative of this for 8 participants. For 23 of the other 31 participants that showed delayed emergence the pattern was more mixed.

Relatedness of Equivalence Class Members: Combined Effects of Nodality and Relational Type

Albright, Fields, Reeve, Reeve and Kisamore (2019) investigated the combined effects of nodal number and relational type on relatedness of stimuli within equivalence classes. They also attempt to quantify the relative strength of the relations and types. Participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Before testing, consequences were thinned with blocks of 75%, 50%, 25% and 0% programmed consequences. Mastery criterion was 100% correct responding. Maximum time for training was set to two hours. Number of trials for each block was 48. The A, B, F, G, H, and I stimuli were nonsense syllables. The C, D and E stimuli were familiar. They added one class of comparison stimuli that were not trained or tested, used in training to increase number of comparison stimuli on each trial.

The test consisted of 144 equivalence trials in three identical blocks of 48 trials. Trials consisted of probes for baseline, symmetry, transitivity, and equivalence relations. The order of the trials was randomized. Criterion for equivalence class formation was 98%, or 46/48 correct in each of the three blocks. The test was followed by a within class preference test. One sample and two comparisons from the same class was presented each trial. Finally, retention of equivalence relations was assessed.

The inclusion of pictures made the yields in class formation higher. In the preference test, nodal effects were present in that the relations of smaller nodal numbers were preferred to the relations with larger nodal number separating the stimuli and the transitive relations were preferred to the equivalence relations. The conclusion is that nodal number and relation type jointly determines the relatedness of the different stimuli in a predefined class.

The Relation Between Sorting Tests and Matching to Sample Tests in the Formation of Equivalence Classes

Arntzen, Granmo and Fields (2017) investigated the relation between sorting tests and matching to sample tests in the formation of equivalence classes. Before training, a sorting was conducted. All stimuli were presented at once and the participants were instructed to click and drag the stimuli to sort them in a way that they perceived as correct. The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Each block in training contained 60 baseline trials, 5 presentations of each relation. Thinning of consequences was conducted at the end of training with one block of 50% and one with 0% programmed consequences presented. Mastery criterion to move forward from one block to the next and from test to training was 100% correct responding.

The test was a between class test for possible emergent relations. Two blocks were presented, consisting of 180 trials each consisting of baseline, symmetry, transitivity, and equivalence relations. Each relation was presented 3 times each block. The criterion for equivalence class formation was set to 95% correct responding. A post training sorting test was also conducted. Participants were split in to two groups where one got the sorting test before the emergence test and the other group was tested in the opposite order.

Results indicated that sorting tests can be used to track immediate emergence of equivalence classes that were included in the experiment. In analyzing the sorting data, they also found that some of the outcomes of the test were influenced by the nodal structure imposed in the training of stimuli. The finding is indicative of nodal number influencing the steady state performance of the stimuli in a class. The way the sorting test was arranged is only one in many ways which it could be arranged and thus further research with differently organized sorting tests could further strengthen and give clarity in terms of the results.

Transitive Inference in Stimulus Equivalence and Serial Learning

Dickins (2015) investigated stimulus equivalence learning and serial learning sets to see how the different types of training affect the results. Before training the participants were given a scenario description for the passport photos informing that there were two classes with different grades. Participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Training was conducted with 1s delay and 3s limited hold. In SL training the relations are presented in serial order with 1s delay and no required responses other than indicating which side of the screen the last sample was on in the last screen. In MTS training each sample was presented with two comparisons. Same or different were the response options.

When 12/12 correct was attained three times in a row, the test phase was initiated. The test of transitive and equivalence relations was conducted with 1s delay and 3s hold - phase 2 and 4 of testing. Phase 1, 3 and 5 consisted of a sorting test where all the stimuli were presented at once and they were sorted by the participants. The researchers looked for class sorting and structure in the results. At the group level there are some indications, but the individual data seems to be inconclusive. All in all, the authors conclude that the study should only be seen as an initial exploration of the relationship between SL and stimulus equivalence training and testing. Looking at the correct responding and reaction time of each member of the group, the results are inconclusive. In terms of nodal number effects, they find that reaction time is a function of number of nodes in the test results for some participants, but not in others.

All Stimuli are Equal, but Some are More Equal Than Others: Measuring Relational Preferences Within an Equivalence Class

Doran and Fields (2012) objectives were to look for preferences between members in an equivalence class and determine if the possible difference in responding is due to nodal number or other factors. Two experiments were conducted. Participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). When the mastery criterion of 100% was met in training there was a thinning of consequences with blocks of 75%, 25% and 0% programmed consequences before testing was initiated. In the mix blocks there were 40 trials, each possible relation presented once.

The test consisted of an emergence test of three 28-trial blocks containing baseline, symmetry, transitivity, and equivalence relations, followed by a class preference test for those who passed the emergence test. In the within class preference test there were probes consisting of one sample and two comparisons from the same class. This test had two phases, one extreme difference phase and one within class relational assessment phase. In the extreme difference the relations between the sample and comparisons varied across several dimension. The within class phase pitted relations that served different functions in three different relational setups. A test was concluded when the participants selected the “simpler comparison” in 15 of 16 trials for a block.

Participants were finally subjected to a derived relations test to see if the relations were retained after within class testing. A criterion of 96% correct responding was set for this phase.

The one participant in experiment 1, and 5 in experiment 2 who formed classes, showed preference for transitive over equivalence and trained baseline over symmetrical relations. The members of equivalence classes are differentially related to each other according to these results. If the members had become equally related to each other, we would expect the relations in the within class preference probes to be chosen an even number of times

A Test of the Discrimination Account in Equivalence Class Formation

Wang, McHugh and Wheland (2012) compared predictions suggested by Saunders and Greene in 1992 and the nodal account, to determine which explanation is better suited to account for unequal relations in an established equivalence class. The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). The relations were presented an equal number of times, with 16 trials in each block. Sixteen consecutive correct responses initiated a new block. Consequence fading was introduced towards the end of training with a block of 50% and 0% programmed consequences.

Test blocks consisted of 40 trials, with each possible relation presented, in at least one block, until correct responding of at least 85% was attained. Results were analyzed for response accuracy and response speed. The results of the test provided evidence against the proposed theory that non-substitutability of stimuli within the same class is due to the confounding effect of repeated exposure to baseline trials. The evidence suggested that the relatedness of stimuli is explained better by the nodal number separating the stimuli in the training structure.

Effects of a Meaningful, a Discriminative, and a Meaningless Stimulus on Equivalence Class Formation

Fields, Arntzen, Nartey and Eilifsen (2012) investigated how a familiar stimulus versus a training of function to a stimulus (Sd) as C stimuli affected the responding in stimulus equivalence tests for emergent relations. The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). One group had a familiar picture as C stimuli, another a pre-training session to make the C stimuli an Sd for a response, the last group had arbitrary stimuli as C (control group). Thinning of consequences in blocks with 75%, 25% and 0% was presented before testing. A mastery criterion of 90% correct responding was set to move from one block to the next. The mix phases included 36 trials. Number of presentations of each trial type was equalized through the specialized software used in the experiment.

The test consisted of 90 trials of all trained and all possible untrained relations in the class. Trials were presented in random order, presented 2 times in separate blocks. Criterion for the formation of equivalence classes was 90% correct responding. Results indicated that approximately 75% of participants in the familiar group formed equivalence classes, 50% in the group with the acquired Sd as C stimuli, and 0% in the abstract group. Pre and post sorting test were conducted where all stimuli in the classes were presented at once, and the participants were to sort them as they found correct. Results of these tests were approximately the same as the emergence test. The results indicate that the presence of a meaningful stimuli in a set of abstract or meaningless stimuli influences the emergence of equivalence classes and enhances the formation of equivalence classes.

In terms of nodal number, the functions of the C stimuli did not influence nodal number results or the delayed emergence of classes. During delayed emergence (the second block of testing) and the accuracy of class-based responding seemed to be a function of the number of nodes separating the stimuli while classes were formed. The differences disappeared when the classes were fully formed.

Preserved Nodal Number Effects Under Equal Reinforcement

Wang, McHugh and Wheland (2011) investigated if nodal effects are no longer present when the reinforcement is equalized across baseline types. They conducted three experiments. Training was conducted using a computer with specialized software. The participants, stimuli, trial setup and programmed consequences are as presented in the table (see Table 2). For experiment 1, a 1s delayed matching-to-sample procedure was used, with programmed consequences of informative text presented upon responding. Participants were split into 4 groups. Half of the participants had a 2s limited hold; the other half had a 5s limited hold condition. Further, half were subjected to equal reinforcement and half to unequal reinforcement. Stimulus relations were introduced serialized for half of the participants and concurrent for the other half. Mastery criterion was set to 8 consecutive correct responses in the last phase of training required to move on to the test phase. In experiment 2 the participants were split in to two groups where one had equal and one unequal reinforcement opportunities for the different relations in training. A transfer test was added. The number of correct responses required in the last phase of training was set to 10 instead of 8. In experiment 3 the training was concurrent. The number of correct responses required in the last phase of training was set to 20.

Participants were tested for response accuracy and response speed in a test for emergent relations in the equivalence classes. Number of trials per block was 40, consisting of baseline, symmetry, transitivity, and equivalence relations. Each participant was presented with two blocks in each session across four sessions in one week in experiment 1. In experiment 2, test consisted of one block of 60 trials repeated a maximum of three times containing the same relational types as in the test in experiment one. Criterion for equivalence class formation was set to 90% correct responding. Participants were then subjected to a function training for one of the stimuli in the classes followed by a transfer test, before being re-exposed to equivalence testing to check for class retention. In experiment 3 the only procedural change from experiment 2 was equal reinforcement.

Results showed that nodal number separating the stimuli in emergent relations was a predictor of reaction time, even with equalized reinforcement options for the different trial types, indicating that nodal number effects are preserved and maintained when the reinforcement is kept equal. Nodal effects were also present in the results of the transfer of function test in experiment 2 and 3. Response accuracy did not show conclusive results in terms of nodal number effects. Observed nodal effects did not seem to be influenced by the unequal reinforcement of different trial types.

Nodal Structure and Stimulus Relatedness in Equivalence Classes: Post-class Formation Preference Tests

Moss-Laurenco and Fields (2011) explored the relatedness of stimuli in an equivalence class under procedural changes that circumvented possible confounding factors. They conducted 3 experiments. Before training, there was a keyboard familiarization training with familiar words. In experiment 1 the participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Experiment 2 was a replication of experiment 1, with an extra comparison class included to make sure that there were three comparisons and avoid learning through exclusion. Experiment 3 expanded the class size to 5 members and 3 nodes to show generality of findings. Thinning of consequences was introduced in the last blocks towards the test phase. A mastery criterion of 100% correct responding was required to move to the next phase in experiment 1 and 2, 92% in experiment 3.

Testing consisted of all possible emergent relations in the equivalence classes with directly trained baseline trials interspersed. A within class preference test was then conducted where different relations within the same class were pitted against each other. Results of experiment 1 returned no clear results. The authors theorized that there could be an issue with learning by exclusion rather than inclusion due to there being only two comparison stimuli. In experiment 2 they corrected for that procedural variable by including a class of stimuli that were only used as a third comparison in trials. They found that nodal number effects were present in preferences within the classes. In experiment 3 they expanded the classes to show generality of findings. The results showed nodal effects in preference.

The summarized conclusion for the experiments is that the cross-class tests showed results indicative of interchangeability in the equivalence classes, while the within class preference tests showed results that indicated differential relatedness within the equivalence classes.

Assessment of the Relatedness of Equivalent Stimuli Through a Semantic Differential

Bortoloti and DeRose (2009) reports on two experiments, where experiment 1 investigates transfer of function and experiment 2 investigates the nodal number effects. Participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). A-stimuli were familiar. Structure of training in the first experiment was A-B, A-C and C-D, and LS in experiment 2. Participants in each experiment were split in to two groups. There was a 2s delay between sample and comparison presentation in the trials of the first group and simultaneous in the second group that was the control group. Mastery criterion set to move from training to testing was no more than one incorrect in a mixed block presenting 36 baseline trials, repeated maximum three times.

The test consisted of an equivalence probe test with 24 trials per block. In experiment 1 the ones that maintained perfect scores in these probes were subjected to semantic differentials for all of the stimuli. In experiment 1 they found a transfer of function from the familiar to the abstract stimuli in the semantic differentiation. In experiment 2, only the D and F stimuli were evaluated in the semantic differentials test. The results indicated that D was evaluated similar to the familiar face stimuli while the F stimuli was not. They conclude in terms of nodal effects that the transfer of semantic variations in the established equivalence classes seem to be affected by the number of nodes separating the stimuli in training.

Nodal Structure and the Partitioning of Equivalence Classes

Fields and Watanabe-Rose (2008) addressed weaknesses from previous experiments that had examined nodal number effects in equivalence classes. Pretraining was conducted before the experiment, with familiar stimuli. The participants, stimuli, sample and comparison presentations, trial setup and programmed consequences are as presented in the table (see Table 2). Criteria for passing the training blocks and move on in the training, and to the test phase, was set to 100% correct responding. There was a thinning of consequences towards the end of the training. After training of the relations was concluded, specific responses were trained to the C stimuli in the class. The responses consisted of a set number of button-presses on a fixed ratio. Following the training of responses to the C stimuli a different fixed ratio training was conducted for the D stimuli in each class.

The first test was an emergence test with all possible untrained relations presented with interspersed baseline relations. The second part of the test was a single-option response transfer test where each of the 12 stimuli in the two classes were presented once in a random order. This block was repeated 8 times. Third, a repetition of the class test was presented to ensure the classes were intact. The fourth phase was a dual-option transfer test. The fifth and last phase was a repetition of class test again, to ensure the intactness of the classes.

Results imply that nodal number separating stimuli is a variable that affects relations among stimuli in a class in a permanent way. The way the relations are trained imposes nodal structure and this structure imparts differential relational strength amongst the stimuli that is a function of the number of nodes separating the stimuli in the class.

Summary of Results

Of the 12 articles included in this review, all show results that lend some degree of support to the nodal number account of stimulus relatedness. One study (Cummins & Roche 2020) broadly demonstrated that the relatedness of the stimuli largely varied as a function of nodal number while implying emergence and function acquisition speed test (FAST) results. Two articles (Arntzen & Mensah 2020; Fields et al., 2012) present evidence that some results in delayed emergence tests were affected by the nodal number separating the stimuli in training. One of these find that the effects disappear with repeated testing (Fields et al. 2012). Reaction time is also found to be a function of number of nodes separating the stimuli in delayed emergence (Fields, et al., 2012; Wang et al., 2012; Wang et al., 2011), and somewhat in SL and MTS testing, but the results are inconclusive (Dickins 2015). Indication of some nodal number effects are found in sorting tests (Arntzen et.al. 2017). In within class preference tests there have been results indicative of nodal number effects (Albright et al., 2019; Doran & Fields, 2012; Moss-Laurenco & Fields, 2011). Further indications have been found in semantic variations tests (Bortoloti & DeRose, 2009). And, in class partitioning tests (Fields & Watanabe-Rose, 2008) One study also found that the functions of a familiar C stimuli did not seem to have any effects on nodal number effects (Fields et al., 2012). Another found that nodal number and relational type jointly determined the relatedness of the different stimuli in an equivalence class (Albright et al., 2019)

Discussion

As summarized by Fields and Moss (2007) prior experiments have resulted in data indicative of nodal number effects in several different conditions: Delayed emergence, transfer of function/response tests, reaction time, derived relations, brain imaging and within-class-preference tests. As seen in the articles included in the current review, further articles have been published that are in some support of the nodal number accounts of stimulus relatedness. Two articles (Arntzen & Mensah 2020; Fields et al., 2012) present evidence that some results in delayed emergence tests were affected by the nodal number separating the stimuli in training. The effects disappear with repeated testing in one experiment (Fields et al., 2012). Reaction time is also found to be a function of number of nodes separating stimuli in delayed emergence (Fields, et al., 2012; Wang et al., 2012, Wang; et al., 2011), and somewhat in SL and MTS testing, but the results are inconclusive (Dickins, 2015), nodal effects are found in results of transfer of function tests (Wang et al., 2011), in sorting tests (Arntzen et.al., 2017), in class partitioning tests, where indications of nodal number effects in test results are also found (Fields & Watanabe-Rose, 2008), and, in within class preference tests (Albright et al., 2019; Doran & Fields, 2012; Moss-Laurenco & Fields, 2011), amounting some further evidence of the nodal number account.

Further, results in different kinds of test and training conditions have emerged in semantic variations tests (Bortoloti & DeRose, 2009). One study (Cummins & Roche, 2020) broadly demonstrated that the relatedness of the stimuli largely varied as a function of nodal distance while implying emergence and function acquisition speed test (FAST). Another found that nodal number and relational type jointly determined the relatedness of the different stimuli in an equivalence class (Albright et al., 2019). One study also found that the functions of familiar C stimuli did not seem to affect nodal effects (Fields et al., 2012).

There are methodological issues in some of the studies presented. Some only present two comparison stimuli upon each sample presentations (Dickins, 2015; Wang et al., 2011). As Carrigan & Sidman (1987) pointed out, the presentation of only two comparisons on a trial could lead to class formation by rejection rather than inclusion in a class through the stimuli being related. Inclusion of a third comparison stimuli could solve the problem of control by negative stimuli, or rejection. Introducing a third class of stimuli as comparisons and repeating the experiments under those conditions could remedy this weakness, and further strengthen the validity of the results.

Another issue is that some results include the 0-node relation as part of the analysis of nodal number analysis (e.g., Cummins & Roche, 2020; Moss-Laurenco & Fields, 2011). These relations are in direct contact in training. These are the symmetry relations and including them in the analysis could distort the effects of nodal distance in favor of lower number of nodes being favored due to a history of direct relation in reinforcement conditions between the stimuli in these relations. Redoing the analysis or experiments without including the 0-node relations or discussing the results in a way that discloses this possible confounding variable, could allow us to see the preferences between the relations separated by nodes in the training structure.

Further, some of experiments have a low number of participants (Arntzen et al., 2017; Doran & Fields, 2012; Fields & Wattanabe-Rose, 2008; Moss & Fields, 2011). It is difficult to conclude from these studies, and a replication with a larger number of participants included would give more generality to potential conclusions in terms of nodal number effects.

Another potential problem is that some experiments have instructional issues, and/or pretraining sessions taking place before the baseline relation training that could affect the results without that being considered when discussing the results (Albright et al., 2019; Dickins 2015;

Moss-Laurenco & Fields, 2011). By correcting for these issues in a replication, one could exclude possible confounding effects from instructions and pretraining.

