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Reexamining nodality in equivalence classes

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Equivalence classes are defined according to the substitutability, or functional similarity, of the stimuli within a stimulus class. Several studies have demonstrated that the degree of functional similarity between stimuli in a class is dependent, in part, upon the number of nodes (intervening stimuli) between the stimuli. Higher nodal number is related to lower functional similarity. This effect is referred to as "nodality." There are three key factors that have not been simultaneously controlled for in the relevant studies: priming effects, reinforcement during training, and multiple stimulus functions of stimuli (sample, comparison, or both). In the present experiment, controlling for these factors, two 6-member, 4-node equivalence classes were established, and a within-class preference assessment was used to evaluate nodality. Of 12 participants, five achieved criterion accuracy (90%) during testing. These participants demonstrated nodality, showing preference for stimuli that were nodally proximal to a sample in the preference test. When distal comparisons were chosen, participants took longer, on average, to make the selection compared to selections of proximal stimuli. These findings are consistent with earlier studies demonstrating nodality, which suggests that nodality is a robust phenomenon and not an artifact of the factors that were controlled for in the present study.

Key words: preference assessment, relatedness, relational responding, stimulus control, stimulus equivalence

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Stimulus equivalence is typically investigated using conditional discrimination procedures in which specific baseline relations among stimuli are trained, and derivation of untrained relations is tested. For example, in the presence of stimulus A1, selection of B1 is reinforced, and in the presence of B1, selection of C1 is reinforced. Selections of stimuli that do not belong to the same class as A1, such as B2 or C2, are not reinforced. After training such baseline relations, tests are used to verify the emergence of derived, or untrained, stimulus–stimulus relations, such as symmetry relations (e.g., selection of A1 in the presence of B1), transitive relations (e.g., selection of C1 in the presence of A1), and equivalence relations (e.g., selection of A1 in the presence of C1). Consistent selection of comparison stimuli from the same class (e.g., selection of A1 in the presence of C1), even though that specific selection was never reinforced in the presence of that sample, provides evidence for the successful formation of an equivalence class (Moss-Lourenco & Fields, 2011). Stimuli in an equivalence class are considered to be functionally interchangeable, or "equivalent" (Doran & Fields, 2012; Sidman, 1994, p. 447-448).

However, equivalence may not be the most appropriate descriptor for the relationship among these stimuli. Depending on factors such as class size, training directionality, and nodal number, one stimulus in an equivalence class may be more, or less, functionally similar to another stimulus in the same class (Albright et al. 2019, Bortoloti & de Rose, 2011; Fields, 2016; Fields & Moss, 2007; Moss-Lourenco & Fields, 2011). Nodal number refers to the number of stimuli (hereafter referred to as nodes) between two given stimuli in the baseline training relations of an equivalence class. For example, if the baseline relations A-B, B-C, and C-D are trained for the class A-B-C-D, then A is separated from B by zero nodes, A is separated from C by one node (B is an intermediate stimulus), and A is separated from D by two nodes (B and C are intermediate stimuli). Stimuli in an equivalence class that are not nodes are referred to

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as "singles" (e.g., A and D in the previous example).

Studies on nodality have indicated an inverse relation between nodal number and functionally similarity (i.e., relatedness), where the functional similarity between two stimuli in an equivalence class decreases as the nodal number increases. This phenomenon has been demonstrated in a variety of tests, including latency, transfer of function, and within-class preference assessments (Albright et al. 2019; Bortoloti & de Rose, 2011; Doran & Fields, 2012; Fields, 2016; Fields et al. 1990; Fields & Moss, 2007; Moss-Lourenco & Fields, 2011). A within-class preference assessment involves presenting one member of an equivalence class as a sample and two or more comparison stimuli from the same equivalence class from which the participant can select. Using within-class preference assessments, Albright et al. (2019), Doran and Fields (2012), and Moss-Lourenco and Fields (2011) found that participants showed preference consistent with nodality; in most trials, they selected the comparison stimulus with the fewest nodes between the comparison and the sample stimulus. Demonstration of nodality does not mean the relevant stimuli are not participating in an equivalence class. Postpreference equivalence tests administered in three studies (Albright et al., 2019; Doran & Fields, 2012; Moss-Lourenco & Fields, 2011) demonstrated the intactness of the originally formed equivalence classes immediately after participants completed a within-class preference assessment.

Although nodality has been consistently demonstrated in previous research, a few methodological issues remain to be addressed. First, in three studies, stimuli that served as singles (i.e., non-nodes), were included in the within-class preference assessment (Albright et al. 2019; Doran & Fields, 2012; Moss-Lourenco & Fields, 2011). It is possible that nodal or non-nodal (single) status of stimuli in an equivalence class influences the outcomes of tests for nodality. Nodes have two functions during training as they serve as both sample and comparison stimuli; singles have only one function (either sample or comparison). For example, one of the preference probes in Moss-Lourenco and Fields (2011) was notated as EDA (the first letter, E, is the sample; the next two letters, D and A, are the comparison stimuli from which the participant could choose; note, we use this same notation herein). Stimulus A was a single (it was the first stimulus in the baseline training arrangement for the equivalence class); during training, Stimulus A only appeared as a sample. In the EDA probe, however, Stimulus A appeared as a comparison stimulus. The participants may have been more likely to reject A simply because selection of A as a comparison stimulus had never been reinforced. Not only do singles have more restricted functions during training, but they also appear less frequently than nodes during training. Increasing the equivalence class size and omitting singles during preference testing (only testing with nodes) would resolve this issue because participants would not encounter stimuli during the preference assessment that only had one function during training.

