The Contextually Controlled, Feature-Mediated Classification of Symbols

by

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Abstract

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The classification of names of people or objects based on the features acquired by the names is a commonplace occurrence. For example, if prompted to classify the names of Renoir, Pollock, James and Voltaire the average adult might ask: "Should I classify them based on what they did or what country they were from?" Little is known, however, about the behavioral repertoires required to produce such classification behavior. The present experiment identified some of the behavioral repertoires that are necessary prerequisites to classification behavior. These data may provide a behavioral model of the establishment of complex classification repertoires. Future work in this area is needed to clarify and further extend the utility of the procedures described here.

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The Contextually Controlled, Feature-Mediated Classification of Symbols

The classification of names of people or objects based on the features acquired by the names is a relatively commonplace occurrence. For example, if prompted to classify the names of Renoir, Pollock, James and Voltaire the average adult might ask: "Should I classify them based on what they did or what country they were from?" Thus, features previously acquired by a name (i.e. Renoir is a painter from France) can exert control over how the name is later classified. This control is exerted even though the features are not physically present at the time classification is occurring. How a name is classified will be based on the specific instructions, or context, provided at the time the names are being classified. For example, if instructed to classify the names of the individuals based on where they were from, the instructions would function to signal that a specific feature of the names, namely their nationality, should be attended to while other features, such as their vocation, should be ignored.

Although this type of classification behavior is quite common, very little experimental data address how this type of behavioral repertoire emerges. Early work in the area of classification focused primarily on identifying the mechanisms involved in the establishment of categories containing stimuli that bore a physical resemblance to one another (Fisher, 1916; Hull, 1920; Smoke, 1932). Specifically, this early literature suggested that the establishment of a concept could be inferred when the necessary and sufficient features of all stimuli within an acquired category could be explicitly identified. Thus, the establishment of the concept of "DOG" could be inferred if a participant was able to consciously identify that all instances of stimuli referred to as dogs share certain features with each other (i.e. tail, paws, snouts, etc.) but not with members of other categories such as cats or horses. This type of concept learning was often referred to as *generalized abstraction* and although it resembles the recent literature on dimensional stimulus classes (Fields & Reeve, 2001), it cannot account for the establishment of relations between physically disparate stimuli. For example, Pollock and Renoir may be classified as painters although the names have no physical features in common. Further, although early behavioral characterizations of concept learning suggested that a concept was based on knowledge of shared features of stimuli within a category, they failed to identify how this knowledge was acquired.

Rosch and Mervis (1975) later sought to functionally characterize the nature of a concept and argued that a demonstration of concept learning required that novel stimuli, that are either physically similar to or functionally related to stimuli in trained categories, could be correctly assigned to a category containing similar stimuli. Thus, a novel instance of a chair could be classified as a chair based on either its physical similarity to other objects within the category of chairs or because it shared the same function as other objects in the category of chairs. This type of category was referred to as a *superordinate semantic category*. Similar to earlier studies, however, the shared physical or functional features of the novel stimuli being assigned to the superordinate semantic categories were present at the time the novel stimuli were being classified. Thus, this type of classification could not account for how features acquired by the stimuli, which are not physically present at the time of classification, could govern classification behavior. For example, Pollock and Renoir may be classified as painters based on their acquired features (both individuals are painters) despite the physical absence of that feature at the time of classification.

Although the work by Rosch and Mervis (1975) has served as the basis for recent cognitively based approaches to the study of classification behavior (Barsalou et al, 2003), these approaches offer little insight into the emergence of classes of stimuli that share a common feature that is absent at the time of classification. In their seminal article, Bush, Sidman & deRose (1989) were the first to address how acquired features of stimuli may exert control over how the stimuli are later classified. The example to follow was adapted from the work presented by these authors.

Assume that 9 individuals come from one of three countries and have one of three professions. The names of the individuals are Pollock, Renoir, Bosch, James, Voltaire, Goethe, Gershwin, Debussy and Beethoven. The three nationalities are thus, American, French and German and the three vocations include painter, writer and composer. The name of each individual is associated with a unique combination of two features: a particular nationality and a particular vocation. The three nationalities are members of a nationality category and the three vocations are members a vocation category. When shown the 9 names and asked to classify them based on nationality, an individual would cluster Pollock, James and Gershwin together (Americans) Renoir, Voltaire and Debussy together (French) and Bosch, Goethe and Beethoven together (Germans). In contrast, when shown those 9 names and asked to classify them based on vocation, an individual would cluster Pollock, Renoir and Bosch together (Painters), James, Voltaire and Goethe together (Writers) and Gershwin, Debussy and Beethoven together (Composers).

When viewed in that way, each name can be said to be acting as a member of two different classes. Because these classes consist of physically disparate stimuli (names) that are related based prior reinforcement contingencies that have linked them to specific features (nationality or vocation), the stimuli may be acting as members of an equivalence class (Sidman, 1971; 1994; 2004). For example, an individual can assign Pollock to the same class as Renoir and Bosch because of their prior linkages to their vocation: painter. Thus, these names are functioning as members of an equivalence class based on a particular vocation. In contrast, the same individual could also assign Pollock to the same class as James and Gershwin because of their prior linkages to the same nationality: American. Thus, Pollock would be assigned to one of two equivalence classes depending upon the feature, vocation or nationality, which is being attended to at the time of classification. The same can be said for each of the nine names in the example. This dual membership would apply to all nine names with each name functioning as a member of one vocation-based class and one nationality-based class. Thus, the 9 names could be said to comprise different equivalence classes: 3 vocation-based equivalence classes (painters, writers, or composers) and 3 nationality-based equivalence classes (American, French, or German).