Another possible issue is in the familiarity of stimuli included in that some experiments include several familiar stimuli that could be in prior relation, or formal similarity to each other (Albright et al., 2019; Dickins, 2015) without possible effects being accounted for before the study is initiated. A replication could be done avoiding possible confounding effects of pre-experimental learning history or formal similarity of the included stimuli. Further several of the experiments have used nonsense syllables or nonsense words (Albright et al., 20019; Cummins & Roche, 2020; Doran & Fields, 2012; Fields & Wattanabe-Rose, 2008; Moss-Laurenco & Fields, 2011; Wang et al., 2011; Wang et al., 2012) which could bare resemblance with actual words to varying degrees. This could have affected the results in terms of preexisting relations. Replication could be done with abstract shapes stimuli, to see if the results hold up with other kinds of stimuli.

To conclude, the results in articles included in this review lend further support to the nodal number account as summarized by Fields and Moss (2007) in terms of delayed emergence tests affected by the nodal number separating the stimuli in training, reaction time is also found to be a function of number of nodes separating the stimuli, nodal effects in results of transfer of function tests and sorting tests are seen, partitioning of equivalence classes, and within class preference tests showing preferences for relations of lower nodal number separating the stimuli. In addition, semantic variations, and relatedness of stimuli in FAST seems to be affected by the nodal number separating stimuli. Further, the inclusion of a familiar stimuli as C stimuli did not seem to affect the nodal distance effects. As discussed, there are a few methodological issues with several of the studies, and unanswered questions that needs to be tackled in future experiments before one can conclude from the results.

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Table 1

Articles included in the present literary review

Authors	Year	Title	Journal
Cummins & Roche	2020	Measuring differential nodal distance using the function acquisition speed test	Behavioral Processes
Arntzen & Mensah	2020	On the effectiveness of including meaningful pictures in the formation of equivalence classes	Journal of the Experimental Analysis of Behavior
Albright et. al.	2019	Relatedness of equivalence class members: Combined effects of nodality and relational type	The Psychological Record.
Arntzen et. al.	2017	The relation between sorting tests and matching-to-sample tests in the formation of equivalence classes	The Psychological Record
Dickins	2015	Transitive inference in stimulus equivalence and serial learning	European Journal of Behavior Analysis
Doran & Fields	2012	All stimuli are equal, but some are more equal than others: Measuring relational preferences within an equivalence class	Journal of the Experimental Analysis of Behavior
Wang et. al.	2012	A test of the discrimination account in equivalence class formation	Learning and Motivation
Fields et. al.	2012	Effects of a meaningful, a discriminative and a meaningless stimulus on equivalence class formation.	Journal of the experimental Analysis of Behavior
Wang et. al.	2011	Preserved nodal number effects under equal reinforcement	Learning and Behavior

Authors	Year	Title	Journal
Moss-Laurenco & Fields	2011	Nodal structure and stimulus relatedness in equivalence classes: post-class formation preference tests	Journal of the Experimental Analyses of Behavior
Bortoloti & deRose	2009	Assessment of the relatedness of equivalent stimuli through a semantic differential	The Psychological Record
Fields & Watanabe-Rose	2008	Nodal structure and the partitioning of equivalence classes	Journal of the Experimental Analysis of Behavior

Note. This table lists citation information on the articles included in the review.

Table 2

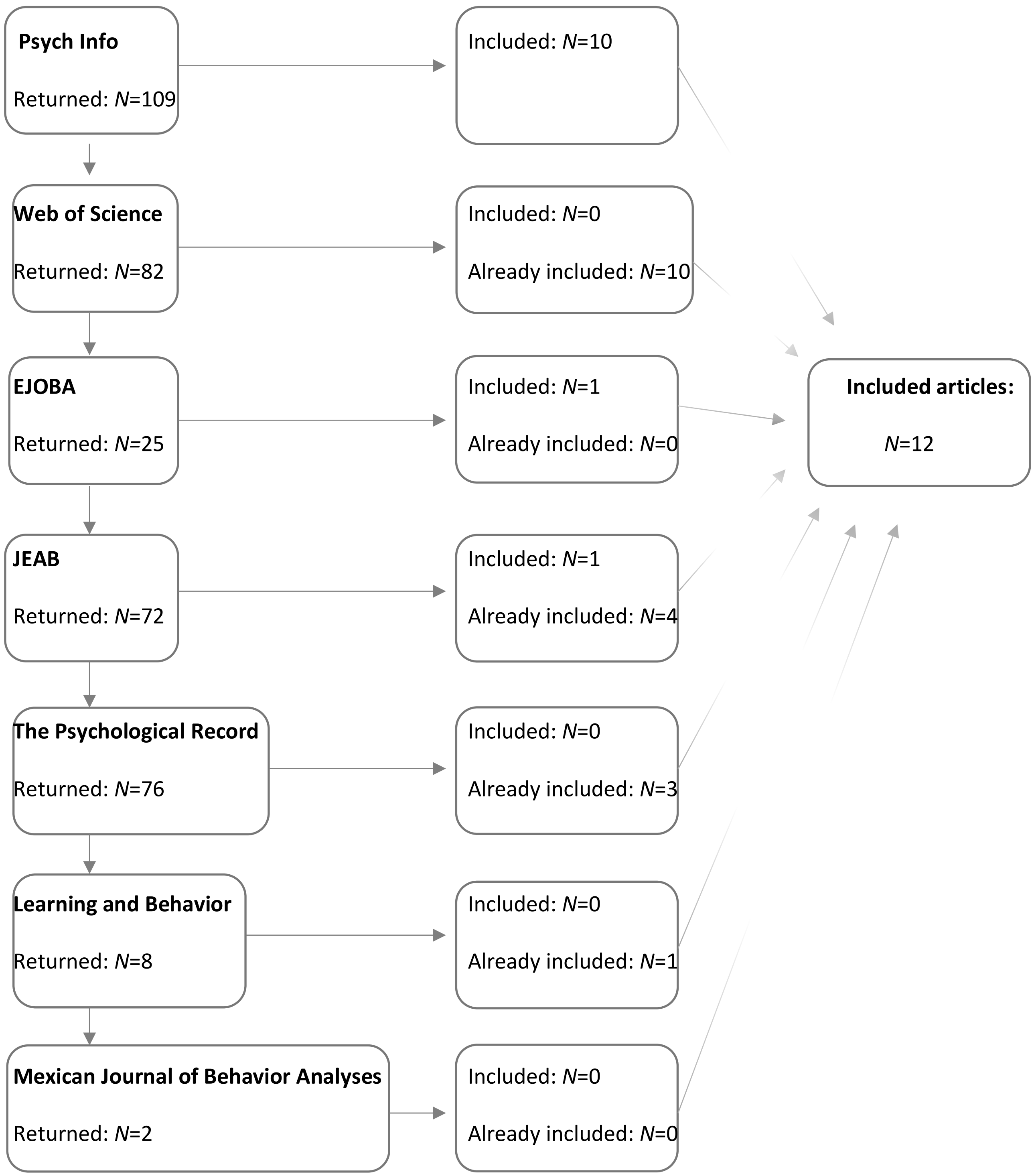
Selection of relevant information point extracted from the articles including in the present literary review

Author & year	Question variables	Participants included	Stimuli	Sample/comparison presentation	Trial setup	Programmed consequence	Pretraining	Instruction issues	Findings	Nodal effects
Cummins & Roche 2020	Equivalence & FAST	16 adults	nonsense syllables 4x4m. 1n.	1s delay	Linear series MTS	Auditory beep and informative text	No	No	Ambiguous	Ambiguous, but some effect
Arntzen & Mensah 2020	Meaningful stimuli	165 adults	abstract and familiar shapes 3x5m. 3n.	Simultaneous	Linear series MTS	Informative text	No	No	Pictures have effects in yields	In delayed emergence
Albright et.al. 2019	Nodal number and relational type	8 adults included	nonsense syllables 2x9m. 7n	Simultaneous	Linear series MTS	Informative text	Yes	Yes: Goes with	Nodal effects and TR. Preferred over EQ.	In within class preference
Arntzen et.al. 2017	Sorting and MTS	18 adults included	Abstract shapes 3x5m. 3n	Simultaneous	Linear series MTS, concurrent	Informative text	No	No	Sorting can track SEQ performance	Sorting for some
Dickins 2015	SE versus SL training	20 adults	passport photos 2x7m. 5n.	1s delay	Linear MTS, and SL training	Information on number of right and wrong after each block	No	Yes – scenario description	Inconclusive	Reaction time in some
Doran & Fields 2012	Post class preference	1 and 5	Computer nonsense syllables, 1 familiar 2x7m. 5n.	Simultaneous	Linear series MTS, concurrent	Informative text	No	No	TR. preferred over EQ and nodal	In preference tests

Author & year	Question variables	Participants	Training apparatus and stimuli	Sample/comparison presentation	Trial setup	Programmed consequence	Pretraining	Instruction issues	Findings	Nodal effects
Wang et.al. 2012	Nodal account	21 adults	pseudo words 2x5m. 3n.	n/a	Linear serialized MTS	Informative text	No	No	Nodal effects despite equal reinforcer presented	Nodal distance explains effect
Fields et.al. 2012	Familiar Stimuli/ abstract/ function	30 adults	abstract shapes familiar C 3x3n. 5m.	Simultaneous	Linear serialized MTS	Informative text	No	No	Meaningful stimuli enhance EQ class formation	Delayed emergence
Wang et.al. 2011	Equal and unequal reinforce	21, 8 and 15 adults	pseudo words 2x5m. 3n.	1s delay	Linear series MTS, concurrent	Informative text	No	No	Nodal number predicted RT in both conditions	Under equal reinforcement
Moss-Laurenco & Fields 2011	Structure and relatedness	8, 7 and 4 adults	nonsense syllables 2x4m. 2n. and 2x5 m. 3 n.	Simultaneous	Simple to complex	Informative text	Yes	No	Nodal effects in preferences in exp. 2 and 3	Within class preference
Bortoloti & DeRose 2009	Semantic relatedness	39 and 44 adults	faces and abstract shapes 3x4 m. 2n. and 3x7m 5n	2s delay	Mixed in exp1 linear in exp 2, Serialized	Auditory tone if correct of black screen 3s	No	No	Exp. 1 transfer to abstract Exp. 2 nodal	Semantic differentiation
Fields & Wattanabe-Rose 2008	Nodal effects in SEQ	15 adults	nonsense syllables 2x6m. 4n.	Simultaneous	Linear series, MTS, concurrent	Informative text	Yes	No	Nodal structure produces differential relations	In steady state performance

Note. This table lists some key information points from the articles included in the review. Some abbreviations have been applied: MTS is matching-to-sample, SEQ is stimulus equivalence, the numbers in the stimuli sections indicate number of classes, number of stimuli and number of nodes.

Figure 1



Note. This figure demonstrates in a flow-chart the number of search results and articles included.

Fragmented Versus Ordered Presentation of Training Trials - Effects on the Formation of Stimulus Equivalence Classes

Abstract

The present paper reports on an experiment with data from 14 participants. They were randomly assigned to four different groups and subjected to different training conditions in a matching-to-sample training procedure. Two different structures of training, both including the same relations and stimuli, were applied. One group trained A to B, B to C, C to D, D to E, and E to F. The other group trained from A to B, E to F, D to E, C to D, and B to C. Each of the two groups were split in half where one group received interspersed mix blocks between the introduction of new relations, while the other half received no mix blocks between the introduction of new stimuli. All the introduced stimuli were presented together in one mix block before training for all groups. The objective was to see how the introduction order and the approximated equalization of possible reinforcement presentations for the relations introduced would affect the formation of equivalence classes, correct responding in relation to nodal number, reaction time in relation to nodal number and within-class preferences in relation to nodal number. In accordance with previous research, the correct responding is higher for the ordered introduction and the yields are generally higher for relations separated by lower number of nodes. In reaction time and within class preference tests, the results in relation to nodal number separating the stimuli were ambiguous.

Key words: conditional discrimination, matching-to-sample, stimulus equivalence, training structure, nodal number, nodal number effects

Through a series of experiments on learning, Sidman and colleagues discovered and classified what we have now come to know as stimulus equivalence (Sidman, 1994). The stimulus equivalence paradigm has not only been of theoretical importance but also practical. As Sidman (1994, pp. 2-15) suggests, equivalence relations could play an important role in several complex behaviors like understanding language, symbolic representation, and creativity in terms of novel, untaught behavior. The reinforcement in this account, does not only produce a relation between the two stimuli that is reinforced, but also relations between stimuli that are not directly trained. In Sidmans account of stimulus equivalence class formation, the idea is that stimulus equivalence emerges directly from the reinforcement contingencies (Sidman, 2000). Sidman suggests that equivalence is a fundamental stimulus function, and that it is not something that is mediated by other behavioral processes. The stimuli become equivalent, in this view, because of the way that we have evolved. The equivalence classes come under contextual control, and therefore it is determined by the stimuli in the environment when the stimuli in a class are equivalent and non-equivalent (Sidman, 1994, pp.389).

In experimental settings, researchers have utilized what is often referred to as a matching-to-sample procedure to train relations within a predefined class of stimuli (Sidman, 2009). The participants in the experiments are subjected to a series of trials, where a sample stimulus is presented, followed by a number of comparison stimuli. The participant then chooses a comparison stimulus among the available set. Programmed consequences are delivered in accordance with how the response is defined as right or wrong in relation to the predefined classes. The correct or incorrect answer is determined by the sample stimulus (Sidman, 2009).

After training is conducted, in accordance with the procedure defined by the experimental setup, the participant is tested. In the test the objective is to look for correct responding in the trained relations to see if conditional discrimination is established. For us to be able to say anything about whether stimulus equivalence is established, more extensive tests than discrimination of the trained relations are needed. Calling the established relations, a matching to sample relation, require that we first test for the possible untrained relations in a class of stimuli (Sidman & Tailby, 1982).

In the testing phase, participants are tested for baseline relations, or the relations established through direct training. In addition, the participants are tested for all other possible relations between the stimuli in the predefined class. Sidman lends his terms in describing these relations from mathematical set theory, and the relational types are characterized by reflexivity, symmetry, and transitivity Reflexivity relations are relations where the sample is to be matched to an identical stimulus. For example, if we train `if A then B`, in the test, A is matched to A in the reflexivity test. Symmetry relations are relations where the opposite direction of what is directly trained is tested for. If one trains `if A then B`, for example, one tests for `if B then A` in the symmetry test. Transitivity relations are relations where the stimuli are only linked by connections to other stimuli during the training phase. If one for instance trains `if A then B` and `if B then C` one tests for `if A then C` in a transitivity test. Global equivalence is a relation that combines both symmetry and transitivity. If one trains `if A then B` and `if B then C` one tests for `if C then A` in a global equivalence relation test, testing both for transitivity and symmetry in one single relation. If all these relations emerge in testing, we say that the stimuli in the predefined class have become equivalent. Stimulus equivalence can never be directly observed, but only inferred by the result of testing as described (Sidman, 1992). Matching to sample is the observed performance. If we observe the emergence of the possible reflexive relations, symmetrical relations, transitive relations, and equivalence relations, after training is conducted, in the results of the test trials, with sample and comparison stimuli that are physically different to each other, the performance can be named arbitrary, nonidentity or symbolic matching (Sidman, 1992).

Nodal Distance and Nodal Number

One can, according to Fields and Verhave (1987), describe these predefined classes of stimuli in a structural manner by describing the class size, number of nodes, distribution of singles and the directionality of training. Class size is the number of stimuli included in the class. Singles are stimuli that are only connected by training to one other stimuli in the class. Nodes are stimuli connected to two or more stimuli in a class. The number of nodes separating two stimuli in a class is called associative, or nodal distance, in their terms. The distribution of singles describes how many singles are linked to one node by training. Directionality refers to how the stimuli are used as samples and comparisons during a training session.

The relations in an equivalence class are trained in a specific structure connecting all the stimuli in the predefined class to at least one other stimuli in the class. The different structures of relations in training can be characterized as linear series (LS), one to many (OTM) and many to one (MOT) (e.g., Arntzen, Grondahl & Eilifsen, 2010). Th different structures can be exemplified by showing how they differ in training a class consisting of A, B, C, D and E stimuli. In a LS setup of training the relations trained would be if \`A then B\`, \`if B then C\`, \`if C then D\`, and \`if D then E\`. In an OTM setup of training the relations trained could be \`if A then B\`, \`if A then C\`, \`if A then D\` and \`if A then E\`. In a MTO setup of training the relations trained could be if \`A then E\`, \`if B then E\`, \`if C then E\`, and \`if D then E.\` These structures produce a set of different relations between the same stimuli. The results of experiments investigating the effects of these different structures indicate that MTO and OTM enhances the formation of equivalence class formation compared to LS structure (e.g., Arntzen et al. 2010). As the example of the different training structures show, not only do the training structure produce a different set of relations, but they also produce a different number of nodes and singles. In an MTO and OTM structure, we get 1 node and 4 singles. In an LS structure we get 2 singles and 3 nodes.

Fields, Newman and Verhave (1990) further expands on their classification by stating that not only can these terms be used to classify the organization of stimuli within a class, but they can also account for individual preferences that in everyday terms can be connected to understanding and connotative meaning. Experimental data has indicated the presence of an apparent nodal number effect in several studies. Examples are in the percentage of correct responding for derived relations has an inverse relation to the number of nodes separating the two stimuli in a relation, and that the reaction time for a relation increases as a function of the number of nodes separating the stimuli (e.g. Albright, Fields, Reeve, Reeve, Kisamore, 2019; Fields, Adams, & Verhave, 1993; Fields, Landon-Jimenez, Buffington & Adams, 1995; Kennedy, 1991; Kennedy, Itkonen &Lindquist; Spencer & Chase, 1996). Within-class preference tests have also been used to produce data that have indicated that there is a preference for the relations separated by the lower number of nodes (e.g., Dorian & Fields, 2012; Moss-Lourenco & Fields 2011). A semantic differentiation test has also been used in proving that the stimuli within a class are differentially related (e.g., Bortoloti & de Rose, 2015). Effects have also been found that indicate nodal number effects in the stability of the transfer of function between members of a stimulus class (e.g., Rehfeldt & Dymond, 2005). Another area of research where indications in the data that are supportive of nodal effects are found is the partitioning of equivalence classes (e.g., Fields & Watanabe-Rose, 2008).