A second issue is that of potential "priming effects" during the within-class preference assessment phase. In three studies, the first probe pairs that were presented in the within-class preference assessment procedure were pairs with the most extreme nodal differences (Doran & Fields, 2012; Moss-Lourenco & Fields, 2011). For example, in the equivalence class A-B-C-D, ABD and DBA probes were presented first in the preference testing phase. Exposure to these extreme probes may have conditioned participants to look for the "closest" comparison stimuli in the remaining preference test probes. It is possible that initial exposure to these extreme comparisons at the beginning of testing influenced the participants' later selections and contributed to nodality-consistent outcomes. The "closest" comparison stimuli in these extreme probes were those with 0-node baseline relations, selection of which were reinforced during training in the presence of the sample stimuli. Although feedback was not provided in these trials, participants attempting to produce a "correct" answer may have been more likely to learn to select the nodally proximal stimulus as a result of this initial exposure to the more easily discriminable nodal differences in the comparison stimuli: "closest" and previously reinforced compared to "farthest" and not previously reinforced. Albright et al. (2019) did the opposite in their study, presenting the least extreme nodal difference probe pairs first in the preference testing phase. They also suggested that the order of trial presentation (least extreme probes first) may have contributed to the nodality effects observed in their study. They recommended that randomization of the probe presentation order would help to address this issue.

A third issue is that of unequal reinforcement resulting from the structure of the trials presented in the training phase, as discussed by Imam (2001; 2006). With sequential training, baseline relations are trained and tested in a cumulative fashion. For example, researchers might train A-B, then test for the derivation of the B-A relation before expanding the training to include both A-B and B-C, followed by testing for additional derived relations. With this method of training, the first baseline relation selections are reinforced more frequently than later baseline relation selections. The simultaneous protocol is an alternative to the sequential protocol that reduces differences in the amount of reinforcement associated with individual relations within a class and has been used in a few studies (Albright et al., 2019; Doran & Fields, 2012; Moss-Lourenco & Fields, 2011). With the simultaneous protocol, the participant learns all baseline training relations prior to any testing, and the number of exposures to each relation can be held constant. However, with large classes, this protocol is extremely difficult and yields a low proportion of participants who achieve criterion responding (Doran & Fields, 2012).

In the present study, we addressed all the aforementioned issues. While some studies have addressed one or more of these issues, none have addressed all at once. The issue of singles being presented in tests for nodality was addressed by using six-member equivalence classes and excluding the two singles in the classes when testing for nodality. The "priming effects" issue was addressed by randomizing the order in which probes were presented during nodality tests. The issue of unequal reinforcement of different baseline relation selections was addressed by using a simultaneous protocol. Because large classes typically produce low yields of equivalence class formation using the simultaneous protocol (Doran & Fields, 2012), we used the smallest equivalence class size that would still allow for an evaluation of nodality, taking the "singles" issue into account (six-member, four-node classes).

Method

Participants

A total of 12 participants took part in the experiment. Of the 12 participants, two were male and 10 were female. All participants were enrolled in psychology courses at the University of Waikato. This study was approved by the Human Research Ethics Committee of the Faculty of Arts and Social Sciences (HREC2019#13).

At the beginning of the experiment, participants read an information sheet that gave them general information about stimulus equivalence and what the experiment would entail. Participants were given up to $20 (NZD) in vouchers for a local department store for participation. The vouchers for each participant were split into two $10 vouchers; one $10 voucher was given for initial participation in the experiment, and another $10 voucher was given when either the program was completed or when participation in the experiment exceeded 2 hr.

Apparatus and Setting

The experiment was conducted over a 2-hr session in a standard university computer lab; a room of approximately 8 x 8 m. The lab consisted of 24 computers arranged in clusters of four. The application was run on a Dell Intel Core i5 seventh generation computer with a 20-in display monitor and a screen resolution of 1920 x 1080 pixels. The operating system was Windows 10. The computer ran a custom application written in Visual Basic, programmed to deliver the matching to sample protocol. The application displayed the sample and comparison stimuli on the monitor. The sample stimulus appeared in the top-middle of the screen. The comparison stimuli appeared below the sample stimulus, an equal distance from each other; the exact locations of the comparison stimuli depended on whether there were two or three comparisons. On trials with two comparison stimuli, the stimuli appeared at the bottom on either side of the sample stimulus (one to the left, and one to the right of the sample); on trials with three comparison stimuli, two were on either side of the sample stimulus, and a third comparison was directly underneath the sample stimulus (see Fig. 1). There were no delays between the appearance of the sample stimuli and the comparison stimuli; all stimuli appeared at the same time in a trial, similar to the trial presentation in McPheters et al. (2021).

Stimuli

The stimuli used in the familiarization phase were common pictures—the sample picture was always that of a king of hearts playing card. The comparison stimuli were pictures of a camel, an apple, and a queen of hearts playing card.