This overlap in class membership poses problems for a simplistic stimulus equivalence account of classification behavior because some experimental demonstrations have shown that when a single stimulus (e.g.: Pollock) serves as a member of two equivalence classes, the classes may merge into one large class (Saunders, Saunders, Kirby & Spradlin, 1988; Sidman, Kirk & Wilson-Morris, 1985). With respect to the present example then, since each name is a member of two classes, all nine names should form one nine-member class. In real world settings, however, such a merger may not be observed. In our example, the maintenance of the separate classes that contain the name Pollock would be due to the different features acquired by the name

(American painter) and would be assigned to a class based on the instructions or contextual cue present at the time of classification. If classification occurred based on nationality, Pollock would be assigned to a class containing James and Gershwin while if classification occurred based on vocation, Pollock would be assigned to a class containing Renoir and Bosch.

To account for the functional separation of two equivalence classes that share a common member, Bush et al. (1989) suggested that contextual cues govern the membership of stimuli within equivalence classes and many experiments have attempted to explore this phenomenon (Bush, et al., 1989; Dymond & Barnes, 1995; Gatch & Osborne, 1989; Gomez, Barnes-Holmes & Luciano, 2002; Griffee & Dougher, 2002; Lynch & Green, 1991; Meehan & Fields, 1995; Perkins, Dougher & Greenway, *In press*; Rehfeldt, 2003; Whelan & Barnes-Holmes, 2004). All of these studies, however, assessed how a single stimulus in an equivalence class comes to switch class membership based on the presence of a contextual cue. This bears little resemblance to the previously described phenomenon in which 9 stimuli can be classified to produce 2 orthogonal sets of 3 equivalence classes. In addition, the switching of class membership in these studies was based on contingency reversals rather than on some acquired feature of the stimuli in question. Because of these restrictions, these studies have not addressed the full phenomenon as originally described by Bush, Sidman and deRose (1989).

Among the more robust of the early attempts to address the phenomenon of contextually controlled equivalence class membership, Lynch and Green (1991) assessed whether contextual stimuli could be used to signal a contingency-based switch in class membership. Integrating the designs of two prior studies (Bush, Sidman & deRose, 1989; Gatch & Osborne, 1989) these researchers initially trained six conditional discriminations (A1-B1, B1-C1, D1-A1, A2-B2, B2-C2 and D2-A2) to form the two, 4-member equivalence classes (A1-B1-C1-D1 AND A2-B2-C2-D2). These classes were comprised of different geometric shapes. Thereafter, four additional conditional discriminations were established in the presence of two different nonsense syllables, BEM and ZUT. In the presence of the putative contextual stimulus BEM, A1-B1 and A2-B2 were reinforced, as during the formation of the prior classes. In contrast, in the presence of ZUT, the relations A1-B2 and A2-B1 were established. Thus, this training would establish the class membership of the B1 and B2 stimuli in either class 1 or class 2. Specifically, because a participant was trained to select B1 given A1 and B2 given A2 in the presence of the contextual stimulus BEM, performances on emergent relations probes should remain consistent with the classes established in the first training phase (A1-B1-C1-D1 AND A2-B2-C2-D2). In contrast, however, because a participant was trained to select B2 given A1 and B1 given A2 in the presence of the contextual stimulus ZUT, performances on emergent relations probes should indicate the establishment of 2 new equivalence classes consisting of A1-B2-C2-D1 AND A2-B1-C1-D2.

To assess these contextually controlled performances, participants were presented with emergent relations probes, some of which might be viewed as conflict tests. These conflict tests involved the presentation of a sample stimulus along with 2 comparisons, both of which had been related to the sample during training. On these trials, however, the contextual cue indicated the correct comparison. For example, on a conflict equivalence probe, the sample C2 might be presented as sample along with A1 and A2 as comparison stimuli. Because C2 was linked to B2 and B2 was linked to A2 in the presence of BEM, selection of the A2 stimulus could be correct. However, because B2 had been linked to A1 in the presence of ZUT, selection of the A1 stimulus given C2 could also be correct. Although both comparison stimuli were equally related to the sample, however, the participant would have to choose one of two potentially correct comparison stimuli. In the presence of a contextual stimulus, however, the prevailing A-B relations would define the correct comparison. Thus, in the presence of BEM, because A2 was trained to B2 and B2 was trained to C2, selection of the A2 stimulus given the C2 stimulus would be correct. In contrast, in the presence of ZUT, because A1 was trained to B2 and B2 was trained to C2, selection of the A1 stimulus given the C2 stimulus would be correct. This procedure resulted in the demonstration of the four equivalence classes predicted by the experimenters in all participants.

The design used by Lynch & Green (1991) provided strong evidence that contextual cues could exert control over the classification of a stimulus that was a member of two equivalence classes. In this study as well as in earlier studies (Bush, Sidman & deRose, 1989; Gatch & Osborne, 1989), however, the contextual cues exerted control over class assignment based on a contingency reversal in which the contextual cue signaled the switching of some of the stimuli from one class to the other. Thus, rather than classification being based on features that were acquired by the stimuli being re-classified, it was based on the contingency used to established direct relations between some of the class members and the contextual cues. This type of contextual control might account for how a single stimulus, such as the name Renoir, based on its prior linkage to the terms French and Painter, might function as a member of a class containing other French citizens in the presence of the word French and as a member of a class containing other painters in the presence of the word painter. This type of demonstration, however, cannot account for how contextual cues can exert control over classification of all of the stimuli in a set based on features previously acquired, but absent during the time of classification.