A suggestion of substituting the term \`nodal distance\`, as proposed by Fields and Verhave (1987) with the term nodal number has been put forward by Sidman (1994, pp.539) as an optional term. He suggested the term on the basis that \`nodal distance\` as a term runs the risk of inserting hypothetical constructs in the terms, and that number of nodes, referring to the least number of nodes involved in a conditional discrimination needed for a stimulus pair to be included in an equivalence relation, is more suitable as it is directly observable. If the terminology would be changed, we would let it tell us something about the number of nodes needed between two stimuli involved in a class rather than possible hypothetical constructs. This paper will be using the term nodal number going forward, as to avoid confusion of terms and possible hypothetical constructs.

Sidman (1994, pp.542) states that possible confounding variables should be ruled out before we can call the results evidence of an effect of nodal number separating the stimuli. He suggests that the results seen may be due to several confounding variables, like reinforcement opportunities and other procedural variables (see Sidman, 1994, 540-542). The idea that nodal number could affect whether a particular stimulus pair can be included in an equivalence relation poses no problems for Sidmans account of stimulus equivalence and could be viable. The problem is the possibility of the proposed permanent differences between pairs based on the number of nodes separating them, as the term equivalence implies mutual substitutability of stimuli in a class. Differences are to be expected between stimuli, as stimuli in an equivalence class are determined by the features that are discriminative for the stimuli in a class while also being environmentally determined and can belong to several comparison classes, dependent on the context (Sidman, pp. 539-544).

An example of a paper contesting the results showing nodal effects is Imam`s (2006) paper on control of the nodal effect by equal presentation of training trials. The results indicate that controlling the number of possible reinforcement presentations for the different relations controls for nodal effects in the results of the test, and thus reinforcement opportunities could be a possible confounding variable in previous papers. Wang, Dack, McHugh & Wheland (2011) later performed an experiment where results indicated that the inequality of reinforcement opportunities did not affect the nodal effects, which were still present under equal reinforcement. The observed differences in results imply that there is a need for further experimental investigations to clarify and expand on knowledge regarding nodal number effects.

Objectives of The Present Experiment

Considering previous findings where nodal effects have often been found under linear serialized training structure presented under simple-to-complex procedures (e.g., Fields et.al., 1993), the aim of this study is to compare a serialized with a fragmented presentation of stimulus relations in training to look at the potential effects of trial order of presentation on nodal effects. The relations that are trained are the same for all participants involved in the study, and they are all linked in a linear manner by training. Linking the stimuli in this manner produces the largest possible number of nodes separating a stimulus in a class and is well suited to investigate the nuance in possible nodal effects. Half of the participants were subjected to a serialized presentation of relations in the training phase, and half were subjected to an introduction of relations that is fragmented, meaning that one relation never structurally follows the next relation that is presented. No experiment was found by the present author, published to date, reporting on the exact order of stimulus pair presentation as presented in the method section of this paper.

Different protocols of training can affect the results of equivalence class formation. The different protocols of procedural configurations can be classified as simple to complex, (STC) complex to simple (CTS) and simultaneous (SIM). In STC one starts off by training the different relations individually and then together, with interspersed tests for equivalence relations separately and then together, followed by a final equivalence test. In CTS one starts off training each baseline relation followed by a combined test for equivalence before the other derived relations are trained and subsequently tested together. In SIM one trains all baseline relations at the same time before testing for all emergent relations. The STC has been shown to produce better outcomes in test results for emergent relations (see e.g., Imam & Warner, 2013).

In regular serialized or simple-to-complex training protocols, the earlier a stimulus is introduced in the training, the more this stimulus is involved in the training and the more chances for reinforcement of the behavior in training are available. The number of training trials varies a great deal for the different stimulus relations in these structures. By removing the interspersed mix phases between the introduction of training new relations for half of the participants in each group in the present experiment, and only do a mixed training phase at the end of introducing all novel relations, the number of trails involving each of the stimuli is more equal. As previous findings (e.g., Imam, 2006; Wang et al., 2011) have shown that there might be an effect in the number of reinforcement opportunities for each relation presented, observed differences in results could be of interest. This approximation to equalization in presentation of training trials is applied for half of the participants in the study from each of the training structures.

The object of the present experiment was to see whether these alternations in the training procedures concerning order of presentation and opportunity of reinforcement for the different relations would affect equivalence class formation and how it potentially would be affected. By analyzing data in terms of correct responding, reaction time and within class preferences, and relating the results to nodal number separating the stimuli in the class established in training, the aim was to provide some additions to previous results in terms of nodal number effects in equivalence class formation.

Method

In this section a comprehensive, replicable overview of the method applied in the present experiment is presented. The section starts of by describing participants, next ethical considerations and risk analysis of the experiment is presented, moving on the setting is described, the apparatus, stimuli included, a display of instructions, general procedural implications, a detailed overview of different training procedures and finally ending on a detailed description of the tests applied.

Participants

Participants in this study consisted of 20 adults, who were recruited through acquaintances and through a visit to a class of undergraduate students. Out of the 20 participants, the data of 14 participants is included in the study, as the remaining six participants did not complete the training phase and could not be subjected to the tests. The reason for not completing, was that three of the participants were experiencing fatigue, and three of the participants had to end their participation before training was complete due to time constraints. The included participants are 7 male and 7 female adults with an average age of approximately 32 years.

Ethical Considerations and Risk Assessment

All participants in the experiment were willing participants. They did not receive any form of compensation for their participation. Participants were able to withdraw from the experiment at any point during the experiment. Data was anonymized the moment the participant had completed the experiment and left the setting. Every participant received written information about the experiment, ethics, and their rights, before the experiment was initiated. All participants signed a written consent form. Signed consent forms were kept in a safe until the experiment ended. Consent forms were safely destroyed by shredding upon completion of the data collection for the project. Treatment of participants and data in the current experiment are in line with the general guidelines for research ethics (The Norwegian National Research Ethics Committees, 2019).

After the experiment was concluded for each participant, the participant was offered to look at the data together with the experimenter, and were encouraged to ask questions they might have with regards to the experiment they had just participated in. Participants were instructed not to talk to other participants about the specifics of the experiment for the duration of the project, as this could weaken internal validity of the experiment, in terms of prior familiarization as a possible confounding variable in the results of the participants.

An application was sent to the Norwegian Center for Research Data (NSD), before the experiment was initiated, describing the experiment, the data that was to be collected, a description of the handling of data, and a copy of the written consent form that was to be presented to the participants prior to participation (see Appendices A and B). The application was approved (reference number 157140).

A risk and vulnerability assessment has been conducted prior to the collection of data, to ensure that the handling of the data would be as safe as possible (see Appendix C). In the analysis the results indicated that the already planned measures for limiting risk and mediating possible damage were sufficient, and these measures were carried out as described.

Setting

Due to availability of participants, the study had to be conducted in 5 different rooms, which were made to be as free of any disturbing stimuli as possible. All rooms were between 3 square meters to 20 square meters big, well lit, with light colored monochrome walls, with a desk facing the wall. Participants were offered to bring something to drink into the room and were asked to leave other possessions outside the room. The desk was fitted with a tablet placed approximately 20 cm from the edge of the desk. Participants were instructed to put their phones on silent mode and leave them outside the room or in their pockets for the duration of the experiment. By organizing the settings in such a way, the aim was to eliminate all possible disturbing stimuli.

Apparatus

Experimental sessions were conducted using a Microsoft Surface tablet model 1724. The software used was a custom matching-to-sample software. Participants responses were recorded through them clicking on the touch screen with a finger or a pointer, or by using the touchpad on the keyboard of the device.

Stimuli

The stimulus set consisted of three classes of stimuli, each consisting of 6 members. All together that makes 18 different stimuli. Stimuli presented were different pictures of abstract and familiar shapes (see Figure 1). They were named A1, B1, C1, D1, E1, and F1 for the first class, A2, B2, C2, D2, E2, and F2 for the second class and A3, B3, C3, D3, E3, and F3 for the third and last class. Pictures included were abstract black and white graphic depictions for the A, B, D, E, and F stimuli.

C stimuli in each class was a stylistic familiar picture. The C1 stimulus depicted a church with a yellow background, the C2 stimulus depicted a crown with a blue background and the C3 stimulus depicted a mailbox with a green background color. Main finding of previous experiments including familiar stimuli as C stimuli is that inclusion enhances equivalence class formation (e.g., Arntzen & Mensah, 2020). The reason for including familiar C stimuli in the present experiment is to enhance equivalence class formation for the participants. The reason for placing the stimuli in the C position is that previous research has found this position to be most effective compared to other placements in enhancing equivalence class formation (e.g., Nartey et.al. 2015b)

When the stimuli in the experiment appeared on the screen, the size of the picture was approximately 3x3cm, with the sample stimulus displayed in the middle of the screen and the comparison stimuli placed in the corners of the screen, separated by approximately 7cm.

Instructions

The following instructions were displayed on the screen before the procedure was initiated:

> *A stimulus will appear in the middle of the screen. Click on this. Three other stimuli will then appear. Choose one of these by clicking on it. 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. 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!*

Procedure

The procedure was a match-to-sample procedure where a sample stimulus was presented followed by three comparison stimuli upon the participant clicking the sample stimuli. Software was set to randomize the presentation of the relations and the placements of the comparison stimuli on the screen throughout the experiment. The procedure was simultaneous, meaning that the sample stimuli stayed visible when the comparison stimuli were presented. Training blocks and equivalence test were presented in one session automated by the software. The experimenter had to manually engage the two within-class preference tests. The design of the experiment is best described as a mix between single subject and group research design where the data of each participant was analyzed with respect to comparisons of variation in performance of the subject itself, and the other participants of the group are in this respect replications of the experimental conditions. Participants data are in addition summarized in groups with respect to the different variations of their training.

Training

When the participant was ready to start, they pressed a start key on the screen, placed directly under the instructional text. The sample stimuli appeared in the middle of the screen. Upon clicking the sample, three comparison stimuli consisting of one member from each predefined class of stimuli appeared. When the sample stimulus was A1, the comparison stimuli were B1, B2 and B3, where B1 was defined as the correct choice. When the participant pressed a comparison stimulus, immediate programmed consequences were presented, as defined in the instructional text. The informative text was displayed for 500ms followed by an additional 500ms blank screen, making the total intertrial interval 1000ms.

The first phase of the experiment was the training. In the training phase participants were assigned to four different groups that were presented different structures of training. Relations trained stayed the same for all participants. A to B, B to C, C to D, D to E, and E to F (see Table 1). Number of trials was dependent upon when the participant reached the mastery criterion of 95% in one block and moved on to the next. If the participant did not meet the mastery criterion, the block was presented again. Each sample stimulus was presented 5 times within one block of training introducing new relations. That makes 15 trials per block. For the last mix blocks where all stimuli were included that makes 75 trials.

The first group was presented with a linear structure: first \`if A then B\`, then \`if B then C\`, \`if C then D\`, \`if D then E\`, and last \`if E then F\`. This condition is named the ordered condition (see Table 1). When the participants reach the mastery criterion of 95% in the A-B block the next training block presents B-C relations. When the participants reach the mastery criterion in the B-C block a mixed training block consisting of A-B and B-C relations follows. The next block is C-D, then a mix of all the relations trained up until this point, then D-E followed by a mix of relations and at last E-F relations, followed by a mixed block of all the trained relations. This is a standard linear serialized structure of training in a matching-to-sample experiment.

For the second group the training structure stayed the same, but the interspersed mix-blocks in between each block of a new trained relation was removed. This condition is named the ordered condition without interspersed mix-blocks (see Table 1). One relation followed the next in this setup, until all the relations were trained to mastery criterion. All relations were then presented in a mixed block. The reasoning behind removing the interspersed mix phases was that the number of training trials were closer to equalized presentation for all the relations so that a possible observation of a nodal distance effect in the data cannot have come to be as an effect of the number of training trial for each stimulus.

For the third group of participants presentation of relations was fragmented so that no trained relation linearly followed the next relation in the setup of training trials. The stimuli were trained in the following order: First \`if A then B\`, followed by \`if E then F\`, \`if D then E\`, \`if C then D\`, and last \`if B then C\`. This condition is named the fragmented condition (see Table 1). This third group was presented with interspersed mix phases in between reaching the mastery criterion of a new trained relation, as presented in the ordered condition with the interspersed mix blocks. The fourth and last group was also presented with the fragmented training structure, but the interspersed mix blocks were removed for this group of participants. This condition is named fragmented condition without interspersed mix-blocks (see Table 1).

The last part of the training for all the different conditions was a mixed block including all the relations that had been directly trained. After reaching the mastery criterion of 95% in the mixed block of all the trained stimulus relations there was a thinning of consequences. For the first mix phase of the complete stimulus set programmed consequences were presented for 100% of the trials, the mix block is then presented again with 75%, then 50% and then finally 0% programmed consequences. When mastery criterion of 95% was reached for the last mix block, test phase was automatically initiated by the software.

Testing

The first part of the test was an equivalence test. Participants were tested for the emergence of all possible untrained relations between stimuli, within all three predefined classes of stimuli in the set. Test included symmetry relations, transitivity relations and global equivalence relations. Baseline relations were also included in the test phase to see if they were maintained throughout the test. Reflexivity relations were not included, as it is assumed that this relation is always present for normally functioning adults. Criterion for equivalence class formation was set to an overall mastery of 95% for the test block. Each possible relation in the test was presented three times. That makes 45 baseline relations, 45 symmetry relations, 90 transitive relations and 90 global equivalence relations. A total of 270 relations were presented in the test phase.

The second test was a relational strength, or within-class preference test where the A stimuli were presented as the sample with all the stimuli that were not directly trained but were defined as part of the same class was included as comparison stimuli, meaning all within-class stimuli except the B stimuli were included as samples for each trial. The third test was a relational strength test where the F stimuli were presented as the sample. All stimuli, other than the E stimuli, predefined as belonging to the same class were included as comparison stimuli for each trial. Each A and F stimuli were presented three times each making the total number of trials for these tests 18. The objective of the within-class preference tests was to see if there were any recurring preferences within the class of stimuli and if there were any observable nodal number effects in the potential preferences exhibited in the choice of comparison stimuli.

Results

In the result section, the test results for the 14 participants who completed training and testing will be presented. The section starts by presenting an overview of the data for the participants in the different groups to provide the reader an overlook, before a detailed account of the different participants data in the different groups are presented, finally the overall results are summarized under summary of results.

Group Overview

Ordered condition training resulted in three participants completing training and testing (P17703, P17714, P17711). Two of the participants formed equivalence classes (P17703, P17714). The third did not (P17711). Data of the participant that did not form equivalence classes showed indications of nodal number effects in the results of the emergence test. Reaction time results indicated that there were some nodal number inferences for one participant (P17703) in the reaction time data, but the results are ambiguous. In the within class preference tests, all participants in this training condition chose the familiar stimuli on all possible trials.

Ordered condition training without interspersed mix blocks resulted in 3 participants completing training and testing (P17713, P17709, P17701). None of the participants formed equivalence classes. Some degree of nodal number effect in correct responding was indicated in the results of the emergence test for all three participants. Reaction time results indicated that some nodal effects were present in the data for one participant (P17713), but the results are ambiguous. In the within class preference tests one of the participants showed clear indications of nodal number effects (P17709), not the others.

Fragmented condition training resulted in 4 participants completing training and testing (P17712, P17708, P17704, P17717). None of the participants formed equivalence classes. Two of the participants showed results in line with nodal number effects in correct responding (P17712, P11717), some ambiguous results are found in one participants data (P17704), the last did not clearly show such results (P17708). Reaction time data indicated that two of the participants show nodal number effects in reaction time (P17712, P17704), while the data of the others did not vary in a linear relation (P11708, P17717). In the within class preference all participants result show some indications of nodal number effects.

Fragmented condition training without interspersed mix blocks resulted in 4 participants completing training and testing (P17710, P17715, P17719, P17706). One of the participants formed equivalence classes (P17710), the others did not. Two of the participants who did not form equivalence classes showed indications of nodal number effects in correct responding (17715, 17719), the third did not. Reaction time results indicate that there are no nodal number effects in the reaction time for the participants in this group. In the within class preference three participants results are to some extent indicative of nodal number effects (P17710, P17719, P17706).

Ordered Condition

A total of three participants completed both the training and testing for this training condition. P17703 responded in accordance with equivalence class formation in the equivalence test (see Table 2, and Figure 2). No nodal effect could be observed in correct responding as accuracy was high for all types of relations for this participant (see Table 3, and Figure 3) Results in reaction time indicate a possible nodal effect, visible in an increasing curve of reaction time with increasing number of nodes (see Table 4, and Figure 4). The participant consistently chose the familiar stimuli in the within class preference test and choices did not seem to depend on nodal relations between stimuli in the set, but rather on familiarity of stimuli (see Table 5, and Figure 5).

P17714 responded in accordance with equivalence class formation in the equivalence test (see Table 2, and Figure 2). No nodal effect could be seen in correct responding as the accuracy in responses was high for all types of relations for this participant. There is a decrease in precision for the 3 and 4 node relations, but no clear increase as a function of nodes (see Table 3, and Figure 3). In the reaction time results there were no clear indications of nodal effects, with a clear increase from directly trained to higher number of nodes, but not a clear increasing curve as a function of increasing number of nodes (see Table 4, and Figure 4). The participant only chose familiar stimuli in the within class preference test and the choices of stimuli seemed to be affected more by familiarity than number of nodes (see Table 5, and Figure 5).

P17711 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, Figure 2). Possible nodal number effect seems to be visible in the correct responding of this participant. Data shows a decrease in correct responding as the number of nodes increase (see Table 3, and Figure 3). In the reaction time results there is a steady increase from the training to the 0 node relations to the 1 node relations, followed by a slight decrease in reaction time for the 2 and 3 node relations ending with a further decrease in reaction time for the 4 node relations. These results are not in accordance with a rise in reaction time with a higher number of nodes separating stimuli, but show some indications (see Table 4, and Figure 4). The participant only chose the familiar C stimuli in the within-class preference test. Familiarity of the stimuli seems to be the controlling factor for the choice of stimuli rather than number of nodes (Table 5, Figure 5).

Ordered Condition Without Interspersed Mix Blocks

A total of three participants completed training and testing for this condition. P17713 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, and Figure 6). Participants data seem to show possible nodal number effects in the amount of correct responding in the results with a steady decrease from 0- to 1-, 2- 3- and 4-node relations (see Table 3, and Figure 7). The participant did show signs of possible nodal number effects in the reaction time results, though not in a linear increase as a function of number of nodes separating stimuli. The data did increase for the relations that were separated by nodes compared to the ones that were directly trained and symmetrical (see Table 4, and Figure 8). The participant did not exhibit any responding in accordance with nodal effects in the within-class preference test. Selection of stimuli was quite evenly distributed between the different nodal relations (see Table 5, and Figure 9).