Eighteen symbols were used for the rest of the phases (simultaneous protocol and preference testing, see Fig. 2). The symbols were chosen based on surveys of 10 students from the University of Waikato. These students did not participate in the experiment proper and were not exclusively psychology students. They were presented with a table of 30 symbols and were instructed to circle any symbol that they felt was familiar. Through this process, familiar symbols were eliminated. Symbols were eliminated if any student circled it. Following this screening process, 18 symbols were chosen from the remaining non-eliminated symbols to form three groups of six symbols each. Of these three groups of symbols, two groups served as the two equivalence classes to be trained, while the third group of symbols served as the distractor stimuli during training and testing. Distractor stimuli were used because, as Sidman (2000) pointed out, having only two comparisons can be problematic: It would be impossible to tell whether participants were making their choice based on selection (of the correct stimulus) or rejection (of the incorrect comparison). Introducing a third comparison stimulus as an option (from the third group of stimuli that served as distractors) would result in participants being unable to simply select the only remaining option after rejecting the incorrect stimulus.

All stimuli were presented in red on a white background that filled the entire 20-in monitor. Some research suggests that certain colors (including red) are better suited for capturing and maintaining attention, even in students with learning disabilities (Belfiore et al. 1996; Gaddy, 1996). The stimuli were size 60 font.

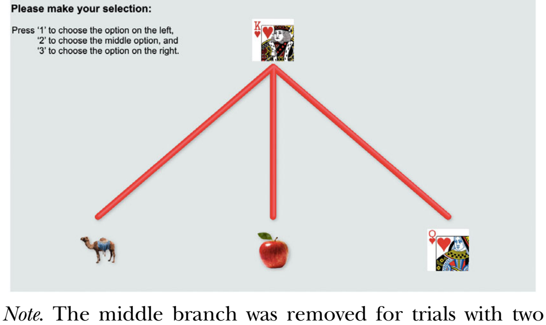
Responses consisted of specific key presses on a standard keyboard. The "1", "2", and "3" keys (on the number row or the number keypad) were used to select left, middle, and right options, respectively. To advance to the next trial within a block of trials, a "W" key press was required to advance to the next trial when the screen showed the feedback "WRONG", the "R" key when the feedback screen showed "RIGHT", and the "E" key when no feedback was given. A spacebar key press was required to progress to the next block of trials or to the next phase of the experiment. Key press requirements were implemented to encourage and confirm participant engagement with the task. A separate custom program, also written in Visual Basic, ran concurrently with the matching-to-sample program and recorded each key press for the participant and the response latency, the choice made, response accuracy, trial number and type, and the current phase.

Trial Format

All trials were presented in a matching to sample (MTS) format. Training and testing trials for stimulus equivalence consisted of a sample and three comparisons, of which one was

Figure 1

Example Layout of the Sample and Comparison Stimuli



Note. The middle branch was removed for trials with two comparison stimuli.

Figure 2

The Three Groups of Symbols Used to Form the Two Equivalence Classes

Class 1	A1	B1	C1	D1	E1	F1
Symbol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Class 2	A2	B2	C2	D2	E2	F2
Symbol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Distractor Set	A3	B3	C3	D3	E3	F3
Symbol	§	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

the positive (i.e., correct) comparison, with the others being stimuli from different classes.

In preference assessment trials, which only consisted of a sample and two comparisons, both comparisons came from the same class. The location of the positive comparison was randomized (left or right), with the only stipulation being that it appeared an equal number of times in each of the three locations.

When a trial was presented, a sample stimulus was displayed in the top center of the screen, along with the three comparison stimuli below it, after which specific keys could be pressed to choose a location ("1" key for left, "2" key for middle, "3" for right). The total number of trials in each phase was divided into blocks of trials. This was done to either manage participant fatigue when there were many trials (at the end of a block the program prompted participants to take a break) or to signal a change in feedback level. Pressing the spacebar key would deliver the next block of trials or start the next phase. During trials with feedback, the programmed consequence was dependent on whether the selection was correct (the screen displayed "RIGHT") or not ("WRONG"). The intertrial interval was self-paced; participants pressed specific keys (e.g., "R" when feedback was correct; "W" when incorrect; spacebar when no feedback was given) to advance to the next trial.

Procedure

Phase 1 – Instructions and Familiarization

At the beginning of the experiment, participants saw these instructions, adapted from those used by Moss-Lourenco & Fields (2011), on the screen:

> Thank you for volunteering to participate in this experiment. PLEASE DO NOT TOUCH ANY OF THE KEYS ON THE KEYBOARD YET! In this experiment you will be presented with many trials. Each trial contains three or four CUES. These will be familiar and unfamiliar picture images. YOUR TASK IS TO DISCOVER HOW TO RESPOND CORRECTLY TO THE CUES. Initially, there will also be INSTRUCTIONS that tell you how to respond to the cues, and LABELS that will help you to identify the cues on the screen. The labels and the instructions that tell you which KEYS to press will slowly disappear. Your task will be to RESPOND CORRECTLY to the CUES and the INSTRUCTIONS by pressing certain keys on the computer's keyboard. The experiment is conducted in phases. When each phase ends, the screen will sometimes tell you how you did. If you want to take a break at any time, please call the experimenter. PRESS THE SPACEBAR TO CONTINUE.

After pressing the spacebar, participants completed prompted familiarization trials consisting of four pictures (one sample, three comparisons,) two of which were semantically related (e.g., KING, QUEEN, APPLE and CAMEL). The first three trials were prompted (i.e., prompting the behavior required to complete a trial), and removal of the prompts depended on whether there was 100% correct responding (if not the trials kept appearing with prompts until three in a row were correct). Once there were three consecutive correct responses to prompted trials, the next three trials were unprompted. Phase 1 ended when there were three consecutive correct responses to unprompted trials.