In an attempt to address how contextual cues might exert control over feature-based classification, Meehan and Fields (1995) sought to demonstrate that multiple exemplar training could establish two stimuli as contextual cues that could spontaneously exert control over the membership of a stimulus in one class or another. This classification was based on some feature acquired by the stimuli in a class. In this study, sets of stimuli that contained 3 graphic symbols were used for the establishment of 3-member equivalence classes. In all sets, the A stimuli consisted of singular graphic symbols, the B stimuli consisted of graphic symbols presented in duplicate, and the C stimuli consisted of graphic symbols presented in triplicate. Thus, the A, B and C stimuli across all sets of stimuli shared common features.

Across all sets, the features shared by the A stimuli, the B stimuli, and the C stimuli allowed for the use of multiple-exemplar training to establish discriminative control by two contextual cues over the switching of the A stimuli from one class to another. Specifically, two, 3-member equivalence classes were established in the presence of a short line such that in the presence of the SHORT LINE: A1-B1 and B1-C1 and A2-B2 and B2-C2 were trained resulting in the establishment of 2 equivalence classes consisting of A1-B1-C1 and A2-B2-C2. In addition, two opposing 3-member equivalence classes were established in the presence of a long line such that in the presence of the LONG LINE: A1-B2 and B2-C2 and A2-B1 and B1-C1 were trained resulting in the establishment of 2 equivalence classes consisting of A1-B2-C2 and A2-B1-C1. This training was conducted with many sets of stimuli that shared the common features and eventually resulted in the spontaneous reassignment of the A stimuli in novel equivalence classes for 3 out of the 5 participants in the study.

The results reported by Meehan and Fields (1995) demonstrated that the control exerted by the contextual cues, SHORT LINE and LONG LINE, could be generalized to novel stimulus sets. This generalization occurred as a result of shared features among the A, B and C members of the equivalence classes. Thus, because training with many sets of stimuli established that membership of the A stimuli in class 1 or class 2 always varied based on the contextual cue that was presented, spontaneous reassignment of the A stimuli in novel stimulus sets occurred based on the presence of the contextual cues and the features associated with the stimuli in the class. Similar to prior studies, however, the features of the stimuli that governed class assignment were present at the time of class assignment.

The most recent work in the area of contextually controlled equivalence classes has continued to advance the behavioral description of complex, rule-governed behavior. This research has sought to assess the emergence of generalized stimulus control over classes of stimuli based on relations among stimuli within a class such as same/opposite (Dymon & Barnes, 1995; Whelan & Barnes-Holmes, 2004) and more than/less than (Dymon & Barnes, 1995). More recent work (Perkins, Dougher & Greenway, 2007) has addressed how a response might generalize to other class members based on the acquired features of stimuli in a class.

Despite the aforementioned extensions, however, there is still a complete lack of experimental data that can account for the phenomenon originally described by Bush, Sidman & deRose (1989). Although the model proposed by these researchers described how a contextual cue could act to produce a generalized repertoire of spontaneous classification based on the acquired features of a set of stimuli, to date, no study has adequately assessed this issue. The present experiment sought to identify the learning histories that might enable an individual to classify symbols based on (a) the features acquired by those symbols, and (b) the context that indicates attention to one set of features instead of another.

In their original example, Bush, et al. (1989) used well-known names with known nationalities and known vocations as the class members. Thus, it would be impossible to study the training histories needed to induce the targeted classification repertoires based on contextual cues and features acquired by these names. To study the training history needed to induce this type of classification it would be necessary to use stimuli that were unknown to a participant at the start of the experiment. Because all of the names provided in the example are textual, however, the stimuli used to explore the establishment of the repertoire should also be textual. The experiment to be described then will use nonsense syllables as proxies for the names, the particular nationalities and the particular vocations described in the original example and arbitrary character strings as proxies for the category labels, or context cues.

For purposes of explication all tables and figures within the present document will refer to the names as symbols and will be represented symbolically with the numerals 1 through 9. Further, the specific vocations and nationalities will be referred to as features with the lowercase letters, p, w and c representing the three vocation-based features (painter, writer and composer, respectively) and the letters a, f and g representing the three nationality-based features (American, French and German, respectively). Finally, the category names will be referred to as categories and will be represented with the uppercase letters N and V (nationality and vocation, respectively).

Figure 1a illustrates the metaphorical example using the names of famous individuals and the classes they might comprise and Figure 1b represents the same set of relations in symbolic format. In Figure 1b, each cell contains a numeral that is the proxy for a name or symbol. The three numerals in a column correspond to symbols that are related to a given nationality-based feature, while the three numerals in a row correspond to the symbols that are related to a given vocation-based feature. Thus, each numeral is related to a unique combination of a nationality-based feature and vocation-based feature. For example, the symbol represented by the numeral 3 is related to the features p and g. Figure 1c illustrates the structure of the classes using the actual stimuli employed by the current experiment.

For purposes of explication within the text this document will use actual names of individuals for the symbols (Pollock, Renoir, Bosch, James, Voltaire, Goethe, Gershwin, Debussy and Beethoven), names of vocations (painter, writer and composer) and nationalities (American, French and German) for the features and the names Vocation and Nationality to represent the categories. This is being done in an effort to facilitate the understanding of the phenomenon being explored. Table 1 specifies all of the terminology used within the document. The first column indicates the type of cue followed by the symbolic (column 2) and metaphorical (column 3) representations of the stimuli and finally, the fourth column lists the actual stimuli used in the experiment.