P17709 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, Figure 6). The participants data indicated possible nodal number effect in correct responding, with a steady decrease from 0- to 1- a slight increase in 2- node relations, and a further decrease for 3- and 4-node relations. Nodal effect is not strictly linear, but the precision generally decreases when the number of nodes increases (see Table 3, and Figure 7). There are some indications of possible nodal effects, but not linear to the number of nodes, in reaction time results. Reaction times increase when there is separation by nodes, but not in a linear manner (see Table 4, and Figure 8). There are some nodal number effects in the results of the within-class preference test where the participant showed a preference for the lower number of nodes separating the stimuli, but not in a linear manner (see Table 5, and Figure 9).

P17701 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, and Figure 6). Data indicate a possible nodal number effect in correct responding with a steady decrease in precision from 0- to 1-, 2- and 3-node relations, followed by a slight increase for 4-node relations (see Table 3, and Figure 7). Data for reaction time is not indicative of nodal number effects linear to the number of nodes separating the stimuli in the relations. There is an increase from the directly trained and symmetry relations to the ones separated by nodes, but the relation is not linear as there is a decrease from 1- to 2-node separation and from 3- to 4-node separation in reaction time (see Table 4, and Figure 8). No nodal number effects are apparent in the data of the within class preference test as the 3- and 4-node relations seems to be the ones that are preferred in responding (see Table 5, and Figure 9).

Fragmented Condition

A total of four participants completed training and tests for this condition. P17712 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, and Figure 10). Data are indicative of possible nodal number effect in correct responding as the accuracy decreases when the number of nodes increases in a linear manner (see Table 3, and Figure 11). Nodal effects are also apparent in reaction time with a linear increase in reaction time with an increase in the number of nodes separating the stimuli in the relation (see Table 4, and Figure12). There are also apparent nodal number effects in within class preference test results as the participant consistently chose 1-node relations on all possible trials (see Table 5, and Figure 13).

P17708 did not meet the criteria for equivalence class formation in the emergence test (see Table 2, and figure 10). There are not clear indications in the data of nodal number effects in correct responding, the results are quite ambiguous with an observed decrease in correct responding from 0- to 1-node followed by an increase for the 2-, 3- and 4- node relations that are all approximately the same rate of correct responding (see Table 3, and Figure 11). No linearly increasing nodal effect in reaction time is observed. There is an increase from relations in training, to directly related to the ones separated by nodes (see Table 4, and Figure 12). Some possible nodal number effects are apparent in the within-class preference test with a clear preference for 1- and 2-node relations over 3- and 4-node (see Table 5, and Figure 13).

P17704 did not meet the criteria for equivalence class formation in the equivalence test with (see Table 2, and figure 10). Possible nodal number effect is visible in correct responding, though not linear in decrease relative to increase in nodes (see Table 3, Figure 11). Possible nodal effect is visible in reaction time with increases linear to the increase of nodal separation of the stimuli in the relations tested (see Table 4, and Figure12). Nodal number effects are apparent in the data of the within-class preference test, with indications for a clear preference for the 1-and 2-node relations over the 2- and 4-node relations (see Table 5, and Figure 13).

P17717 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, and figure 10). Apparent nodal number effects are visible in correct responding with an observed decrease in precision linear to the number of nodes separating the stimuli (see Table 3, and Figure 11). When looking at the reaction time results there is an increase in reaction time to the comparison times from training, to directly related 0-node relations to relations separated by nodes. This is only a linear relation until we hit the 3- and 4-node relations, where there is a slight decrease in reaction time (see Table 4, and Figure12). Possible nodal number effects are a tendency in the data of the within-class preference test a clear preference for the 1-node relations (Table 5, Figure 13).

Fragmented Condition Without Interspersed Mix Blocks

A total of four participants completed training and testing for this condition. P17710 did reach the criteria for equivalence class formation in the equivalence test (see Table 2, and Figure 14). No nodal number effect can be seen in precision as the precision is high for all the relational types. A slight decrease in precision as the number of nodes increase can be seen, especially for the 4-node relations (see Table 3, and Figure 15). Nodal effect is not clear in the reaction time data for this participant, however there is an increase from the reaction time in training to the 0-node and a further increase for the 1-node relations. From there the numbers are ambiguous (see Table 4, and Figure 16). Possible nodal number effects can be seen in the data of the within-class preference test where the results show a preference for the1-node relations, slightly lower for the 2-node and 3-node relations and no preference for the 4-node relations (see Table 5, and Figure 17).

P17715 did not reach the criteria for equivalence class formation in the equivalence test (see Table 2, and Figure 14). Nodal number effects are apparent in the data on correct responding with a steady decrease in precision as the number of nodes in the relations increase. Data indicates a linear inverse relation between correct responding and number of nodes separating the stimuli (see Table 3, and Figure 9). For the reaction time there is an increase from training to the directly linked 0-node relations, and from 0-node to 1-node relations, with a decrease in reaction time seen for the 3- and 4-node relations. No clear linear indications of nodal number effects are seen in the reaction time data (see Table 4, Figure 16). In the within-class preference test there seems to be a preference for the relations separated by lower number of nodes, a nodal effect seems to be visible in the data (Table 5, Figure 17).

Participant number 17719 did not meet the criteria for equivalence class formation in the equivalence test (Table 2, Figure 14). There are some possible nodal number effects in the correct responding sorted by nodes with a steady decrease in precision from the 0- to the 1-, 2- and 3-node relations, followed by an increase for the 4-node relations (see Table 3, figure 15). In the reaction time results there are some apparent nodal effects starting with an increase from the 0- to the 1- and 2-node relations. When we get to the 3- and 4-node relations we do however see a slight decrease in reaction time, so the results are not in accordance with nodal number effects (Table 4, Figure 16). In the within-class preference test there are no apparent nodal number effects as the choices seem to be somewhat scattered among the relations separated by different number of nodes with a decrease from 1- to 2-node relations, followed by an increase in choice of 3-node relations and a decrease in 4-node relations (see Table 5, and Figure 17).

P17706 did not meet the criteria for equivalence class formation in the equivalence test (see Table 2, Figure 14). No apparent nodal number effect is observable in correct responding with a higher precision in the 0-node relations followed by a low and steady precision for the 1-, 2- 3- and 4-node relations (see Table 3, and Figure 15). No clear nodal number effects are observed in reaction time for this participant. There seems to be a slight increase from training to no nodes separating the stimuli to separation by nodes, but there is no linear relationship with an increase in number of nodes separating the stimuli (Table 4, Figure 16). There are some nodal effects in the data from the within-class preference test for this participant. With a rather even distribution of responding across the 1-, 2- and 3-node relations and only one choice for the 4-node relations (see Table 5, Figure 17).

Summary of Results

Three participants in this study reached the equivalence criteria of 95% correct responding. Two of these were subjected to the ordered condition with the mix-blocks (P17704, P17714), one was subjected to fragmented condition without mix-blocks (P17710) (see Table 2).

Across the 11 participants that did not reach the equivalence criteria, 5 participants exhibited clear signs of possible nodal number effects in the data on correct responding. Participants were subjected to all four different conditions of training, with two participants in the fragmented condition with no interspersed mix phases (P7711, P17713, P17712, P17717, P17715). Four participants showed apparent nodal number effects, but with deviating numbers for one node relation. These numbers are a bit more ambiguous, but still indicative of possible nodal effects (P17709, P17701, P17704, P17719). That especially goes for participants that deviate in the higher number of nodes as the data points for the 3- and 4-node relations are fewer than the other relations and could be more vulnerable to outliers in the material (P17701, P17719). Two participants who did not meet the criterion for equivalence class formation (P17708, P17706) did not show any clear signs of nodal number effects in correct responding. All participants in all conditions showed results indicative of decrease in precision from the stimuli directly linked in training, but not directly trained (0-node/symmetry relations) and the relations separated by nodal stimuli in the training (see Table 3).

In reaction time results only two participants have clear indications of possible nodal number effects in their data, both having been subjected to the fragmented condition (P17712, and P17717). The rest of the averaged reaction times are ambiguous (P17703, P17713), or not showing any clear linear relations of increased reaction time with increased number of nodes (P17714, P17711, P17709, P17701, P17708, P17717, P17710, P17715, P17719, P17706). The only common results for all participants in terms of reaction time is an increase from training to testing and a further increase from stimulus relations directly related in training (0-node relations) to stimuli separated by nodes in the training structure (see Table 4).

In the within-class preference test, the results for 11 participants are indicative of nodal number effects (P17703, P17714, P17711, P17709, P17712, P17708, P17704, P17717, P17710, P17715, P17706). As the results of the nodal number effects are overlapping with the possible controlling element of the familiar stimuli in the class, the results are not very reliable to say anything about nodal effects in that 8 of the participants chose the familiar stimuli in at least half of the trials (P17703, P17714, P17711, P17712, P17708, P17717, P17710, P17706). This especially goes for the participants that have been subjected to the ordered condition with the interspersed mix blocks, who chose the familiar stimuli on every trial. No other participants having been subjected to other conditions share these results. Further, P17712 is the only participant that seemingly exclusively favors the lower nodal number in every possible trial (see Table 5). Participant number 17712 is also the only participant whose has data is clearly indicative of nodal number effects in every part of the analysis.

Discussion

The object of this study was to see whether the fragmentation of trial presentation order and the removal of interspersed mix blocks, to approximate equalization of reinforcement options for the stimulus pairs, would have an effect in terms of equivalence class formation, correct responding by nodal number separating the stimuli in the relations, reaction time by nodal number separating the stimuli in the relations and within-class preferences by nodal number separating the stimuli in the relations. As the results show, there are some tendencies, but also some ambiguities. These results will be further discussed in the following section of the paper.

Effect of Nodal Number on Correct Responding

It seems that the results are somewhat in accordance with previous research results in nodal number effects, in that there are indications of an inverse relation between number of nodes separating the stimuli and the percentage of correct responding prior to the emergence of equivalence classes (e.g., Albright et al., 2019; Fields et al., 1993; Fields et. al. 1995; Kennedy, 1991; Kennedy et al.,1994; Spencer & Chase, 1996). Effects are clear for 5 of 11 participants that completed the training and testing, who did not form equivalence classes. An inverse relation of correct responding to number of nodes separating the stimuli in the relations seems to be present. There are further indications in the data of 4 other participants showing nodal effects with 2 showing these effects for all other relations than the 3/4-node (see Table 3). It is uncertain whether the participants showing deviations is due to the small amount of datapoints for the 4 node relations or to some procedural factor like the fragmented presentation in training where fewer participants data were indicative of such results. Further, two participants did not show any nodal effects at all in correct responding. The participants in question are subjected to the ordered condition without mix blocks and the fragmented condition without mix blocks.

In terms of correct responding across conditions the participant in the ordered condition and the ordered condition without mix blocks that did not form equivalence classes did show effects in terms of nodal number in the results of correct responding to some extent. In the fragmented training condition two participants data show possible nodal number effects in correct responding while one participant results gave some e indications and the last did not show any nodal effects at all. In the fragmented training condition without interspersed mix blocks two participants showed correct responding results indicative of nodal number effects in correct responding. The present findings are indicative of possible procedural variables in order of the presentation of the training relations having influenced how many of the participants, that did not form equivalence classes, who are showing results in terms of nodal number effects in correct responding. All participants with an ordered presentation of relations have results indicative of some degree of this effect, while 5 out of 7 in the fragmented training conditions have results indicative of this effect to some extent. These findings are indicative of possible procedural variables confounding the observed effect of nodal number as proposed by Sidman (1994, pp.542). Further experiments including more participants would have to be conducted to clarify possible effects and ensure the generality of the present findings as the number of participants in the present experiment is low.

Effect of Nodal Number on Reaction Time

For the reaction time results there only seems to be clear indications of nodal distance effects in two of the 14 participants. These participants were both subjected to the fragmented condition with the interspersed mix blocks and did not form equivalence classes. Some further ambiguous effects are found in two participants data, but the increase in reaction time with increased number of nodes is not linear. The findings are not quite in accordance with previous findings in support of the nodal distance effect where a linear increase in reaction time has been found with an increase in the number of nodes separating the stimuli in a relation (e.g., Fields et.al., 1995). Reaction time data has however failed to show a relation with number of nodes in other studies on equivalence class formations (e.g., Arntzen, Peturson, Sadeghi & Eilifsen, 2015). The results are showing an increase in reaction time from baseline relations to untrained relations, with further increase to nodal relations and a further increase to transitive and equivalence relations for all participants. These findings are in accordance with previous findings (e.g., Arntzen, 2004; Bentall, Dickins, Fox, 1993; Eilifsen & Arntzen, 2009; Holth & Arntzen, 1998; Holt & Arntzen, 2000; Spencer & Chase, 1996). It has been suggested that the reaction time data is a most sensitive measure, and that the methods used for investigating the data is not always sufficient to capture the results (e.g., Whelan, 2008).

In terms of reaction time variations across different conditions, only ambiguous results were fount indicating nodal effects in the reaction times for one of the participants in the ordered training and one in the ordered without interspersed mix blocks. Two participants data indicative of nodal number effects in reaction time in the fragmented condition. Results in reaction time are not clearly indicative of differences in reaction times between the different training condition. As there is a low number of participants data included in the present study, a larger group of participants would be favorable in terms of inferring anything from these results. In previous studies nodal number effects in reaction times have been found in steady state performance (e.g., Bentall, Jones & Dickins, 1999) Only one participant who had formed equivalence classes in the present experiment showed some signs of nodal number effects in the reaction time results, but the relation was not strictly linear.

Effect of Nodal Number in Within-Class Preferences

For the within class preference test there are some indications that there is a link between the chosen sample stimuli within the class and the nodal number to the comparison. The data of 11 participants are indicative of nodal number effects in this test (see table 5).

Previous research has found a preference for the relations where the stimuli are separated by lower number of nodes in training, in within class preference tests (e.g., Dorian & Fields, 2012; Moss-Lourenco & Fields, 2011). It was unclear to what extent the results were replicated in the present study, as the result for this test seems to have been affected by the presence of a familiar stimuli. This is discussed more in the section on effects of meaningful stimuli. Participants in the ordered condition chose the familiar stimuli on all possible trials in the within class preference test, indicating that there was an effect of the presence of the familiar stimuli produced by this training condition that was not produced by the other conditions. Results of these participants are indicative of nodal number effects, but possibly confounded. One participants data showed results indicative of nodal number effects in within class preference tests in the ordered condition without the mix blocks. All participants showed results indicative of nodal number effects in the within class preference tests in the fragmented condition. Three participants results are indicative of nodal number effects in the within class preference test in the fragmented condition without interspersed mix blocks. This might indicate some degree of control over nodal number effect in within class preference test of the more equalized presentation of reinforcement opportunities as all participants in the conditions with the mix blocks and 4 out of 7 in the conditions without the mix blocks show results indicative of this effect. This might lend some degree of support to the findings of Imam (2006) but are contradictory to the findings of e.g., Wang et al. (2011) where nodal number effects were found in results of participants that had been subjected to an equal number of reinforcement opportunities. Further experiments, preferably with a larger number of participants would have to be conducted to clarify the findings and allow for any generalization from the results.

Effect of Meaningful Stimuli

In terms of equivalence class formation there seems to be a higher percentage correct responding in the ordered condition with the interspersed mix phases included. In this condition two of the three participants met the criteria of 95% correct responding. The third participant had 57% correct responding (see Table 2, and Figure 2) This is in accordance with previous research on linear training structure as not all participants form equivalence classes under this type of training. Formation of equivalence relations is expected to be much higher if a one node to many singles or many singles to one node training structure is implied (e.g., Arntzen & Hansen, 2011). Formation of equivalence classes in the present study is somewhat higher than expected for linear series with abstract stimuli. Familiar, or meaningful stimuli, in a class of abstract stimuli have been known to enhance equivalence class formations (e.g., Arntzen & Mensah, 2020). Inclusion of the familiar C stimuli might have contributed to enhance the results in terms of formation of equivalence classes. In accordance with previous studies, the inclusion of a meaningful stimuli in a group of abstract stimuli produces higher yields than if the group only contains abstract stimuli (e.g., Arntzen & Mensah, 2020; Arntzen, Nartey & Fields 2014, 2015, 2018). Enhancement of class formation might come about as the result of the stimulus control functions of a meaningful stimulus and as an effect of the meaningful stimuli being part of many other equivalence classes.

There are clear indications that the C stimuli, the familiar stimuli, is chosen more often than the others. Especially for the participants of the ordered condition where all three participants only chose the familiar stimuli on all possible trials. It is also evident in the other conditions with an over all of 8 out of 11 participants with results in some accordance with nodal effects chose familiar stimuli in at least half of the trials (see Table 5). A study by Nartey, Arntzen and Fields (2015b), concluded that he placement of the familiar stimuli did not affect the yields. In the present results there does seem to be implications of effect in terms of the familiar stimuli being preferred in within class preference tests. These effects could be further investigated through future studies including familiar stimuli in preference tests.

Implications of Current Findings

Present findings are of theoretical interest. According to Sidman (2009), dependent on the context, the stimuli in a class are equivalent. This term implies mutual interchangeability. As previous findings are in support of there being nodal effects in the data, the possibility of such effects occurring and an explanation as to why they might occur is of interest to the field.

Fields et al. (1990) found that nodal number effects were present early on in testing and disappeared with repeated presentation. They discuss, among other theories, the possibility of verbal mediating and remembering the verbal behavior might cause the effect, but finds the proposal unsustainable, because of lack of accuracy in responding in test. Fields et al. (1990) find similarities in the fields of sematic memory networks and serial learning, but state that there are a lot of differences in theory and procedure that requires further inspection before one can be building bridges. They conclude that the relations are jointly determined by number of presentation and nodal number separating the stimuli in the relations.

Fields et.al. (1993) reviewed studies of different effects of nodal number and finds that the effect is present in tests results for emergent relations in correct responding and in reaction time. They also find that results of within-class preference tests are influenced by the nodal distance. In addition, they find evidence of the transfer of functions within an equivalence class is also a function of number of nodes separating the stimuli. Fields and Moss (2007) suggested upon summarizing further evidence in support of nodal number effects, that the effects could be emerging due to the fact that the stimuli in an equivalence class acquire both a class based and a nodal based function, and further that that the functions are under conditional control of the test format and that weather the between class choices or the within class choices are signaled by the contingencies of the trial determines which functions takes effect.