Phase 2 – Baseline Relations Training

In this phase, the simultaneous protocol was used to train two 6-member equivalence classes (with four nodes). In this protocol, the baseline relations for all classes were presented in one block of trials, with 100% feedback. The trials were presented in random order. There were five baseline relations (AB, BC, CD, DE, and EF) for each of the two classes that were trained. The classes were structured linearly (i.e., A→B→C→D→E→F). Trials consisted of presenting a sample (e.g., 'A1' from the A1-B1 relation) and the correct comparison, along with the two corresponding comparisons from the other class and the distractor set (e.g., B1, B2, and B3 as comparisons). This was presented three times over the course of the training block, so that the correct comparison ('B1' in the case of the example) appeared in all the three locations. There were 10 total baseline relations to train (five from each of classes 1 and 2), each presented three times, totalling 30 trials in a single training block. At the start of training trials, participants received feedback for selection responses on all trials in a block; this continued until they achieved 100% accuracy for the block on this level of feedback. Once this was achieved, the next block had the same number of trials, but feedback was only provided for 50% of the trials. Once 80% accuracy was achieved at this level, the next block featured no feedback. Low participant yield has been an issue with the simultaneous protocol in previous research. For example, Doran & Fields (2012) applied a 96% criterion in their first experiment and only 17% percent of participants met criterion. Therefore, an 80% criterion was chosen for this study, as this increased the likelihood that participants would meet criterion. Achieving 80% correct on the no feedback level enabled participants to progress to Phase 3. If criterion was not met on a block with reduced feedback for three consecutive blocks, the next block provided the previous level of feedback (increased feedback). If participants were still on the training level when the 2-hr limit was reached, the participant was excused from the study. Blocks ended with the message, 'press spacebar to start next block'.

Phase 3 – Derived Relations Testing

Once progress was successfully made through training by achieving criterion accuracy (80%) at the final feedback level of baseline training, a test was run to evaluate the trained and untrained relations in the two trained classes. Each possible relation among all stimuli in each stimulus class (see Appendix A) was presented three times (to have the positive comparison appear equally at each location). Each trial had items from the distractor set appearing as distractor options. The 180 test trials were divided into six blocks of 30 trials per block. Within each block, the trials were presented in a random order, and the set of six blocks of 30 trials (180 trials total) was repeated up to three times, or until an accuracy of 90% was achieved in one set of six blocks, after which the participant progressed to the preference testing phase. If the 2-hr limit was reached before participants could achieve the 90% criterion, they were excused from the study.

Table 1

All Possible Preference Probe Combinations for the Trained Equivalence Classes

Sample	Possible Probe Combinations		
B	BCD	BCE	BDE
C	CBD	CBE	CDE
D	DBC	DBE	DCE
E	EBC	EBD	ECD

Note. Each probe type was presented twice for both equivalence classes (total of four presentations for each probe type; e.g., two B1C1D1 and two B2C2D2).

Phase 4 – Within-class Preference Assessment

Once Phase 3 was completed, a within-class preference assessment was conducted. This test also used a matching-to-sample procedure, but the sample and the two comparisons in each trial were from the same stimulus class. One comparison was nodally proximal to the sample, while the other was nodally distal.

The preference tests never included the stimuli in the two trained classes that were singles (A1, F1, A2, F2). The four nodes for both classes (B1, C1, D1, E1, and B2, C2, D2, F2) were presented in trials without feedback (e.g., in a BCD probe, B was the sample stimulus, and C and D were comparisons from the same class). All combinations that were possible with the four nodes, 12 different combinations for each of the trained equivalence classes, were presented, giving a total of 48 trials. Table 1 shows all trial combinations that were presented in the preference assessment phase.

Results

Of the 12 participants, two failed to meet the training phase criterion, and five failed to meet the testing phase criterion (see Table 2). The five remaining participants required only one attempt to meet criterion at the 50%-feedback and no-feedback levels of baseline training. Four of the five participants that made it to the preference testing phase only required a single exposure to the testing phase

Table 2

The Number of Exposures to each Phase of the Simultaneous Protocol and Testing of Derived Relations, and Completion of Preference Testing for Individual Participants

Participants	Simultaneous Training: Feedback Levels			Testing of Derived Relations	Preference Testing Completed
	100%	50%	0%		
1	10	1	1	1	Yes
2	4	1	1	1	Yes
3	29	49	0	0	No
4	44	55	0	0	No
5	9	1	1	3	No
6	10	1	1	3	No
7	12	1	1	2	Yes
8	4	1	1	1	Yes
9	3	1	1	3	No
10	29	4	1	3	No
11	6	1	1	1	Yes
12	46	1	1	3	No

to achieve the 90% accuracy criterion, while one participant required two exposures to achieve the 90% accuracy criterion. All five completed the final preference test.

Figure 3 shows the percentage of trials in the preference testing phase where the participants selected the comparison choice that was nodally proximal to the sample stimulus. The percentage of nodally proximal comparison stimulus selections was calculated for all the preference probes, with the exception of the CDB and DEC probes which have equal nodal number between both comparisons and the sample stimulus.