Relying upon a phenomenological description of the target behavior, the present experiment sought to experimentally produce the sources of stimulus control needed to govern the type of classification presented in the metaphorical example provided above. Using this approach, 3 types of stimulus relations were derived that should be required for the emergence of this type of classification behavior. Initially, relations between the vocations and the category Vocation and between the nationalities and the category Nationality would need to be established. These types of relations might be established by reinforcing selection of the appropriate category name, Vocation or Nationality, in the presence of the appropriate exemplars of those category names: painter, writer, composer and American, French, German respectively. This might be done using a one-to-many training procedure (Adams, Fields & Verhave, 1993) such that all 3 vocation-based exemplars were directly trained to the category name Vocation and all 3 nationality-based exemplars were directly trained to the category name Nationality. These procedures would establish relations between 3 Vocation-based feature stimuli p, w, c and the category name Vocation, and between 3 Nationality-based feature stimuli a, f, g and the category name Nationality.

Next, relations between the names of the 9 individuals and the vocations they practiced would need to be established. Here, an equivalence model might be used to account for the relations between the names of the individuals and the vocation they practiced. An equivalence class can be established by training (N - 1) of relations between stimulus pairs where N = the number of stimuli in the set. Thus, to form a 4-

member equivalence class, relations between 3 stimulus pairs would be trained. It is often observed that as a result of this limited training, all remaining untrained, and thus novel, relations emerge without training. These various emergent relations document the properties of reflexivity, symmetry, transitivity and equivalence among the stimuli in a class and indicate that the set of stimuli are functioning as members of an equivalence class.

Using this type of approach, 3, 4-member vocation-based equivalence classes comprised of the names of 3 individuals and the vocation they practiced might be established. For example, a 4-member equivalence class may consist of the category name painter and the names of three famous painters such as Pollock, Renoir and Bosch. Using a comparison-as-node training procedure in a matching-to-sample format, selection of the category name painter but not selection of the category names writer and composer, in the presence of the names Pollock, Renoir and Bosch would occasion reinforcement. Following this training, emergent relations including symmetry (i.e. selection of Pollock given the category name painter) and equivalence (i.e. selection of the Renoir given Pollock) would document the establishment of a painter-based equivalence class. Thus, this type of procedure, applied to all names and their respective vocations would establish three, 4-member equivalence classes. Each of these classes would be comprised of the names of 3 individuals and the vocation they practiced. Metaphorically, these classes would consist of painters–Pollock-Renoir-Bosch, writers–James-Voltaire-Goethe, and composers–Gershwin-Debussy-Beethoven. These classes are illustrated metaphorically in the columns of Figure 1a and are ringed in red.

In a like manner, relations between the names of the individuals and their nationalities might be established through the formation of three other 4-member equivalence classes each of which was comprised of the names of three individuals and their respective nationalities. Metaphorically, these classes would be comprised of Americans–Pollock-James-Gershwin, French–Renoir-Voltaire-Debussy, and German–Bosch-Goethe-Beethoven. These classes are illustrated metaphorically in the rows of Figure 1a and are ringed in blue.

The establishment of the feature category relations, the nationality-based equivalence classes and the vocation-based equivalence classes should provide all of the logically necessary relations for the spontaneous classification of the names of individuals into different equivalence classes based upon their acquired features. In addition, however, it is necessary to show that trained relations between a name and its corresponding vocation as well as its nationality coexisted even though they were not trained together. These so called *symbol-dual feature* relations could be assessed by the presentation of a name as the sample stimulus along with a compound stimulus that contained both a vocation-based and nationality-based feature. For example, the compound stimulus *American painter* might be presented as a positive comparison stimulus for Pollock presented as a sample. In this case, multiple negative comparisons such as *French writer* or *German composer* would be available. The existence of these symbol-dual feature relations would be demonstrated by the selection of American painter instead of French painter or American composer given the sample name Pollock. These performances would have to occur for all of the names and in the absence of feedback.

Once the name-dual feature relations had been demonstrated, classification based on category name and acquired features could be assessed. Assessment of classification would determine whether the names could be categorized into different equivalence classes based on the presence of the previously trained category names Vocation and Nationality and the vocation-based and nationality-based features acquired by the names. Classification probe trials would involve the presentation of a name as the sample stimulus. Two comparison stimuli consisting of names that are equally associated with the sample would also be presented. Thus, the name used as one comparison would practice the same vocation as the person in the sample and the other comparison name would be of the same nationality as the person in the sample. These *conflict tests* are unsolvable because either of the comparisons would be correct. With the addition of the category name, however, the classification probe trial becomes solvable because it would function to indicate which acquired feature of the sample stimulus should be attended to when selecting the comparison stimulus.

For example, a classification probe trial may be comprised of the name Pollock presented as the sample stimulus with Renoir and James presented as comparisons. In this case, Pollock and Renoir share a vocation-based feature (painter) but not a nationality-based feature (Pollock is American while Renoir is French). Pollock and James, however, share a nationality-based feature (American) but not a vocation-based feature (Pollock is a painter and James is a writer. Thus, in this case, Pollock is equally related to both Renoir and James. This classification probe trial is illustrated in Figure 2a and represents an unsolvable test.