Data in the present study indicate that there are nodal number effects in correct responding for several of the participants that have not met the criteria for equivalence class formation. As Sidman (1994, pp. 541) suggested, observed nodal effects might be more a question of when the stimuli become equivalent, than if they become equivalent. As such, these parts of the findings are in accordance with the Stimulus equivalence and nodal number account by Sidman (1994). Indications of these effects in the data lend further support to results indicative of nodal number inferences in the formation of equivalence classes (e.g., Fields et al., 1995). We further see that all members in the ordered presentation that did not form equivalence classes, and 5 out of 7 members in the fragmented conditions show these effects, indicative of some degree of effect of the order of presentation of the stimulus pairs having influenced results, lending some degree of support to Sidmans account of equivalence class formation in that procedural variables might be key in explaining the observed nodal number effects (1994, pp. 540-542)

The findings are not fully in support of nodal number effects on reaction times, as only two participants data clearly display signs of such effects, while others show more ambiguous or nonexistent effects. There are some commonalities in the reaction time for all participants in that there is an increase from baseline to symmetry and further to stimuli separated by nodes in training structure (transitive and equivalence relations). As discussed, the sensitivity of this measure might account for some of the numbers, and the reaction time results in this respect can only be described as ambiguous. The low number of participants showing clear signs of nodal number effects might lend some further support to Sidmans (1994) account in that the stimuli in a class are interchangeable.

the effects shown in within class preference tests are ambiguous as the relation to the familiar stimuli seems to have an interfering effect for several of the participants. The results here could lend some support to previous studies indicative of nodal number effects (e.g., Albright et al., 2019) However, the apparent influence of the familiar stimuli is an issue that needs to be investigated further before we can conclude from the results.

Limitations

As mentioned in the method section, the research had to be conducted in several different rooms due to availability of subjects and facilities. This makes it hard to completely control for the effect of extraneous stimuli. Even though the rooms, decor and colors are similar it is difficult to control for smell, noise, and lighting etc. in the different locations. No systemic variations were apparent over the results or the training conditions in accordance with the rooms the participants were placed in. It could however not be guaranteed that some effect on the data on an individual level might occur. Internal validity of the results could have been strengthened if it would have been possible to conduct the experiment in only one location.

Another limitation that is important to consider is that the number of participants included in the study is relatively low. This is partly due to time constraints and partly due to the high number of participants not completing the training, resulting in six participants not being included in the results. It would have been preferable to include more participant, as the external validity of the experimental results could have been strengthened. A greater number of participants could have allowed for statistical measures of group results could being implied, rather than data only being displayed in tables and graphical representations as is.

Time and fatigue are other constraints that should be taken into consideration for future studies, as three of the six participants included had to end their participation before completion out of fatigue, and three out of personal time constraints, two of them after sitting in for the experiment for an extended period of time. The experimenter could possibly have mediated better for the participants dropping out with clearer instructions and setting a longer time frame for the experiment, so that time constraints could have been ruled out as a reason for quitting before completion of training. As 6 out of 20 participants did not complete the training, the high number of participants failing to complete the testing could have been mediated for by taking measures as listed above, or by potentially making changes in the experimental setup. One possibility could be to include pretraining with familiarization to the process so that one ensured that the participants were fully on board with the task at hand. This has shown to improve yields in previous studies (e.g., Nartey, Arntzen & Fields, 2015a) Of course, the addition of such an addition in the procedure would have to be carefully implemented in such a way as not to distort the results.

A further effect that could have been mediated for is the effect of the meaningful stimuli on the within-class preference test. Effects of the interference of the familiar stimuli could have been modified in the present study or a replication of the setup by placing the stimuli in a different position in the set so that it could be naturally removed in a within class preference test without interfering with the preferences over nodes, or just removing it from the test as the setup is in the present experiment.

Future Research

As different facilities had to be used in the present experiment, it could be interesting to do a replication where all the participants are in the exact same setting to see if the results would hold up in an identical setting. As the participant group was of modest size, it could, for future research, be interesting to do a replication in a larger scale to see if the presented findings hold up in results of a larger number of people under the same conditions of training. Having a larger number of participants would also allow for statistical methods to be implied to generalize the findings, which could be of interest to further analyzes of the results on the group level.

It has been indicated that pretraining could aid in the participants yields in the class formation and this could shorten the time frame for the training phase (e.g., Buffington Fields, & Adams, 1997; Nartey et.al., 2015a). The inclusion of this kind of training could possibly aid in instructing participants, shorten the time used, and lessen the risk of fatigue.

Further interesting approaches could be to do more tests with the same kind of training used in the current experiment by repeating the test block, possibly at a later time, requiring participants to sit in for two sessions. With more replications in testing, one could see if delayed emergens would appear in the results. If delayed emergence was to occur, the nodal results in the accuracy of responding would seem to fade over training trials. There have been indications of nodal number effects in delayed emergence of equivalence classes in terms of when relations are established (e.g., Arntzen & Mensah, 2020; Fields et.al., 2012).

Another test that could be modified in future experiment would be the within-class preference test. As seen in the result section, there seems to be an inference of the presence of the familiar stimuli. By moving the placement of the familiar stimuli in such a way as to exclude it from partaking in the test, one could remove the confounding effects and thus strengthen the results of the within-class preference testing. As placement could affect yields (e.g., Nartey et.al., 2015b), another possibility would be to keep the placement as is, and just remove the familiar stimuli from the set of comparisons in the within class preference test.

Other interesting directions could be to see what kind of practical implications that could come about if the observed nodal effect shows up in situations more closely related to everyday life situations. An example could be to look at transfer of function with the same kind of semantic differentiations as mentioned in Bortoloti and DeRose`s (2009) study and applying this kind of testing to different applied settings. This kind of semantic differentiation could also be used as a measure of relatedness in experimental settings like in the Bortoloti and DeRose`s (2015) study. This could be an interesting additional measure in a possible replication.

There are examples of studies utilizing this approach in more applied settings (e.g., Arntzen & Eilertsen, 2020, 2017; Arntzen, Eilertsen & Fagerstrøm, 2016). To expand on something in this direction, it would be advisable to modify the structure of training, as linear serialized training is related to a low degree of correct responding and other structures are thus favorable (see e.g., Arntzen et.al., 2010). One could for instance establish smaller classes by training with node to single or opposite. These training structures are called one to many and many to one. This type of training has been proven more efficient for establishing stimulus equivalence classes (e.g., Arntzen & Hansen, 2011). One could further link these classes by merging them and training a function to a single in the merged equivalence class, resulting in a greater number of nodes separating the stimuli while still getting high enough correct responding to form and test for equivalence classes. This kind of setup would differ from the present experiment to such an extent that it would be a different experiment all together, and thus shall not be discussed further in the present paper.

Conclusion

The objective of the present experiment was to see how an ordered and a fragmented presentation, with more and less equalized presentations of training trials, influenced the formation of equivalence classes, on nodal number effects in correct responding, on nodal number effects in reaction time and on nodal number effects in within class preference tests. Results showed that there were some indications of nodal number effects, especially in correct responding on number of nodes separating the stimuli for the participants who did not form equivalence classes. While results in reaction time seem not to be in complete accordance with previous nodal number effect finding, with some participants data indicating an effect, and others not. The within-class preference tests could lend some support to previous findings on nodal number effects. Results are ambiguous as they seem to be influenced by the presence of the familiar stimuli.

Structure of training had an effect in that the participants subjected to the linear serialized ordered condition with mix blocks showed higher precision in testing and in addition the participant of this group exclusively chose the familiar stimuli in the within class preference test. Nodal number effects in precision were maintained for several of the participants subjected to all the conditions, and there seems to be some inference in that the two ordered conditions of training produced a higher rate of nodal number effects in this respect relative to number of participants in each group. Little clear evidence is found in support of reaction time effects in accordance with nodal number in the results of the present study. Evidence for within class preferences is seemingly confounded by the effects of the familiar stimuli and should possibly be reproduced without this possibility of confounding effects. Other possible weaknesses mentioned are the use of different experimental settings, the low number of participant and high incompletion rate, and the time frame for participating. To better the reliability of the results, several mediating propositions are made for possible future experiments and possible replications of the current training structure.

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Table 1

Experimental setup for the training conditions

Ordered	Ordered, no mix	Fragmented	Fragmented, no mix
A -> B	A -> B	A -> B	A -> B
B -> C	B -> C	E -> F	E -> F
MIX A -> B & B -> C	C -> D	*MIX A -> B & E -> F*	D -> E
C -> D	D-> E	D -> E	C -> D
MIX A -> B, B -> C & C -> D	E -> F	*MIX A -> B, E -> F & D -> E*	B -> C
D -> E		C -> D	
MIX A -> B, B -> C, C -> D & D -> E		*MIX A -> B, E -> F, D -> E & C -> D*	
E -> F		B -> C	
MIX ALL	MIX ALL	MIX ALL	MIX ALL
MIX ALL 75% feedback	MIX ALL 75% feedback	MIX ALL 75% feedback	MIX ALL 75% feedback
MIX ALL 50% feedback	MIX ALL 50% feedback	MIX ALL 50% feedback	MIX ALL 50% feedback
MIX ALL 0% feedback	MIX ALL 0% feedback	MIX ALL 0% feedback	MIX ALL 0% feedback
EQ.TESTING	EQ.TESTING	EQ.TESTING	EQ.TESTING
WITHIN CLASS	WITHIN CLASS	WITHIN CLASS	WITHIN CLASS
PREFERENCE A	PREFERENCE A	PREFERENCE A	PREFERENCE A
WITHIN CLASS	WITHIN CLASS	WITHIN CLASS	WITHIN CLASS
PREFERENCE F	PREFERENCE F	PREFERENCE F	PREFERENCE F

Note. The table shows the experimental setup for the different conditions of training. Each column is one condition and each window represent one block. The white areas and lighter gray areas show the training phases and the difference in structure for each of the conditions. The darker gray areas depict the test blocks. These are all the same regardless of training condition.

Table 2

Equivalence test results for all participants included

Participant	Baseline in test	Symmetry	Transitivity	Equivalence	ECF
			Ordered		
17703	1,00	1,00	0,98	0,99	0,99
17714	1,00	0,98	0,93	0,96	0,96
17711	0,96	0,91	0,40	0,38	0,57
			Ordered no mix		
17713	0,93	0,93	0,67	0,74	0,78
17709	0,91	0,84	0,39	0,44	0,57
17701	0,89	0,78	0,34	0,37	0,51
			Fragmented		
17712	1,00	0,91	0,40	0,38	0,71
17708	0,96	0,93	0,44	0,49	0,63
17704	0,89	0,84	0,42	0,38	0,56
17717	1,00	0,91	0,23	0,18	0,46
			Fragmented no mix		
17710	1,00	1,00	0,97	0,98	0,98
17715	0,98	0,91	0,50	0,38	0,61
17719	0,76	0,67	0,51	0,41	0,54
17706	0,87	0,78	0,37	0,32	0,50

Note. The table shows the correct responding in test for baseline, symmetry, transitivity, and equivalence relations. Correct answers are given in percentage correct. The participant numbers and training conditions are indicated in the left-hand column. The following columns are baseline, symmetry, transitivity, and equivalence. The column on the right-hand side shows total equivalence class formation.

Table 3

Correct responding sorted by nodal relations for all participants included

Participant	0-node	1-node	2-node	3-node	4-node
Ordered					
17703	1,00	0,96	1,00	1,00	1,00
17714	0,98	0,97	0,98	0,86	0,89
17711	0,91	0,51	0,37	0,28	0,17
Ordered no mix					
17713	0,93	0,83	0,69	0,64	0,39
17709	0,84	0,58	0,30	0,36	0,22
17701	0,78	0,40	0,35	0,22	0,39
Fragmented					
17712	0,91	0,51	0,37	0,28	0,17
17708	0,93	0,51	0,33	0,53	0,50
17704	0,84	0,36	0,50	0,47	0,06
17717	0,91	0,39	0,17	0,00	0,00
Fragmented no mix					
17710	1	0,99	0,98	0,97	0,89
17715	0,91	0,59	0,41	0,28	0,22
17719	0,67	0,58	0,41	0,31	0,39
17706	0,78	0,35	0,31	0,36	0,39

Note. The table shows in correct responding in test results sorted by nodal number. The correct responding is indicated in percentage correct. On the left-hand side, the first column indicates the type of training and the participant numbers. The following columns divide test trials by nodal number in the relations that are not directly trained.

Table 4

Reaction time sorted by number of nodes for all participants included

Participant	RT training	RT 0-node	RT 1-node	RT 2-node	RT 3-node	RT 4-node
			Ordered			
17703	2,1	2,2	5,2	8,6	6,9	10,0
17714	1,0	2,6	4,1	3,7	7,2	6,9
17711	1,6	2,2	4,4	3,8	4,0	2,0
			Ordered no mix			
17713	1,7	2,3	5,4	6,4	4,7	7,1
17709	2,2	2,6	21,2	14,2	18,5	17,6
17701	1,9	3,0	3,8	3,6	6,4	2,7
			Fragmented			
17712	1,3	2,0	2,9	6,3	7,4	8,7
17708	3,1	5,2	7,6	11,8	4,9	6,1
17704	1,4	1,8	3,3	5,7	7,3	8,7
17717	1,6	3,2	6,6	8,8	5,0	6,5
			Fragmented no mix			
17710	1,3	3,1	11,9	7,1	8,6	5,9
17715	1,0	2,1	8,1	20,4	11,1	4,9
17719	1,2	2,7	4,6	6,6	4,3	2,2
17706	2,3	2,1	4,6	2,8	3,4	2,9

Note. The table show reaction time in seconds for all participants. The column on the left-hand side indicates training condition and participant number. The neighboring column indicates the reaction time average for the last five trials in training. The following columns indicate the average reaction time over the first five trials in training, for 0-node, 1-node, 2-node, 3-node, and 4-node relations in the test phase that are not directly trained.

Table 5

Within class preference test sorted by nodal number

Participant	1-node	2-node	3-node	4-node	Familiar
		Ordered			
17703	9	9	0	0	18
17714	9	9	0	0	18
17711	9	9	0	0	18
		Ordered no mix			
17713	5	4	3	6	5
17709	8	8	1	1	8
17701	4	1	6	7	1
		Fragmented			
17712	18	0	0	0	9
17708	8	7	0	3	13
17704	5	7	3	3	7
17717	14	2	0	2	9
		Fragmented no mix			
17710	8	4	6	0	10
17715	16	2	0	0	7
17719	4	3	7	4	3
17706	6	6	5	1	10

Note. The table shows responding in within class preference test, sorted by nodal number and familiar stimuli. The column on the left-hand side indicates participant number and training condition. In the within class preference test the directly trained stimuli is removed, so the following columns indicate the 1-, 2-, 3- and 4- node relations. The right-hand column indicates the familiar stimuli. The results are given in number clicked. The total number of trials for this test is eighteen.

Figure 1

Stimulus classes

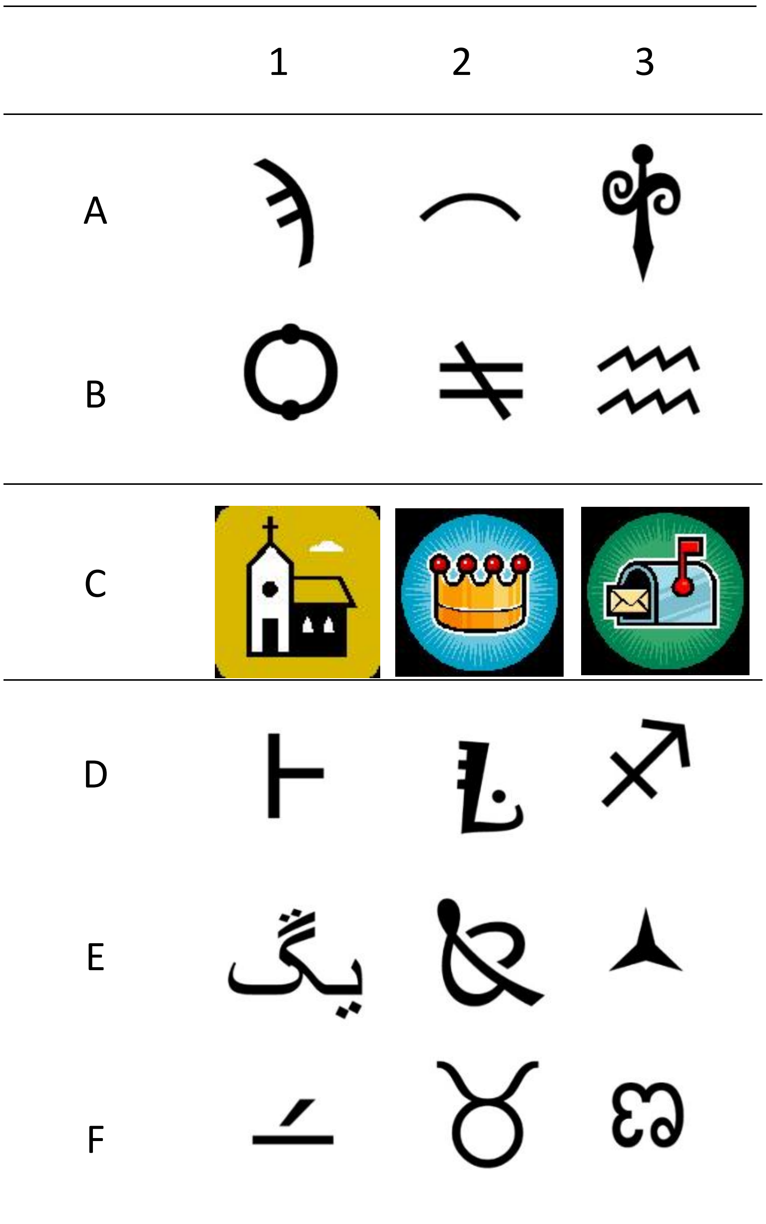

Fig 1. The figure shows stimuli used in the experiment divided by experimentally defined classes vertically and comparison stimuli shown together in a trial horizontally.