As Figure 3 shows, in most trials, participants tended to show either complete (selecting the nodally proximal comparison stimulus 100% of time; Participant 11) or majority (60%, 82.5%, 80%, and 70% for Participants 1, 2, 7, and 8, respectively) preference for the nodally proximal comparison stimuli. On average, the five participants who completed the within-class preference assessment selected the nodally proximal comparison stimuli on 78.5% of probe trials. Some probes involved preferences between one baseline relation and an untrained relation. The unequal training history, rather than nodality, could be responsible for selection of the nodally proximal stimulus in these instances. Removing all probes with a baseline relation (BCD; BCE; CDE; DEB) showed an average preference of 77.5% for the nodally proximal comparison.

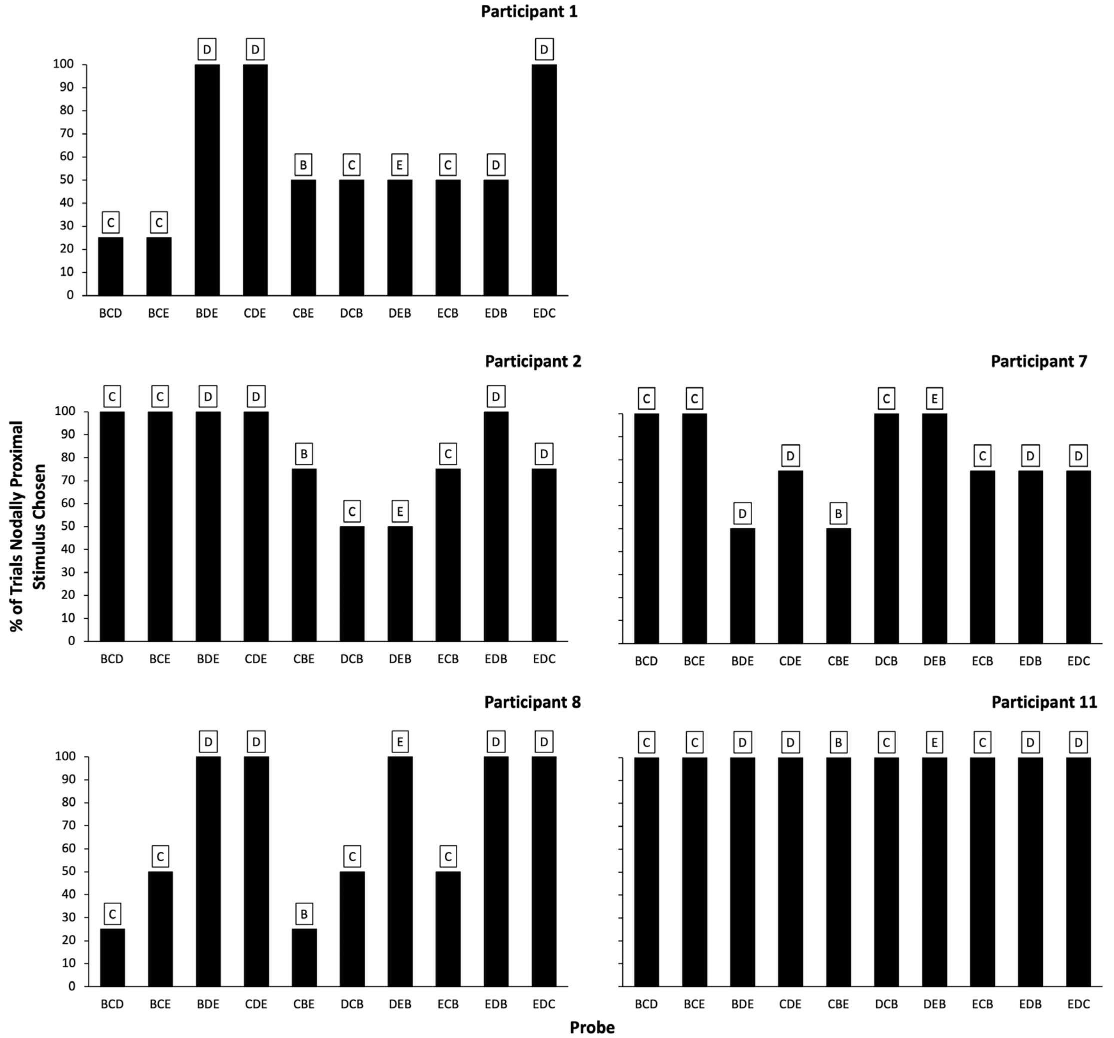
The average time taken for participants to select the nodally distal and nodally proximal comparison stimuli on probe trials is shown in Table 3. Only data from probe trial variants in which participants selected the nodally distal comparison stimulus at least once could be included in this analysis. Because Participant 11 always selected the nodally proximal stimulus, this analysis could not be performed for this participant.

Participants took longer, on average, to select the nodally distal comparison stimulus for a given probe trial variant. The first trial time was removed from this analysis due to all participants taking an abnormally long time to complete the trial compared to the other trials (following the experiment, the participants explained that they were still thinking about the instructions while Trial 1 was on the screen). Participant 11 never made the nodally distal comparison stimulus selection in any of the probe trials that contained nodally proximal versus nodally distal comparisons, always selecting the nodally proximal comparison stimuli. Although Participant 11 never selected nodally distal comparison stimuli, Participant 11 took much longer to make the proximal choice, on average, than any other participant who completed the preference test (the average time taken by Participant 11 to select the nodally proximal stimulus in each trial was 14.97 s, $SD = 14.61$).