With the addition of a category name, however, the correct comparison becomes discernible. For example, presenting the category name Nationality prior to the presentation of the sample stimulus disambiguates the trial by indicating that comparison selection should be based on the shared nationality feature amongst the sample and comparison stimulus. This is illustrated in Figure 2b. Figure 2c provides the symbolic and metaphorical description of the test trial that is illustrated in Figures 2a and 2b.

During this classification probe, if the comparison stimulus Renoir was selected when nationality was the category name, and the comparison stimulus James was selected when vocation was the category name, we could conclude that comparison selection was determined by the joint control of the prevailing category cue and the features acquired by the names presented in the test trials, even though the features (i.e. French and writer) were not present at the time of classification. Were this to occur for all classification probes, it would imply that each name was functioning as a member of two separable equivalence classes. Such an outcome would account for the phenomenon originally described by Bush, Sidman and deRose (1989) and would represent a significant progression from previous demonstrations of contextually controlled equivalence class membership.

Method

Participants

Fourteen undergraduate students were recruited through flyers posted on the campus of Queens College in Flushing New York. Participants were paid $10 per hour for their participation. The duration of the experiment ranged from 6 to 8.5 hours and was completed within 3 sessions over a maximum of 5 days.

Apparatus

Hardware and software. An MS-DOS compatible microcomputer and custom software was used to control stimulus presentation and for data collection. Each participant was seated at a table within a cubicle that holds the computer, a monochrome monitor, and a keyboard. During all phases of the experiment responses were made by pressing specified keys on the keyboard. Each stimulus used during training and testing was presented on the monochrome monitor and was contained with a 2-inch x 2-inch space. All aspects of the experiment were controlled by a customized software package, which also collected all data on a trial-by-trial basis.

Stimuli. The stimuli used in the present experiment are described in the introduction and are listed in Table 1.

Procedure

Trial structure, contingencies, and responses within a trial. All training and testing trials were conducted using a two-choice matching-to-sample (MTS) procedure. Each trial began when the phrase Press ENTER to begin appeared on the screen. Pressing the ENTER key replaced this message with the sample stimulus. Pressing the SPACE BAR in the presence of a sample produced the Co+ and the Co-. The sample and comparison stimuli were presented in the array of an isosceles triangle with the sample at the vertex and the comparisons at the ends of the base. Participants made their selection by pressing the 1 key for the comparison located on the left or 2 key for the comparison located on the right. Any selection resulted in the end of the trial and all responses produced a written feedback message in the center of the screen.

On trials in which differential feedback was scheduled, if the Co+ was selected, the word RIGHT appeared on the screen until the participant pressed the R key on the computer keypad. If the Co- was selected, the word WRONG appeared on the screen until the participant pressed the W key on the computer keyboard. On trials in which non-differential feedback was scheduled, either selection produced the letter E on the screen until the participant pressed the E key. Pressing the R, W, or E key cleared the screen and initiated the next trial. The E key was selected because it is between the R and W keys on the keyboard (Fields et al, 1993].

Acquisition and Feedback Reduction. When a training block was introduced, selection of either comparison was followed by differential feedback. Initially, all conditional discrimination training trials were conducted with 100% feedback. Each training block was repeated until the participant achieved the mastery criterion. The mastery criterion for a block was determined by the number of trials within the block but was always at least 95% correct. Upon achieving the mastery criterion at the 100% feedback level, differential feedback was reduced in successive blocks of trials from 100%, to 75%, to 25%, and finally to 0% provided that the mastery criterion was maintained at each level.

Design

The experiment was conducted in 7 phases: Keyboard Familiarization Training (Phase 1), Feature-Category Name Training (Phase 2), Vocation-based and Nationality-based Equivalence Class Formation (Phase 3 and 4), Symbol-Dual Feature Tests and Dual Feature-Symbol Tests (Phase 5 and 6) and finally, Classification Tests (Phase 7). Each phase is described below in detail.

Phase1: Keyboard familiarization. During keyboard familiarization training, common English words were used as samples and comparisons and participants were trained to emit the appropriate within-trial keyboard responses by the serial deletion of the on-screen instructional prompts. Participants were initially provided with the following instructions:

> Thank you for volunteering to be a subject 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 contains three CUES. These will be common words or three-letter nonsense words such as ZEQ or WUV.
>
> ***
>
> YOUR TASK IS TO DISCOVER WHICH CUES GO TOGETHER.
>
> ***
>
> Initially there will also be INSTRUCTIONS that tell you how to respond to the cues, as well as LABELS that will help you identify the cues on the screen. The labels and the instructions, which tell you which KEYS to press, will slowly disappear. Your task will be to RESPOND CORRECTLY to the CUES and the INSTRUCTIONS by pressing a key on the computer's keyboard.
>
> ***
>
> The experiment is conducted in phases. SOMETIMES you will see information on the screen that tells you how you did in the previous phase. If you want to take a break, you may do so at any time by calling the experimenter.

After the subject read the instructions the experimenter answered any questions the participant may have had and then left the room.

Phase 2: Feature-Category Name Training. This phase of training was used to establish relations between 3 Vocation-based feature stimuli represented as painter (p), writer (w), and composer (c) and the category name Vocation (V), and between 3 Nationality-based feature stimuli represented as American (a), French (f) and German (g) and the category name Nationality (N). These relations were established using a many-to-one, or comparison-as-node, conditional discrimination training procedure. Using this procedure, the 3 vocation-based features (p, w, c) and the 3 nationality-based features (a, f, g) were presented as samples along with the category names (V and N) as comparison stimuli in a matching-to-sample format. Thus, on any given trial if one of the three vocation-based features was presented as a sample, the category name Vocation served as the Co+ and the category name Nationality served as the Co-. Conversely, on any trial where one of the three nationality-based features were presented as sample, the category name Nationality served as the Co+ and the category name Vocation served as the Co-. These relations were established in a serial manner over 3 phases of training (T1-T3) and 2 phases of testing (M2 and M3), and are illustrated in Table 2a. Table 2b lists the specific stimuli used in all trial configurations during each phase of training.