Figure 2

Correct responding for ordered condition

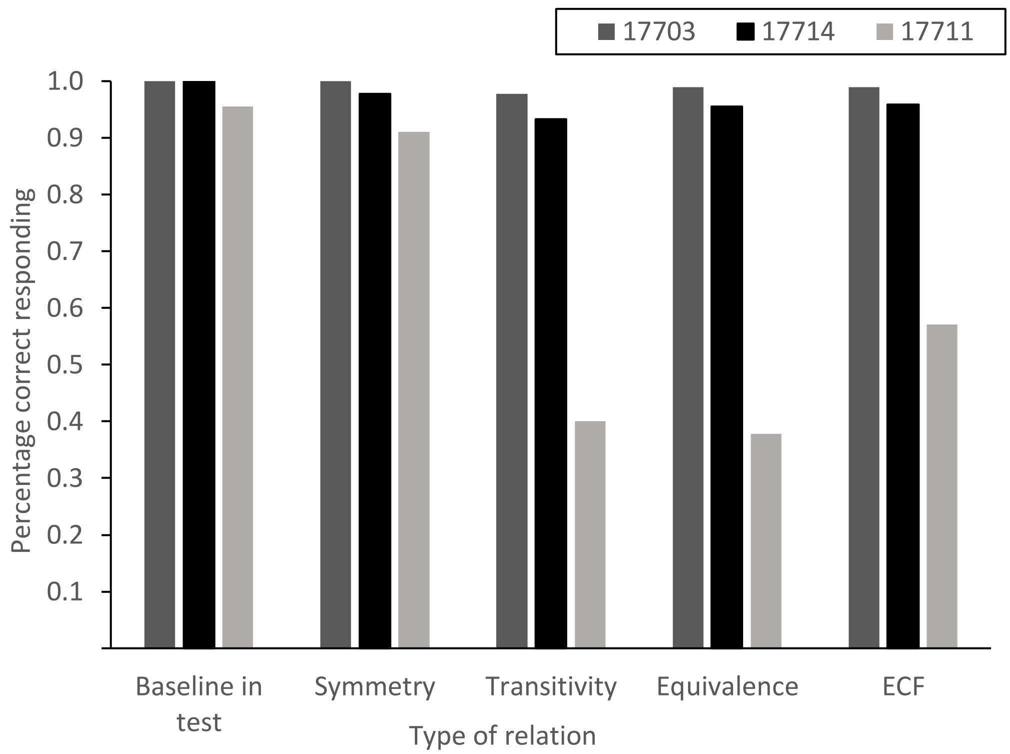

Fig 2. The figure depicts equivalence class formation for the participants in the ordered condition with mix blocks. The correct responding for each relational type is shown in percentage correct.

Figure 3

Correct responding by nodal number for ordered condition

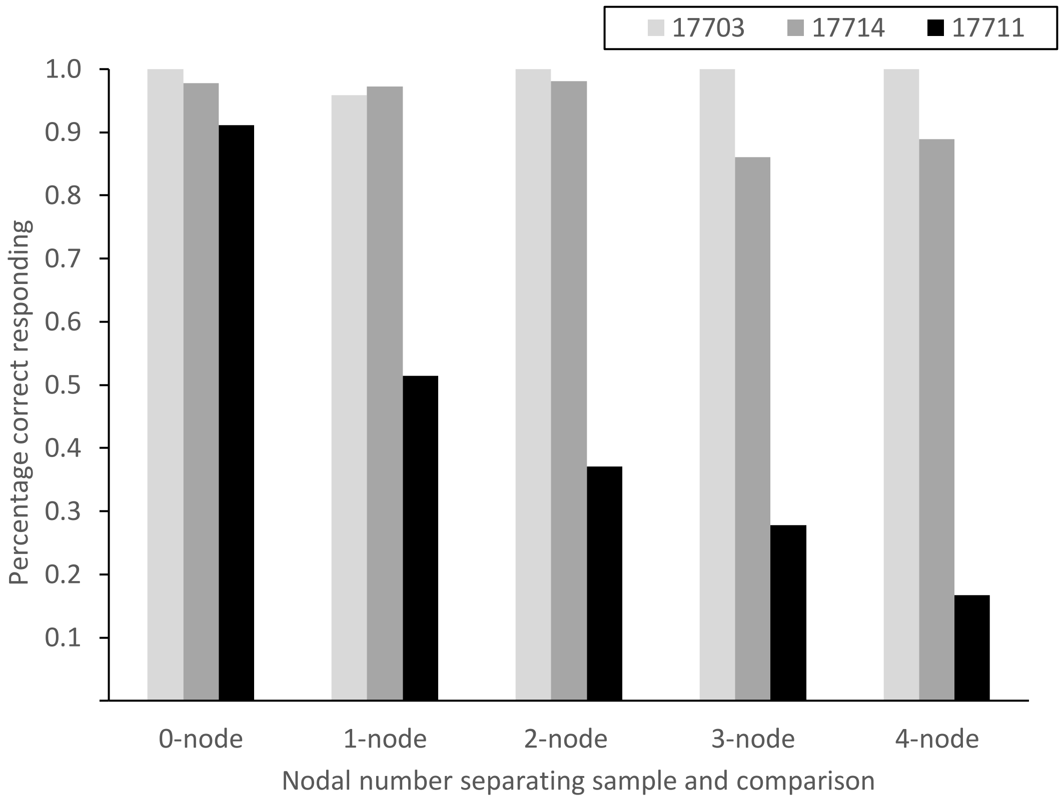

Fig 3. The figure depicts the percentage of correct responding in test trials sorted by nodal number for the ordered condition with mix blocks.

Figure 4

Reaction time on nodal number for ordered condition

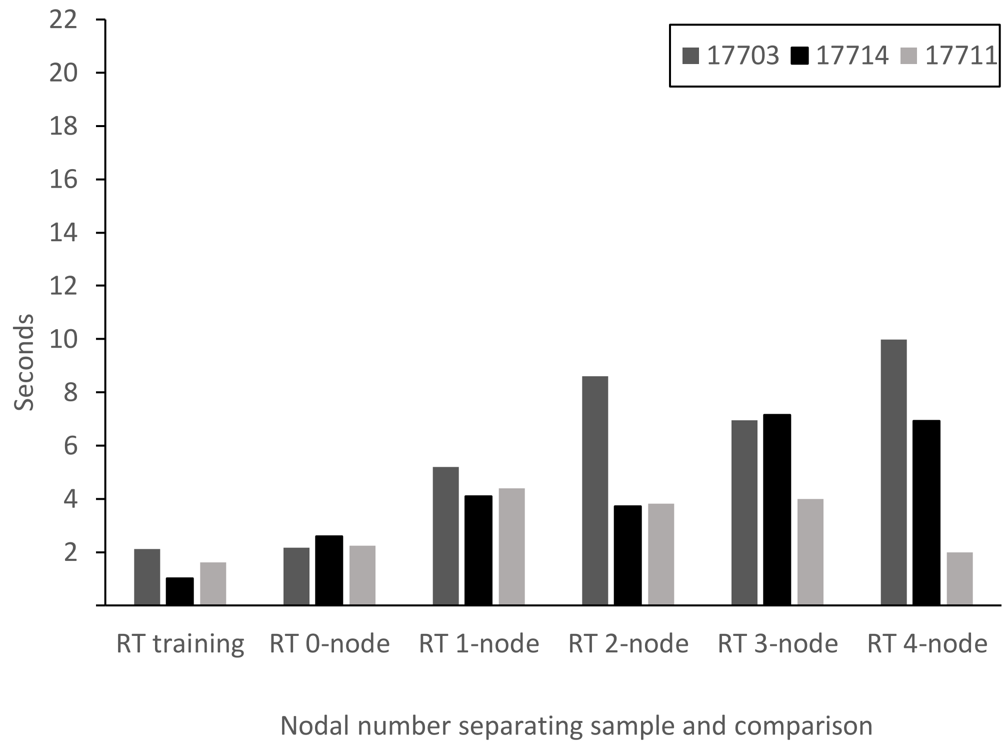

Fig 4. The figure depicts reaction time for the participants in the ordered condition with mix blocks. RT training is the average for the five last trials in the training. The following columns indicate the average of the five first trials for the 0-, 1-, 2-, 3- and 4-node relations that are tested for but have not been directly trained. The results are indicated in seconds.

Figure 5

Within class preference test for ordered condition

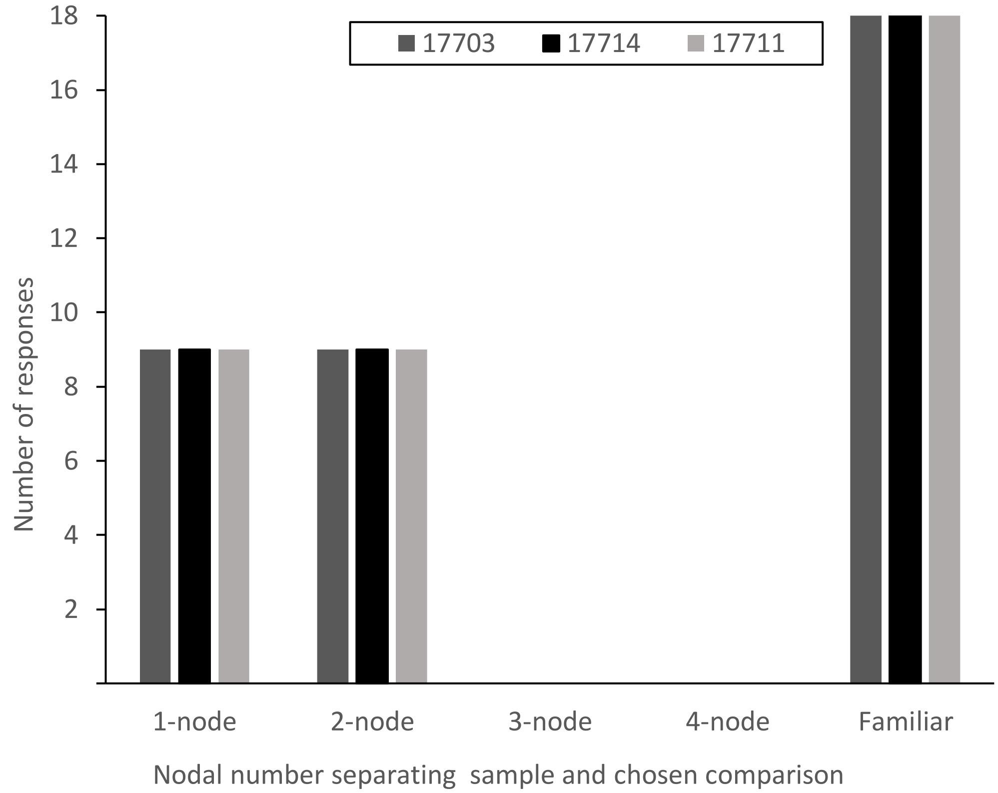

Fig 5. The figure depicts the number of clicks in the within class preference test for the ordered condition. The total number of clicks for the test blocks is 18. The possible choices of stimuli are divided in to type of nodal relation by 1-, 2-, 3- and 4-node relations. The right-hand column indicates the number of stimuli chosen that are the familiar C stimuli.

Figure 6

Correct responding for ordered condition without mix

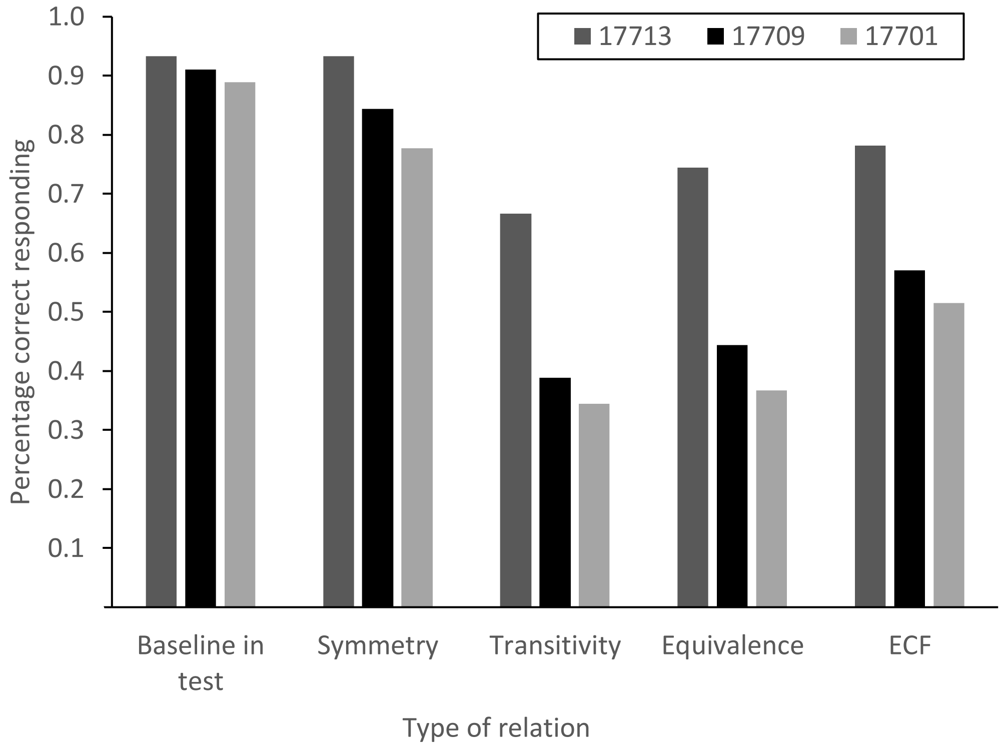

Fig 6. The figure depicts equivalence class formation for the participants in the ordered condition without interspersed mix blocks. The correct responding for each relational type is shown in percentage correct.

Figure 7

Correct responding on different nodal number for ordered condition without mix

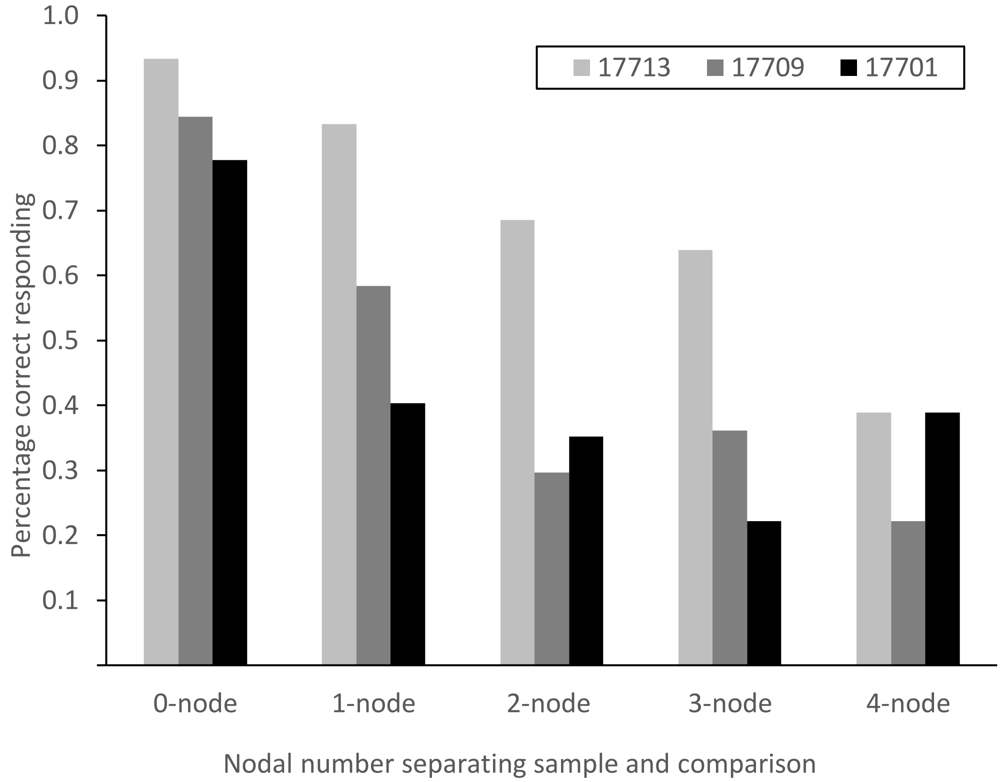

Fig 7. The figure depicts the percentage of correct responding in test trials sorted by nodal number for the ordered condition without interspersed mix blocks.

Figure 8

Reaction time by nodal number for ordered condition without mix

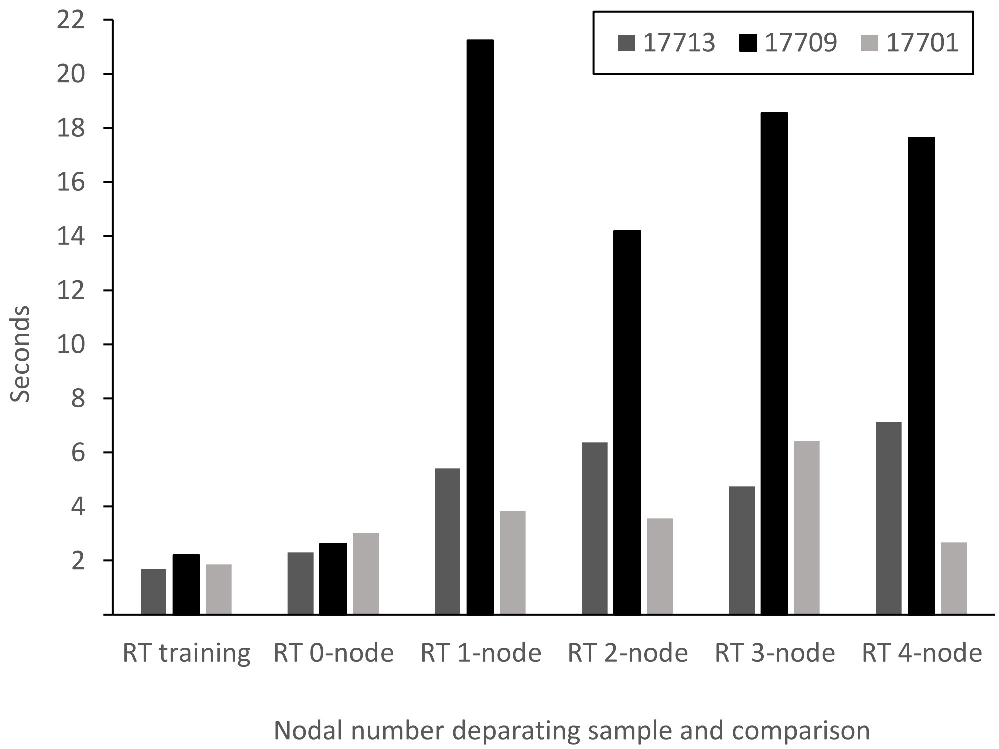

Fig 8. The figure depicts reaction time for the participants in the ordered condition without interspersed mix blocks. RT training is the average for the five last trials in the training. The following columns indicate the average of the five first trials for the 0-, 1-, 2-, 3- and 4-node relations that are tested for but have not been directly trained. The results are indicated in seconds.