Response latency as a function of nodal number (i.e., the number of nodes between

Figure 3

Percentage of Within-Class Assessment Trials in which the Nodally Proximal Comparison was Selected



Note. The nodally proximal choice is indicated in the box above the bars. Probes are identified as follows: first letter = sample stimulus, second letter = proximal comparison stimulus, and third letter = distal comparison stimulus.

the sample and comparison stimuli) during the derived relations testing phase was analyzed using a linear mixed model (LMM) test with nodal number as a fixed factor and participant as the random factor (see Fig. 4). The LMM showed a significant effect of nodal number, $F(4.31) = 17.13$, $p = .015$, and a significant participant effect, $F(9.29) = 36.91$, $p < .001$. Separating the nodal number data into forward (i.e., only baseline and transitive relations) and backward (i.e., only symmetry and equivalence relations) direction, relative to the baseline relations, yielded similar results forward (nodal number effects: $F[3.58] = 20.30$, $p = .029$; participant effect: $F[7.15] = 40.50$, $p = .002$) and backward (nodal number effects: $F[5.21] = 11.76$, $p = .007$; participant effect: $F[17.62] = 39.78$, $p < .001$).

Figure 5 shows the percentage of times each participant selected the correct response at

Table 3

Average Time Taken to Make Nodally Proximal (NP) and Nodally Distal (ND) Choices in the Preference Testing Phase, and Standard Deviations (SD)

	Average response latency (s)			
Participant	NP	*SD*	ND	*SD*
1	2.34	0.77	3.09	1.39
2	1.55	10.37	6.64	5.84
7	2.32	0.66	3.23	2.37
8	2.94	0.79	4.24	1.95

each nodal number during the derived relations testing phase. The same LMM test that was applied to response latency was also used to evaluate the percentage of trials on which the correct comparison was chosen as a function of nodal number. This test evaluated correct responses as a function of nodal number, irrespective of the direction of the relation (e.g., baseline and symmetry relations would be included together for analysis because they were both 0-node relations). There was no significant effect of nodal number ($F[0.94] = 39.06$, $p = .467$), but there was a significant participant effect ($F[7.76] = 323.06$, $p = .001$).

In the preference testing phase, two probes (CDB, DEC) had comparison stimuli that were nodally equal (0 nodal number from the sample). The only difference is that one was a trained baseline relation while the other was an untrained symmetry relation. Participant 11 selected baseline over symmetry 100% of the time, so their data had to be omitted for this analysis. Evaluating the responses to the baseline versus symmetry trials (CDB and DEC) for the four participants revealed that, overall, the percentage of times they selected the baseline relation stimulus was similar to the number of times they selected the symmetry relation stimulus (53.13% baseline selection; 46.87% symmetry selection). A Fisher's exact test indicated that there was no statistically significant association between baseline and symmetry choices for these trials (two-tailed $p = .10$).

Discussion

In this investigation of nodality, we controlled for three factors that had not been simultaneously controlled for in previous nodality studies. Priming effects were controlled for by presenting the preference trials randomly rather than presenting extreme difference tests first. Different stimulus functions associated with "singles" (those stimuli that served only as a sample or comparison stimulus during training) were controlled for by omitting singles from preference (i.e., nodality) tests. Reinforcement frequency was controlled by using the simultaneous protocol, where all training trials are presented in one block in random

Figure 4

Participants' Average Response Latency to Select Stimulus at Each Nodal Number During Derived Relations Testing Phase

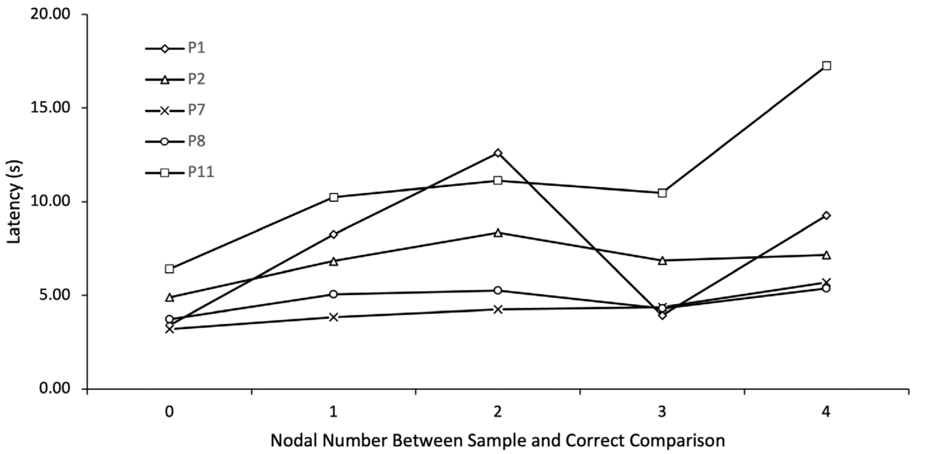
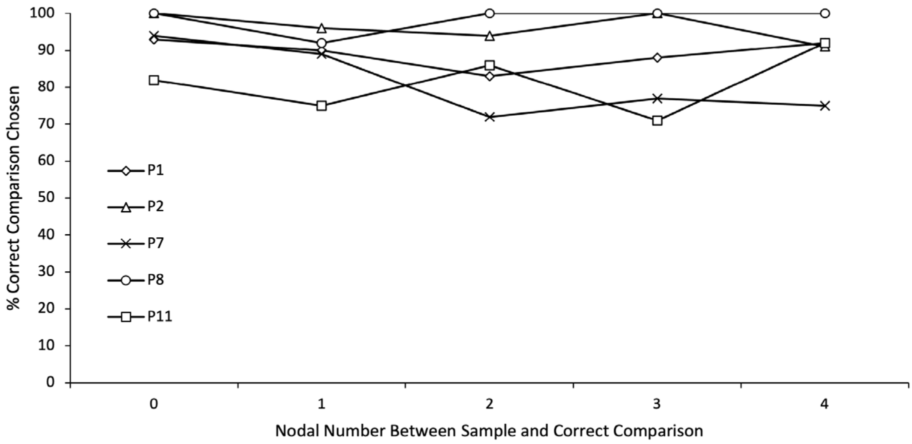