Within each training block, informative feedback was initially presented on 100% of trials and was decreased to 75% then 25% and then 0% upon the subject reaching the mastery criterion of 100% correct. During blocks where informative feedback was less than 100%, if the mastery criterion was not met within 4 blocks the participant returned to the previous level of feedback until the mastery criterion was met before returning to the failed block. Upon completion of feature-category name training, participants progressed to Phase 3.

Phase 3: Establishment of Vocation-based equivalence classes. The purpose of this phase of training was to establish three, 4-member equivalence classes each of which was comprised of 3 names and the Vocation they practiced. Metaphorically, these classes consisted of, painter-Pollock-Renoir-Bosch, writer-James-Voltaire-Goethe, and composer-Gershwin-Debussy-Beethoven. These classes are illustrated metaphorically in the columns of Figure 1a and are ringed in red. Their symbolic representations are illustrated in the columns of Figure 1b and are also ringed in red. Finally, the actual stimuli used to form these classes are illustrated in Figure 1c and are also ringed in red.

Using a comparison-as-node or many-to-one training structure, conditional discriminations were established between the symbols and their corresponding Vocation-based features. This training is illustrated in Table 3a. The Co-'s during these trials consisted of the alternative Vocation-based features. For example, in the presence of the symbols Pollock, Renoir or Bosch, which were presented as samples, reinforcement required the selection of painter while selection of writer or composer did not occasion reinforcement. Alternatively, when presented with the symbols James, Voltaire or Goethe, reinforcement required the selection of writer while selection of painter or composer did not occasion reinforcement. Finally, in the presence of the symbols Gershwin, Debussy or Beethoven reinforcement required the selection of composer while selection of painter or writer did not occasion reinforcement.

Equivalence class training was conducted in accordance with a simple-to-complex (STC) protocol. This protocol requires that tests of any emergent relation (i.e. equivalence) be preceded by the demonstration of all prerequisite relations (i.e. symmetry and transitivity). Thus, the STC protocol involves the sequential training and testing of the relations necessary for the demonstration of an equivalence class.

Using the STC protocol, the first set of conditional discriminations, which included Pollock→painter, James→ writer and Gershwin→composer were trained. These relations are illustrated in Table 4 and correspond to Block T1 (Training block 1). These relations were randomized within a single block and within each training block informative feedback was initially presented on 100% of trials. Over successive training blocks informative feedback was decreased from 100% to 75% then 25% and then 0% upon reaching the mastery criterion of 100% correct. During blocks where informative feedback was less than 100%, if the mastery criterion was not met within 4 blocks the participant returned to the previous level of feedback until the mastery criterion was met before returning to the failed block. Upon establishment of these conditional discriminations, the symmetrical properties of these trained relations were assessed to determine whether the sample and comparison stimuli used during conditional discrimination training were interchangeable.

During symmetry testing, the features (p, w, c) were presented as samples along with the names (1 – 9) as comparison stimuli. On any given trial, the Co+ consisted of the symbol that corresponded to the feature presented as the sample while the Co- consisted of one of the other symbols. All symmetry probes were randomized within a single block and presented in the absence of informative feedback. These symmetry tests are illustrated in Table 4 and correspond to Block S1 (Symmetry block 1). Upon meeting the mastery criterion on these probes, which was defined as 100% correct, the next set of conditional discriminations consisting of Renoir→painter, Voltaire→writer and

Debussy→composer were established. Following the establishment of these relations the symmetrical properties of these trained relations were assessed. These relations are illustrated in Table 4 and correspond to Blocks T2 (Training block 2) and S2 (Symmetry block 2), respectively. Upon demonstration of symmetry for this second set of relations a mixed block was presented that included all of the previously trained and tested relations. This mixed test block, which is illustrated in Table 4 and corresponds to block MS1 (Mixed Symmetry block 1), was presented in the absence of informative feedback and progression to the next phase of training occurred only after the mastery criterion of 100% correct on two successive blocks was achieved.

Upon the satisfactory completion of this mixed test block, tests for the emergence of equivalence relations were conducted to demonstrate that the symbols within a class (i.e. Pollock, Renoir) had become related to each other through linkage to the nodal feature stimulus, Vocation (i.e. painter). These relations are illustrated in Table 4 and correspond to Block E1 (Equivalence block 1). Because there were 96 novel equivalence probes to be evaluated the presentation of a single test block would have been excessive. Thus, to keep the number of trials within the equivalence blocks to a tolerable level for the participants, each trial configuration was presented two times rather than 4 times within the block. To keep the number of presentations of each trial configuration the same across all training and testing conditions, however, the block was repeated so that each trial configuration was presented 4 times. During these equivalence tests the mastery criterion was defined as maximum of 2 errors within a block or at least 95% correct.

All of the equivalence probes presented to track the formation of the vocation-based equivalence classes never contained Co-'s that would function as Co+'s during the subsequent establishment of the nationality-based equivalence classes. For example, on an equivalence probe in which Renoir was presented as the sample, although Voltaire and Debussy could have served as a Co-'s based on differences in their vocation-based feature, they were never used as Co-'s because they shared a nationality-based feature with the sample stimulus.