Figure 9

Within class preference for ordered condition without mix

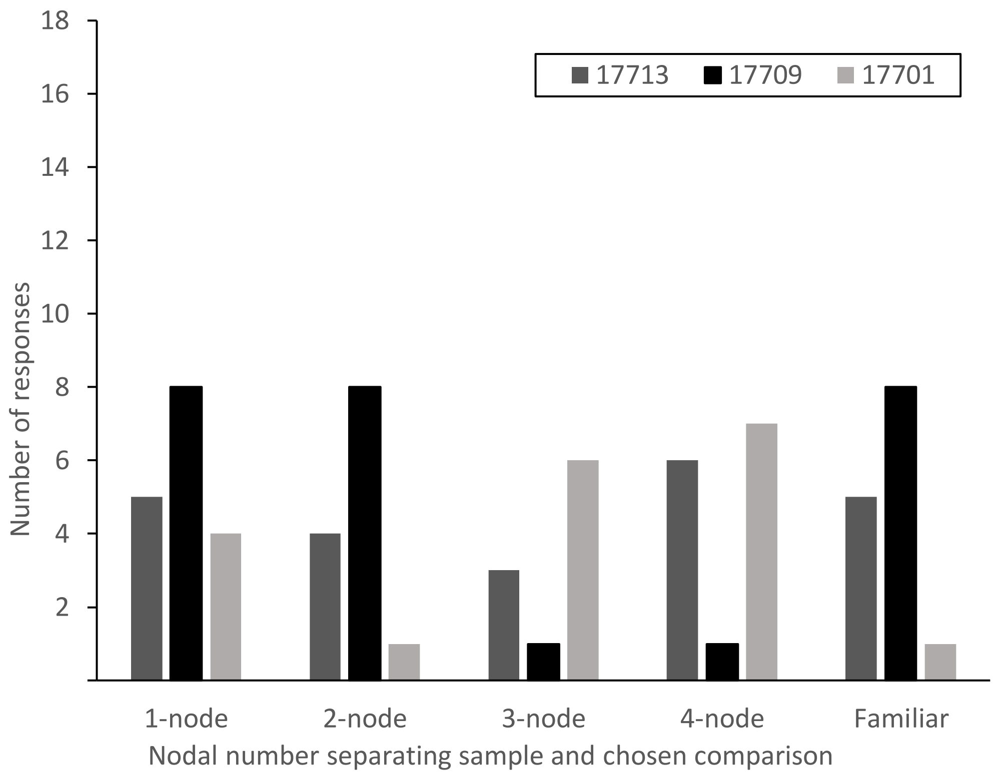

Fig 9. The figure depicts the number of clicks in the within class preference test for the ordered condition without the interspersed mix blocks. The total number of clicks for the test blocks is 18. The possible choices of stimuli are divided by number of nodes separating the stimuli in 1-, 2-, 3- and 4-node relations. The right-hand column indicates the number of stimuli chosen that are the familiar C stimuli.

Figure 10

Correct responding for fragmented condition

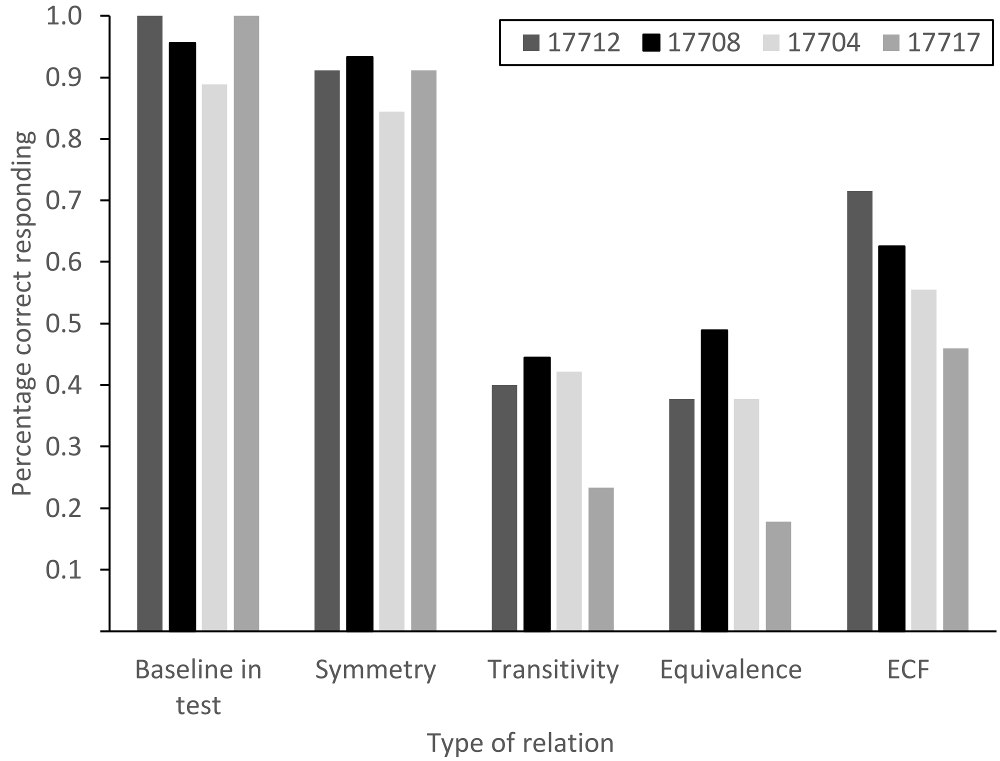

Fig 10. The figure depicts equivalence class formation for the participants in the fragmented condition with mix blocks. The correct responding for each relational type is shown in percentage correct.

Figure 11

Correct responding by nodal number for fragmented condition

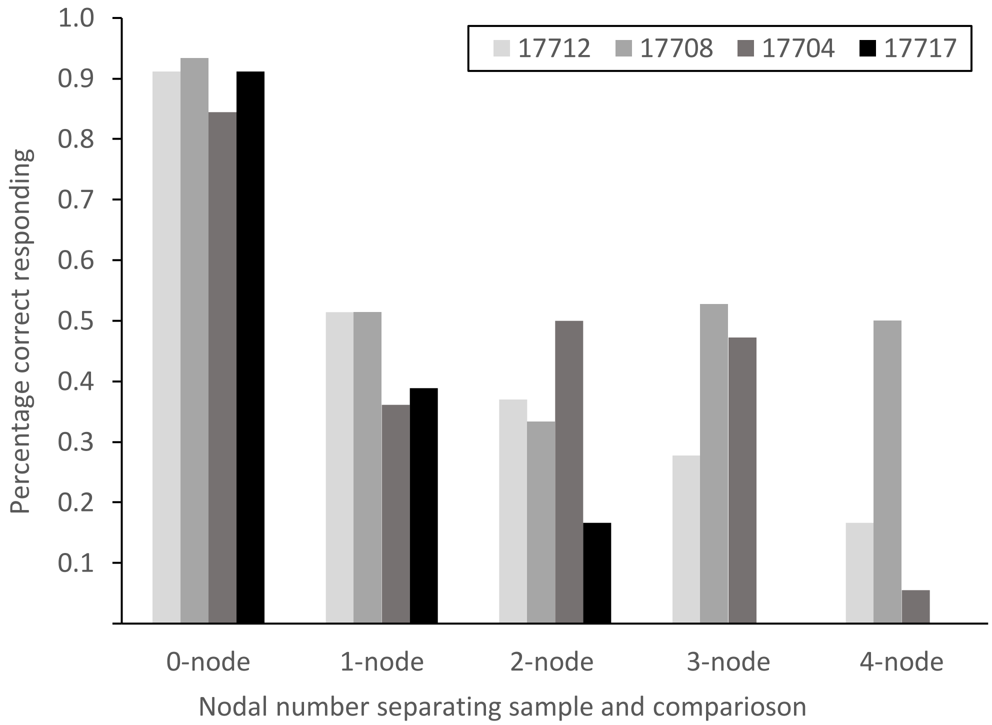

Fig 11. The figure depicts the percentage of correct responding in test trials sorted by nodal number separating the sample and comparison for the fragmented condition with mix blocks.

Figure 12

Reaction time on nodes for fragmented condition

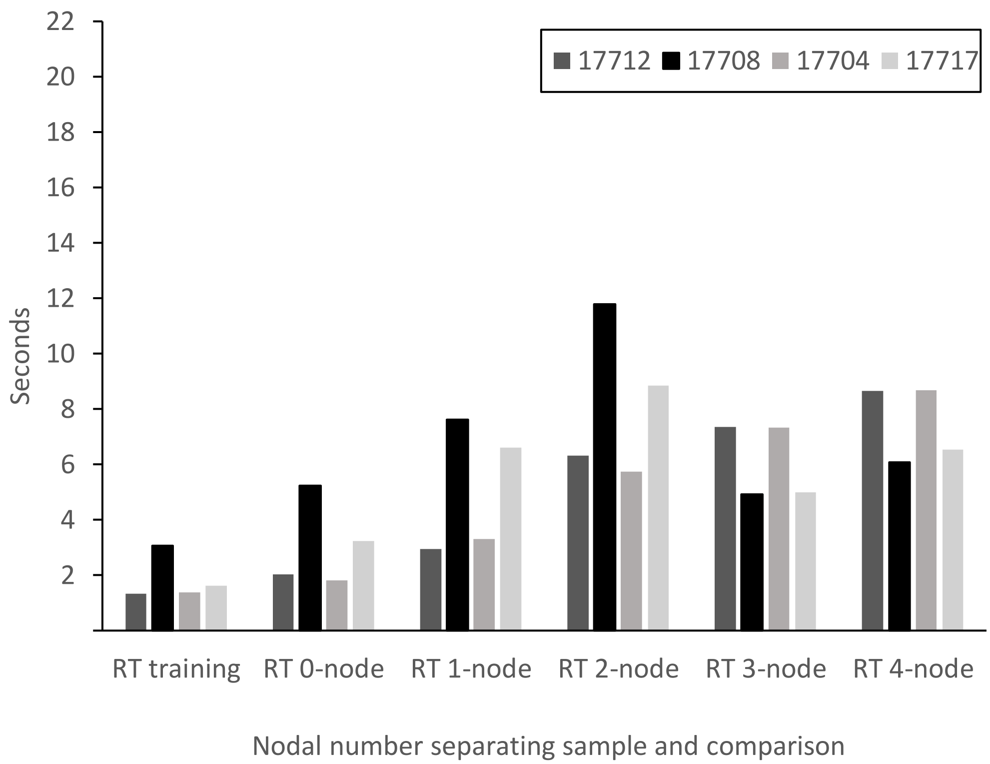

Fig 12. The figure depicts reaction time for the participants in the fragmented condition with mix blocks. RT training is the average for the five last trials in the training. The following columns indicate the average of the five first trials for the 0-, 1-, 2-, 3- and 4-node relations that are tested for but have not been directly trained. The results are indicated in seconds.

Figure 13

Within class preference test for fragmented condition

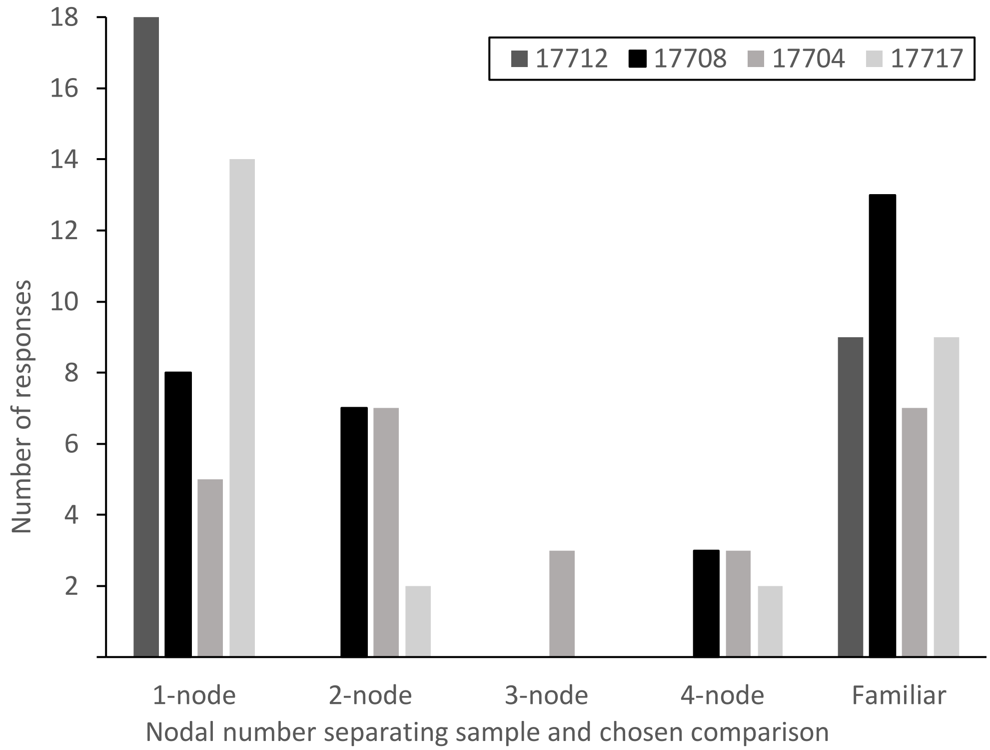

Fig 13. The figure depicts the number of clicks in the within class preference test for the fragmented condition. The total number of clicks for the test blocks is 18. The possible choices of stimuli are divided in to type of nodal relation by 1-, 2-, 3- and 4-node relations. The right-hand column indicates the number of stimuli chosen that are the familiar C stimuli.

Figure 14

Correct responding for fragmented condition without mix

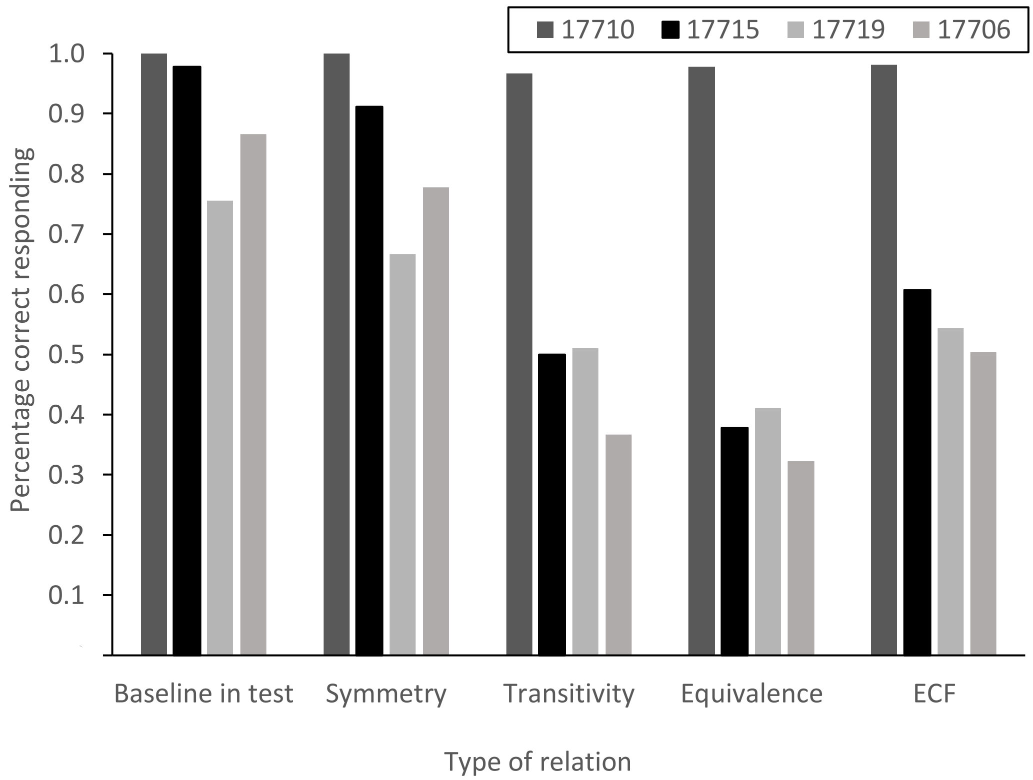

Fig 14. The figure depicts equivalence class formation for the participants in the fragmented condition without interspersed mix blocks. The correct responding for each relational type is shown in percentage correct.

Figure 15

Correct responding by nodal number for fragmented condition without mix

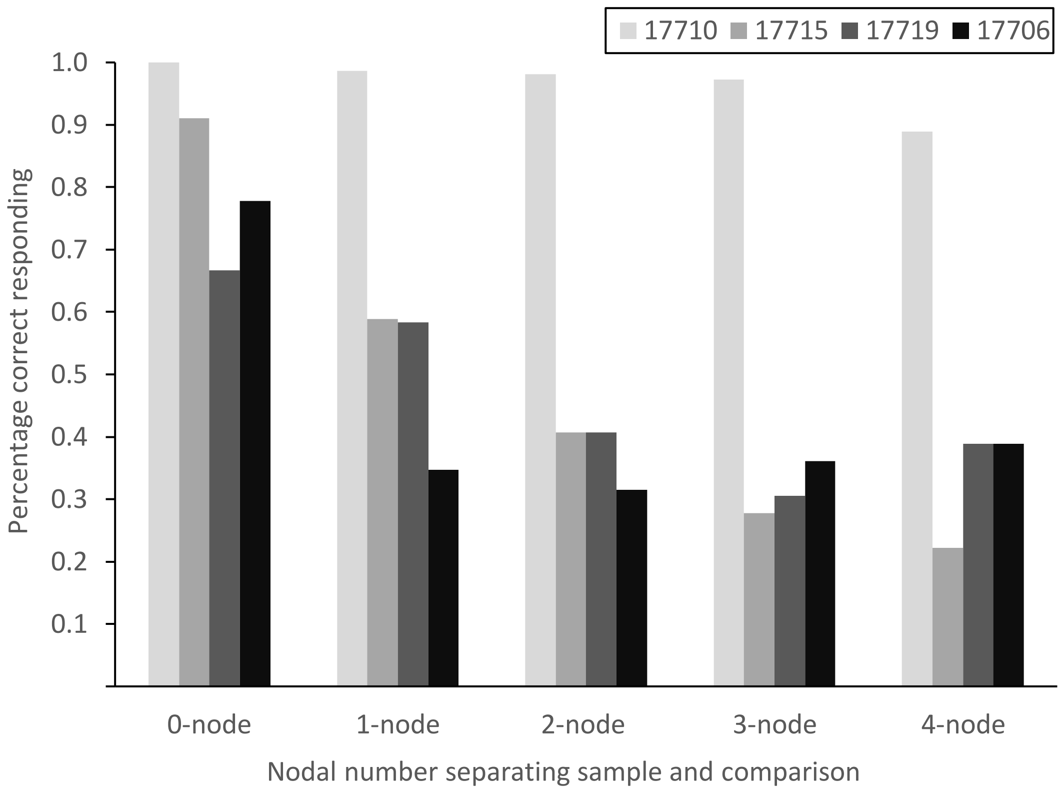

Fig 15. The figure depicts the percentage of correct responding in test trials sorted by nodal number for the fragmented condition without interspersed mix blocks.