Figure 5

Participants' Percentage of Correct Selections at Each Nodal Number During Derived Relations Testing Phase



order, therefore equalizing the number of reinforcement opportunities associated with each stimulus relation. Previous studies controlled for a combination of these issues, but none controlled for all of them simultaneously. With all of these issues controlled for simultaneously in the present study, there was still strong evidence for nodality within trained equivalence classes from the five participants who met training criteria.

The participants who completed the preference assessment demonstrated a preference for nodally proximal stimuli in the within-class preference assessment phase and took longer on average to select nodally distal stimuli compared to nodally proximal stimuli. Participant 11 demonstrated complete preference for nodally proximal stimuli, while participants 1, 2, 7, and 8, despite making some nodally distal selections, selected nodally proximal choices more frequently. There were several preference probes (BCD; BCE; CDE; DEB) that had a comparison that previously participated in a baseline relation with the sample (e.g., in the BCD probe, the C comparison choice is a trained baseline relation to the sample B). Removing these probes from the analysis showed only a 1% decrease (78.5% to 77.5%) in average preference towards nodally proximal stimuli. The participants who did occasionally make distal selections (participants 1, 2, 7, and 8) took longer to make distal selections than they took to make proximal selections, on average. This finding aligns with findings from previous studies that have explored nodality through response latency (Bentall et al. 1999; Spencer & Chase, 1996; Wang et al., 2011). The results of this experiment appear to support the findings from other studies on nodality, specifically the contention that all stimuli in an equivalence class are equal in terms of being substitutable for each other but, in certain contexts, they are also unequally related.

Moss-Lourenco and Fields (2011) and Doran and Fields (2012) have proposed that there are at least two key factors influencing within-class differences in relational strength—nodal number and relation type. In this study, two of the preference probes (CDB and DEC) were 0-node probes that only differed in relation type (baseline and symmetry). The participants in this experiment showed a similar preference for both baseline and symmetry relations (53.13% baseline, 46.87% symmetry). In this experiment, it does not appear that this relation type (baseline or symmetry) had a strong effect on preference. Future research exploring the relative influence that nodality and relational type exert together on an equivalence class could provide a better understanding of these two parameters and how they interact. Albright et al. (2019) found that when nodal number is held constant, the "simpler" relation (transitive over equivalence) is almost always preferred. When the nodal number of the "simpler" relation is increased while the nodal number of the more complex relation is held constant (1-node equivalence relation vs. 1- to 5-node transitive relation), the preference depends on the nodal number (participants switched preference to the equivalence relation when the transitive relation had a nodal number of 2). In the present study, participants were not presented with both transitive and equivalence preference assessment probes with equal nodal number (other than baseline and symmetry probes, discussed above). A minimum of five relata would be required to do additional comparisons holding nodal number constant, but there were only four relata in each class after removal of the singles.

The simultaneous protocol (used in this study) minimizes the unequal reinforcement of trained baseline relations by simultaneously presenting all baseline training trials in a single block of trials. However, with the simultaneous training protocol, participants do not demonstrate equivalence as readily as they do when they are trained using a sequential training protocol, in which each baseline relation is trained in a sequential and additive fashion (Fields et al. 1997). In the present study, only 5 of 12 participants (41.67%) met the completion criteria for the within-class preference assessment phase. This low yield is consistent with some studies that used the simultaneous protocol, such as Doran and Fields (2012) in which 1 of 6 participants met completion criteria (16.67%) in one experiment, and 5 of 13 were successful (38.46%) in another experiment. Exclusion of participants based on performance criteria reduces the number of participants who contribute data to nodality tests and may produce bias in the sample of participants who produce the data in tests for nodality. Low participant yield is a limitation that could be addressed in future research. Some methods have been developed and tested that appear to increase participant yield in stimulus equivalence studies. For example, adding a unique "anchor" stimulus, such as a pictorial stimulus, among the abstract (or "nonsense") stimuli in each equivalence class appears to improve performance (Albright et al. 2019; Arntzen & Mensah, 2020; Doran & Fields, 2012; Mensah & Arntzen, 2017).

Participant yield appears to be an inverse function of class size (Fields et al., 2000). However, the class size in this study (six-member classes) was the minimum size that allowed for tests with basic stimulus combinations for studying nodality, given that we controlled for different stimulus functions by removing the "singles" in each class during nodality tests. A larger class size would allow a broader range of tests for nodality and other factors. For example, Albright et al. (2019) established a nine-member, seven-node class (A = B = C = D = E = F = G = H = I). This allowed for tests pitting 1-node equivalence relations against 1- to 5-node transitive relations. However, increasing class size also extends the time required to establish the equivalence classes. To reduce the total time required for participation in the current study, we omitted postpreference tests to ensure equivalence classes were still intact at that point. Albright et al. conducted postpreference tests and showed that the classes remained intact after the preference assessment. This suggests that the preference test in the present study was unlikely to significantly disrupt the classes. Meeting criteria in the initial derivation test (accuracy of 90% was required to progress) indicated that equivalence classes were intact just prior to the nodality tests.