Following the satisfactory completion of equivalence testing, all of the previously trained and emergent relations (symmetry and equivalence) were combined into a mixed test. This mixed block is illustrated in Table 4 and corresponds to Block M1 (Mixed Test block 1). Again, due to the large number of trials required for this assessment (288) and to keep the number of presentation of trial configurations the same, this test block was presented twice. The mastery criterion for this mixed testing was defined as a maximum of 4 errors or at least 95% correct.

Upon satisfactory completion of the mixed test block, the third and final set of conditional discriminations was established. These included the relations Bosch→painter, Goethe→writer, and Beethoven→composer. These relations are illustrated in Table 4 and correspond to Block T3 (Training block 3). Following the establishment of these relations the symmetrical properties of these trained relations were assessed and upon demonstration of the symmetrical relations a mixed symmetry block that included all previously trained baseline conditional discriminations and their symmetrical relations were assessed. These are also illustrated in Table 4 and correspond to Blocks S3 (Symmetry block 3) and MS2 (Mixed Symmetry block 2), respectively.

Following the mixed symmetry block equivalence among all relations were assessed in a mixed block. These test trials are illustrated in Table 4 and correspond to Block E2 (Equivalence block 2). In this case, the number of novel trial configurations to be assessed (144) warranted 3 repetitions of the test block. Upon demonstration of these equivalence relations all previously trained and baseline and equivalence relations were assessed in a mixed block. This block is illustrated in Table 4 and corresponds to Block ME1 (Mixed Equivalence block 1). Following the demonstration that all baseline and equivalence relations were intact, all trained and emergent relations were assessed in 3 final mixed test blocks. This final block is illustrated in Table 4 and corresponds to Block M1 (Mixed Test block 1). Upon the successful completion of these training and testing blocks, training on the nationality-based equivalence classes was initiated.

Phase 4: Establishment of Nationality-based equivalence classes. The purpose of this phase of training was to establish three, 4-member equivalence classes each of which were comprised of the names of three individuals and their Nationality. Metaphorically, these classes consisted of American-Pollock-James-Gershwin, French-Renoir-Voltaire-Debussy, and German-Bosch-Goethe-Beethoven. These classes are illustrated metaphorically in the rows of Figure 1a and are ringed in blue. Their symbolic representations are illustrated in the rows of Figure 1b and are also ringed in blue. Finally, the actual stimuli used to form these classes are illustrated in the rows of Figure 1c and are also ringed in red.

Using a comparison-as-node or many-to-one training structure, conditional discriminations were initially established between the symbols and their corresponding Nationality-based features. This training is illustrated in Table 5. Training and testing of the Nationality-based classes then progressed in the same way, using the STC protocol as previously described for the Vocation-based classes.

Each equivalence probe that tracked the emergence of the nationality-based classes never contained a Co- that would have been correct during an equivalence probe that had been used to track the formation of a vocation-based class. For example, on an equivalence probe in which Renoir was presented as a sample, although Pollock or Bosch may have served as a Co- based on differences in their nationality-based features, they were never used as Co-'s because they shared a vocation-based feature with the sample stimulus.

Further, during the establishment of the nationality-based classes the vocation-based features of the Co+ and Co- were always held constant. Thus, on any equivalence probe, the Co+ and Co- always came from the same vocation-based class. For example, on an equivalence probe in which Renoir was presented as a sample and the Co+ was Voltaire, the Co- consisted of either James or Goethe because they came from the same vocation-based class as Voltaire (writer). This was done to prevent vocation-based features from disrupting control of behavior by the nationality-based features of the comparison stimuli. An example of this equivalence probe is illustrated in Figure 3. Following the completion of the nationality-based equivalence class training, participants advanced to the next phase of the experiment.

Phase 5: Symbol-Dual Feature Tests. These tests, which were conducted in the absence of feedback, assessed the maintenance of the relations between the symbols and their corresponding vocation- and nationality-based features. These tests were presented in a standard matching-to-sample format. Initially, testing involved the presentation of the symbols as samples with comparisons that contained a compound stimulus that consisted on one vocation and one nationality feature separated by a / (i.e. French/painter). These tests are illustrated in order of the symbols in Table 6.

During the symbol-dual feature tests, each symbol was presented as a sample stimulus along with combinations of vocations and nationalities. The Co+ on any given trial consisted of a compound stimulus containing the vocation-based feature associated with the sample as well as the nationality-base feature associated with the sample. For example, on a trial in which the symbol Pollock served as sample, the Co+ consisted of features consistent with the nationality-based class that Pollock functions as a member of, American, and with the vocation-based class that Pollock functions as a member of, painter. Thus, on trials where the name Pollock served as a sample, the Co+ would be American painter. Alternatively, the Co- may have contained neither of the class consistent features (i.e. French composer) or one class consistent feature (i.e. American composer or French painter). These test trials were used to test for the emergence of relations between each symbol and the combined features, nationality and vocation, to which they had been associated. These tests were analogous to asking the participant to indicate the characteristics of the individual being named and correct performances indicated that the names had acquired each of the two features to which they had been associated with.