Figure 16

Reaction time by nodal number for fragmented condition without mix

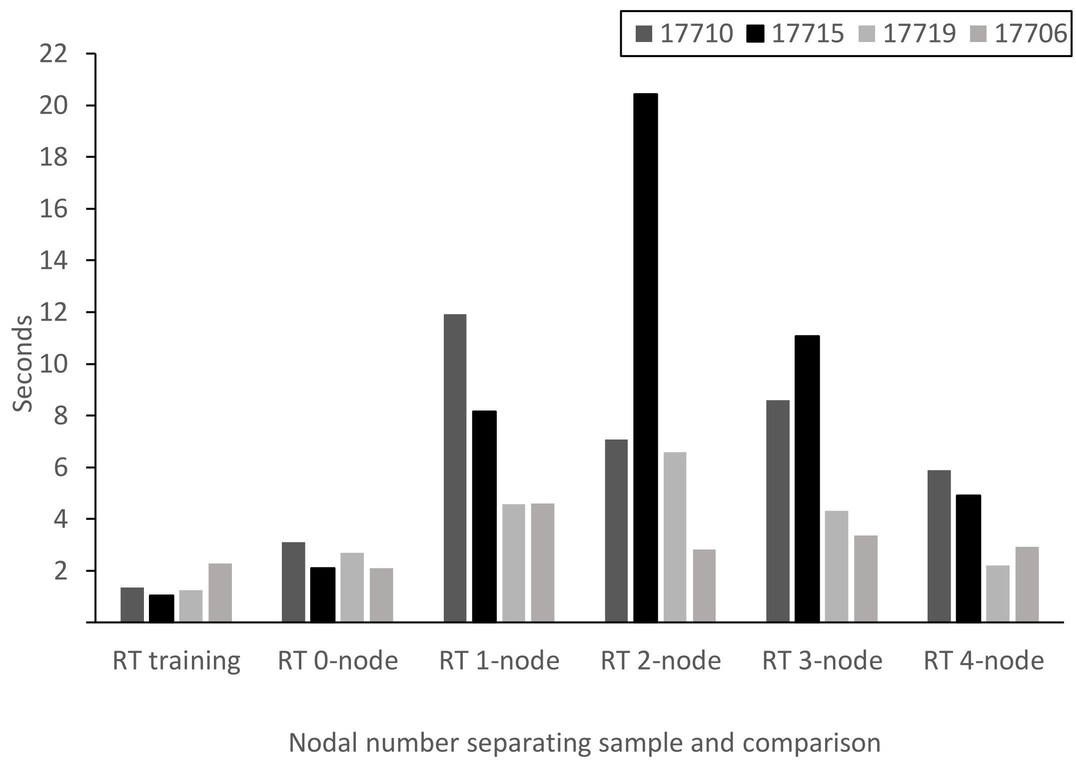

Fig 16. The figure depicts reaction time for the participants in the fragmented condition without interspersed mix blocks. RT training is the average for the five last trials in the training. The following columns indicate the average of the five first trials for the 0-, 1-, 2-, 3- and 4-node relations that are tested for but have not been directly trained. The results are indicated in seconds.

Figure 17

Within class preference test for fragmented condition without mix

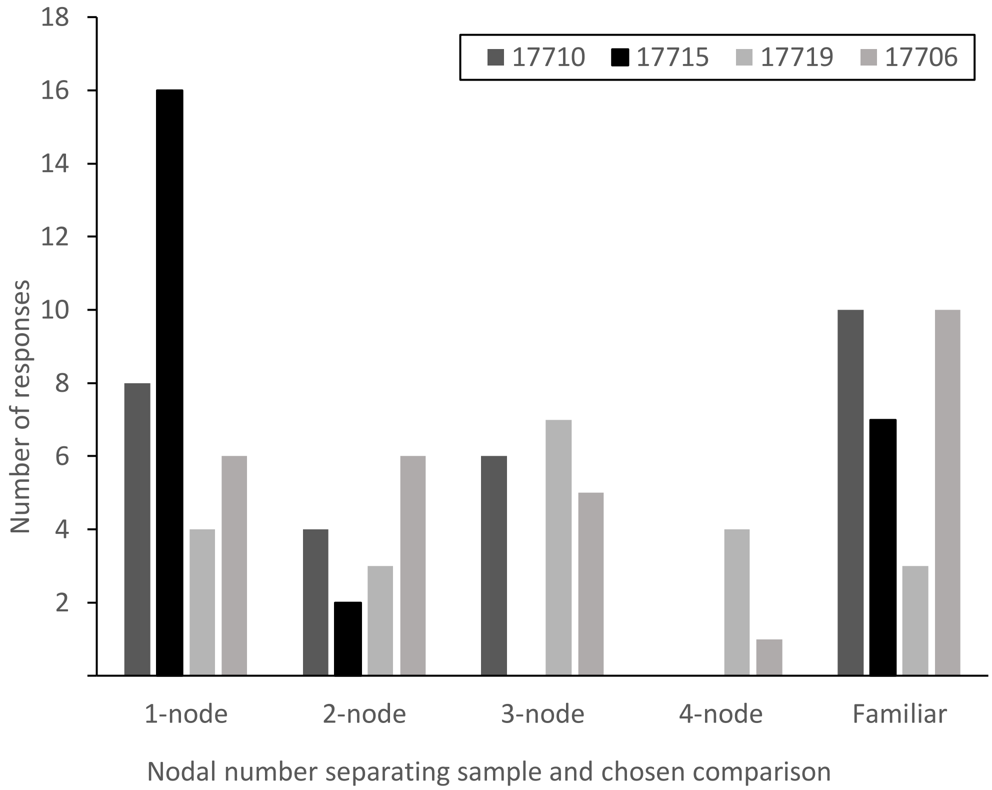

Fig 17. The figure depicts the number of clicks in the within class preference test for the fragmented condition without the interspersed mix blocks. The total number of clicks for the test blocks is 18. The possible choices of stimuli are divided in to type of nodal relation by 1-, 2-, 3- and 4-node relations. The right-hand column indicates the number of stimuli chosen that are the familiar C stimuli.

Appendix A

NORSK SENTER FOR FORSKNINGSDATA

Meldeskjema 157140

Sist oppdatert

14.05.2020

Hvilke personopplysninger skal du behandle?

Navn (også ved signatur/samtykke)

Type opplysninger

Skal du behandle særlige kategorier personopplysninger eller personopplysninger om straffedommer eller lovovertredelser?

Nei

Prosjektinformasjon

Prosjekttittel

Fragmented versus linear training structure and the formation of stimulus equivalence relations

Begrunn behovet for å behandle personopplysningene

De opplysningene som er person-sensitive (navn) vil være nødvendige for å kontakte personer før forsøket og
innhente samtykke før oppstart. De vil oppbevares i safe og aldri komme i direkte kontakt med data output
innhentet til videre bruk i eksperimentet.

Ekstern finansiering

Type prosjekt

Studentprosjekt, masterstudium

Kontaktinformasjon, student

Renate Follerås, s311359@oslomet.no, tlf: 97780664

Behandlingsansvar

Behandlingsansvarlig institusjon

OsloMet - storbyuniversitetet / Fakultet for helsevitenskap / Institutt for atferdsvitenskap

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Erik Arntzen, erik.arntzen@oslomet.no, tlf: 67236442

Skal behandlingsansvaret deles med andre institusjoner (felles behandlingsansvarlige)?

Nei

Utvalg 1

Beskriv utvalget

Voksne, normalt fungerende

Rekruttering eller trekking av utvalget

Rekruttering gjennom bekjentskap/eget nettverk og institusjon

Alder

18 - 80

Inngår det voksne (18 år +) i utvalget som ikke kan samtykke selv?

Nei

Personopplysninger for utvalg 1

Navn (også ved signatur/samtykke)

Hvordan samler du inn data fra utvalg 1?

Annet

Beskriv

Elektronisk eksperiment - ingen personsensitive opplysninger tilknyttet data, kun anonymisert output vedrørende valg av stimuli i forsøk på data.

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Informasjon for utvalg 1

Informerer du utvalget om behandlingen av opplysningene?

Ja

Hvordan?

Skriftlig informasjon (papir eller elektronisk)

Tredjepersoner

Skal du behandle personopplysninger om tredjepersoner?

Nei

Dokumentasjon

Hvordan dokumenteres samtykkene?

Manuelt (papir)

Hvordan kan samtykket trekkes tilbake?

En person vi i dette forsøkt motta skriftlig informasjon og undertegne samtykke ved oppmøtet. Personen kan når som helst trekke seg fra forsøket så lenge det pågår eller like etter gjennomføring og alle person data vil i så tilfelle destrueres. Etter gjennomført forsøk vil forskningsdata anonymiseres totalt og umiddelbart.

Hvordan kan de registrerte få innsyn, rettet eller slettet opplysninger om seg selv?

Frivillig informert samtykke vil innhentes på papir ved oppstart av forsøk. Dette vil oppbevares i kodet safe på institusjonens område. Navneliste vil opprettes ved oppstart av prosjekt, denne vil også oppbevares i safe og destrueres umiddelbart etter bruk. Ved forespørsel til forskningsleder vil samtykke skjema kunne vises, rettes eller slettes for den det gjelder. Datafiler anonymiseres så fort personen i forsøket er ute av døren. Det vil derfor gjøres en gjennomgang av denne med personen(e) rett etter gjennomført forsøk. Deretter vil det ikke være tilgang til filene for personen. Disse opplysningene er ikke person-sensitive og kommer heller ikke på noe tidspunkt i kontakt med person-sensitive opplysninger. Det er kun forsøksansvarlig og student som har tilgang til rådata.

Totalt antall registrerte i prosjektet

1-99

Tillatelser

Skal du innhente følgende godkjenninger eller tillatelser for prosjektet?

- Annen godkjenning

Annen godkjenning
Godkjenning av prosjektskisse for masteroppgave ved institutt

Behandling

Hvor behandles opplysningene?

Mobile enheter tilhørende behandlingsansvarlig institusjon

Maskinvare tilhørende behandlingsansvarlig institusjon

Fysisk isolert maskinvare tilhørende behandlingsansvarlig institusjon

Private enheter

Hvem behandler/har tilgang til opplysningene?

- Prosjektansvarlig
- Student (studentprosjekt)

Tilgjengeliggjøres opplysningene utenfor EU/EØS til en tredjestat eller internasjonal organisasjon?

Nei

Sikkerhet

Oppbevares personopplysningene atskilt fra øvrige data (kodenøkkel)?

Ja

Hvilke tekniske og fysiske tiltak sikrer personopplysningene?

- Opplysningene anonymiseres
- Adgangsbegrensning
- Andre sikkerhetstiltak

Hvilke

Dokumenter og isolerte enheter låses inn i kodet safe på institusjonens område

Varighet

Prosjektperiode

31.01.2019 - 01.09.2020

Skal data med personopplysninger oppbevares utover prosjektperioden?

Nei, data vil bli oppbevart uten personopplysninger (anonymisering)

Hvilke anonymiseringstiltak vil bli foretatt?

Annet

Data vil kun navngis i form av tall og vil fra det øyeblikket deltaker har gjenomført forsøket være anonyme.

Vil de registrerte kunne identifiseres (direkte eller indirekte) i oppgave/avhandling/øvrige publikasjoner fra prosjektet?

Nei

Tilleggsopplysninger

Appendix B

Vil du delta i dette forskningsprosjektet om stimulusekvivalens?

Dette skrivet er en forespørsel til deg om å delta i et forsknings prosjekt innen feltet lærings psykologi. I dette skrivet vil vi gi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Dette er ett forskningsprosjekt innen fagfeltet læringspsykologi hvor formålet er å undersøke forhold omkring stimulusekvivalens. Hensikten er å undersøke hvilke variabler som påvirker stimulusekvivalens. Det å oppnå kunnskap om hvilke variabler som påvirker stimulusekvivalens kan være avgjørende for bedre å forstå de fenomener man til daglig kaller hukommelse, problemløsning, språk og symbolbruk. Prosjektet er en mastergrads studie innen Læring i Komplekse Systemer ved Oslo Met.

Av hensyn til studiens resultater vil jeg på det nåværende tidspunktet ikke kunne gi noen nærmere informasjon om stimulusekvivalens begrepet, men det vil foretas en gjennomgang av begreper og data, med mulighet for å stille spørsmål, umiddelbart etter gjennomføring.

Ansvarlig for prosjektet
Prosjektet gjennomføres i regi av Oslo Met. Professor Erik Arntzen er ansatt ved institutt for atferdsvitenskap og er den ansvarlige for prosjektet. Han kommer til å være delaktig både i planlegging og gjennomføring av prosjektet. Om deltakere skulle ha spørsmål kan han kontaktes på telefon 67 23 64 42.

Renate Follerås er mastergradsstudent ved Oslo Met og vil gjennomføre forsøkene under veiledning av Erik Arntzen.

Hvorfor blir du forespurt om å delta?
Utvalg av deltagere blir valgt gjennom bekjentskapskrets eller rekruttering skjer gjennom tilhørighet til institusjonen Oslo Met.

Hva innebærer det for deg å delta?
Dersom du velger å delta i eksperimentet innebærer dette at du gjennomgår en sesjon foran PC hvor du presenteres for ulike stimuli. Du vil bli gitt instruksjoner enten av forsøksleder eller på datamaskin om hva du skal gjøre. Forsøkets varighet er om lag 2 timer.

Forsøkene vil ikke på noen som helst måte påføre deltakere noe som helst form for ubehag. Forsøkene vil foregå i en rolig atmosfære og personen som utfører forsøkene vil være spesielt trent til dette.

Det er frivillig å delta
Deltakelse i prosjektet er frivillig. Hvis du velger å delta kan du når som helst avslutte mens forsøket pågår, dine data vil da anonymiseres og persondata destrueres. Etter forsøket er gjennomført vil dine data være anonymisert.

Personvern
Data fra forsøket vil være totalt anonymisert fra du forlater lokalet etter endt forsøk ved at navnet ditt erstattes med en kode. Når data senere brukes i artikler eller fremlegg vil de være totalt anonyme.

Dine personlige opplysninger (underskrift på dette skivet og ditt navn) vil oppbevares slik at de ikke på noen som helst måte på noe som helst tidspunkt kan kobles sammen med de data som er innhentet og vil destrueres ved forsøkets slutt. Dersom du velger å ikke delta i forsøket vil navnet ditt umiddelbart fjernes fra listen over mulige deltagere.

Både data fra forsøket og dine personlige opplysninger vil oppbevares slik at det kun er tilgjengelige for medlemmer av EBSCoHuB lab gruppe ved Oslo Met.

Hva skjer med data etter endt forsøk?
Når forsøket er ferdig, senest 01.06.2020, vil de persondata som er innhentet om deg på papir som navn og underskrift destrueres. De resterende data vil eksistere i anonymisert form og vil ikke kunne spores tilbake til deg.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet har du rett til:
- Innsyn i hvilke personopplysninger som er registrert om deg
- Å få rettet personopplysninger om deg
- Å få slettet personopplysninger om deg
- Å få utlevert en kopi av dine personopplysninger
- Å sende en klage til personvernombudet eller datatilsynet om behandling av dine personopplysninger

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Oslo Met har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Har du spørsmål om studien eller ønsker du å benytte deg av dine rettigheter, ta kontakt med prosjektansvarlig Erik Arntzen ved Oslo Met på telefon: 67 23 64 42

Vårt personvernombud: Ingrid S. Jacobsen, epost: personvernombud@oslomet.no

NSD: på epost: personvernombudet@nsd.no eller telefon: 55 58 21 17

Med vennlig hilsen

Prosjektansvarlig:	Student:
Erik Arntzen	*Renate Follerås*

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Samtykkeerklæring

Jeg har lest og forstått denne informasjonen og fått utlevert en egen kopi av denne.

Jeg har fått svar på eventuelle spørsmål jeg måtte ha.

Jeg er innforstått med at dersom jeg på noe som helst tidspunkt har spørsmål vedrørende prosjektet kan jeg kontakte Dr. Erik Arntzen på telefon 67 23 64 42

Jeg samtykker til:

- Å delta i forsøket på PC
- At mine personopplysninger oppbevares til prosjektslutt
- At mine data fra forsøket behandles, publiseres og lagres anonymt

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(Deltakers signatur/ Dato)

Appendix C

Oppsummering/tiltaksplan på grunnlag av risikovurderingen:

I risikovurderingen (forrige ark), beskrev du ulike hendelser, risikonivåer og eksisterende samt nye tiltak knyttet til disse.

I denne oppsummeringen/tiltaksplanen ønsker vi at du beskriver nærmere hvordan du har prioritert de valgene du har gjort knyttet til å behandle data i prosjektet.

Skriv gjerne kort om hvilke vurderinger du har gjort for tiltakene du har valgt, og hvilke risikoreduserende tiltak som skal gjennomføres i den forbindelse.

Det er viktig at du tar med alle handlingstrinn, fra innsamling til endelig avslutning. Inkluder kort plan og tidsramme for tiltak som ikke allerede er gjennomført. (Tenk deg også inn i en situasjon der du skal overta prosjektrollen fra noen andre, og hvilken informasjon det er viktig at du kjenner til når det gjelder risikoanalyse).

I denne type forskning, skal det ikke eksistere noen form for kobling mellom forsøkspersonene og resultatfilene. Resultatfilene får et nummer (eks. 13423) Disse tallene kan aldri spores til forsøkspersonen, dersom dette ikke konkret gjøres av forsker. Resultatfilene inneholder ingen personsensitiv informasjon, (eks. Sykdom, sivilstatus, etc.). Resultatfilene inneholder kun bokstaver og tall som representerer oppgaver forsøkspersoner har gjort på en datamaskin. De eneste opplysningene som kan identifisere deltakerne er signerte skjema for samtykkeerklæring. Disse oppbevares separat fra data i en safe og destrueres ved prosjektets slutt. Valgene er prioritert utfra risikosituasjoner som kan oppstå ved presentasjon, databehandling og datainnsamling. Vurderingene er basert på tidligere oppståtte situasjoner, og sannsynlighet for at hendelser inntreffer. Etter utført risikoanalyse ser det per i dag ikke ut til at det bør endres på de tiltakene vi allerede har iverksatt for å bevare konfidensialitet, integritet og tilgjengelighet under dette forsøket.

Note. Appendix C provides an overview of the results and conclusions that were drawn from the results of the risk and vulnerability assessment conducted prior to the experiment.