Sidman (2000) suggested that nodality may be a result of reinforcement contingencies and structural variables when establishing equivalence classes. Based on our findings from conditions under which the reinforcement contingencies associated with base relations were controlled, it appears that the structural variables associated with training are the key determinants of nodality. But further exploration of this topic and the underlying mechanisms related to the unequal outcomes associated with stimuli as a function of these structural variables in this conditional discrimination task is warranted, not only because nodality appears to be an important phenomenon, but such research may also shed additional light on the behavioral mechanisms underlying stimulus equivalence itself.

Sidman (1994; 2000) suggested that including nodality as a characteristic of an equivalence class contradicts the definition of stimulus equivalence. However, some have argued that nodality should be seen as an important characteristic of an equivalence class because nodality not only appears to be present whenever equivalence classes are established but also influences how participants respond to stimuli within the established equivalence classes, and may influence the formation of new equivalence classes (Fields 2016; Fields et al., 1997; Moss-Lourenco & Fields, 2011). Imam (2001, 2006) argued that nodality is only present due to differential reinforcement during baseline training, and when reinforcement of baseline relations is kept equal, there is no nodality associated with members of an equivalence class. The present study minimized differential presentation and reinforcement of baseline relations by using the simultaneous protocol and presenting all baseline relations equally and randomly. Even with equal reinforcement of baseline relations during training, nodality was observed. This finding aligns with Wang et al. (2011) who also found nodality after equalizing reinforcement of baseline relations during training. It appears that procedural differences (such as trial format and stimuli used) affect the results of equivalence and nodality research, which is why the present study attempted to address some of the key procedural issues (priming, unequal reinforcement, and differential functions of stimuli). The results of this study demonstrate that nodality is present even after controlling for these factors.

Understanding nodality is not solely an esoteric pursuit. In addition to advancing our fundamental understanding of stimulus equivalence, it may help us to predict and control the specific stimulus functions of equivalence class members. For example, when someone is prompted to recall an item from an equivalence class with many members, an understanding of the structure of the underlying base relations in the class can help us to predict which member of the class will be emitted, taking nodality into account. This information might improve the design of instructional programs and lead to other socially significant positive outcomes.

Conclusion

The current study replicated and extended previous work on nodality within established equivalence classes, controlling for several factors that had not been simultaneously controlled for in prior research. The results suggest that stimuli in an equivalence class are substitutable for each other in certain contexts. However, in other contexts, stimuli in an equivalence class are unequally related to each other as a function of nodal number. These findings suggest that the degree of transfer of stimulus functions among stimuli in established equivalence classes are determined, in part, by the number of nodes between stimuli in base relations.

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A. **Appendix**

List of Trials in the Derived Relations Testing Phase

Relation Type	Notation	Class 1			Class 2			Distractor
		Sa	Co+	Co-	Sa	Co+	Co-	Co-
Baseline	AB	A1	B1	B2	A2	B2	B1	B3
	BC	B1	C1	C2	B2	C2	C1	C3
	CD	C1	D1	D2	C2	D2	D1	D3
	DE	D1	E1	E2	D2	E2	E1	E3
	EF	E1	F1	F2	E2	F2	F1	F3
Symmetry	BA	B1	A1	A2	B2	A2	A1	A3
	CB	C1	B1	B2	C2	B2	B1	B3
	DC	D1	C1	C2	D2	C2	C1	C3
	ED	E1	D1	D2	E2	D2	D1	D3
	FE	F1	E1	E2	F2	E2	E1	E3
Transitive (1-node)	AC	A1	C1	C2	A2	C2	C1	C3
	BD	B1	D1	D2	B2	D2	D1	D3
	CE	C1	E1	E2	C2	E2	E1	E3
	DF	D1	F1	F2	D2	F2	F1	F3
Equivalence (1-node)	CA	C1	A1	A2	C2	A2	A1	A3
	DB	D1	B1	B2	D2	B2	B1	B3
	EC	E1	C1	C2	E2	C2	C1	C3
	FD	F1	D1	D2	F2	D2	D1	D3
Transitive (2-node)	AD	A1	D1	D2	A2	D2	D1	D3
	BE	B1	E1	E2	B2	E2	E1	E3
	CF	C1	F1	F2	C2	F2	F1	F3
Equivalence (2-node)	DA	D1	A1	A2	D2	A2	A1	A3
	EB	E1	B1	B2	E2	B2	B1	B3
	FC	F1	C1	C2	F2	C2	C1	C3
Transitive (3-node)	AE	A1	E1	E2	A2	E2	E1	E3
	BF	B1	F1	F2	B2	F2	F1	F3
Equivalence (3-node)	EA	E1	A1	A2	E2	A2	A1	A3
	FB	F1	B1	B2	F2	B2	B1	B3
Transitive (4-node)	AF	A1	F1	F2	A2	F2	F1	F3
Equivalence (4-node)	FA	F1	A1	A2	F2	A2	A1	A3