Phase 6: Dual Feature-Symbol Tests. Following the demonstration that each symbol has acquired the appropriate feature relations, the symmetrical properties of these relations were evaluated with dual feature-symbol tests. During this phase, sample stimuli consisted of all possible combinations of features, (vocation and nationality), with the symbols as comparisons. On these trials, the Co+ consisted of the symbol that was associated with both features. For example, on trials where American painter was presented as the sample, the Co+ would consist of the symbol Pollock because that is the stimulus that is associated with both features. Alternatively, the Co- may have been associated with neither feature (i.e. Debussy: French composer) or with only one feature (i.e. Gershwin: American composer or Renoir: French painter). These test trials, which are illustrated in Table 7, were used to test for the symmetrical property of the relations between each name and the combined features, nationality and vocation. This test was analogous to asking the participant to identify the name of the individual with these characteristics and correct performance on these tests indicated that the features had become associated with a specific name.

Phase 7: Classification Tests. This phase of the experiment was used to evaluate whether participants could categorize the symbols into different equivalence classes based on the presence of the previously trained category names, vocation and nationality, and the features acquired by those symbols. During this phase, participants were presented with classification probes trials in which each trial contained 3 symbols, one as a sample and two others as comparisons. In these tests both comparison stimuli shared either a vocation-based or nationality-based feature with the sample stimulus. Thus, both comparison stimuli were equally related to the sample. These conflict tests were presented in the presence of one of the 2 category names (Vocation or Nationality).

Table 8 lists each of the 36 classification probes used to evaluate the categorization of the symbols based on prevailing category name and the acquired vocation-based and nationality-based features of the symbols. Each row contains information for one of the classification probes. The first column indicates the Block that contained the classification probes identified in the second column. The third column contains the category name that is presented during a probe. The subsequent columns contain the symbols, along with their acquired features, presented as sample and comparison stimuli in each classification probe.

Each test block presented during the classification tests contained trials from four classification probes. The evaluation of performances produced by each classification probe involved the presentation of eight trials. Four of these trials were presented with the "Vocation" category name and 4 trials were presented with the "Nationality" category name. Thus, a total of 32 trials were presented in each classification test block (4 classification probes and 8 trials per classification probe). All trials in a classification test block were presented in random sequence without replacement and the computer program that controlled the experiment randomized the sequence of trials in a classification test block differently for each block and for each participant. Performances occasioned by the entire test battery were used to determine whether contextual stimuli controlled the categorization of stimuli into equivalence classes based on the acquired characteristics of the stimuli.

Phase 6a: Feature–Category Re-training. Based on performances of the first two participants it appeared that the relations between the features and the category names had either not been maintained (TF3157AL) or had degraded (TF3166DH). Thus, for 4 of the 6 subjects, we repeated the feature-to-category training. This training was identical to the training in Phase 2.

Phase 6b: ABA reversal design to assess control by Vocation and Nationality category names. To determine the effects of the presence of the category names on the performances evoked by the classification probes, one subject was tested using an ABA reversal design.

The A condition: Test with conflict probes in the absence of the contextual stimuli. During this phase, the classification tests were presented in the absence of the category names to assess what might control responding on these ambiguous trials. Thus, during this phase each sample presented was related to both of the comparison stimuli. During these tests, the participant may choose randomly, may choose only the comparison that shares the same nationality feature with the sample or may choose only the comparison that shares the same vocation feature with the sample.

The B condition: R*etest with conflict probes in the presence of contextual stimuli*. During this phase, the classification tests were re-presented with the category names present to demonstrate that the category names and acquired features of the symbols were still able to jointly control responding.

Results

General

Although 14 subjects were recruited for participation in the present experiment, 8 subjects did not successfully complete the experiment. Of those that were excluded from the final data analysis, 4 did not pass the tests necessary for the demonstration of the first trained 3-member Vocation-based equivalence classes (TF3134OP, TF3169MI, TF3164ET, TF3160YR, TF3158ML) and 3 withdrew before any meaningful data could be collected (TF3167SK, TF3161MH, TF3162NK). Finally, one subject who had successfully completed all of the training and testing prior to exposure to the final classification test could not complete the classification test due to a programming error (TF3154AL). Of note, when this subject was exposed to some of the correctly programmed classification test probes, she accurately selected the correct comparison. Unfortunately, she was unable to return for re-testing with the corrected classification probes.

Feature-Category Training

Figure 4 presents data for the performance of participant TF3156YK during Feature-Category Name Training. Data are presented for each phase of training and the specific relations trained are indicated in the boxes above each segment. Lower case letters represent the features. Each arrow connects two stimuli that were the sample and comparison in a conditional discrimination with the sample at the tail of the arrow and the comparison at the head of the arrow. The first, second and fourth segment of the graph depict the acquisition of the 3 individual conditional relations while the third and fifth segments depict the maintenance of the previously established conditional relations.

Feedback level during each phase of training and testing is indicated on the abscissa and ranged from 100% to 0% during all training blocks. The number of blocks required to reach the percent correct criterion is indicated on the ordinate. The gray portion of each bar indicates the minimum number of blocks that were required to meet the mastery criterion while the black bars indicate blocks in excess of the minimum requirement. The absence of a black bar indicates that the % correct criterion was met in the minimum number of blocks required.

For this particular subject, one additional block in excess of the minimum was required to meet the mastery criterion during p→V and a→N training (first segment) as well as w→V and f→N training at the 100% feedback level. Further, one additional block in excess of the minimum was required for p→V←w and a→N←f training at the 75% feedback level. For this subject, the mastery criterion for all other training blocks was achieved in the minimum number of programmed blocks.

Figure 5 shows the performances of all of the participants during feature-category training. The graph in each panel has the same format described in Figure 4. Each of the six participants learned 3 pairs of conditional discriminations equaling 18 cases; these are illustrated in the first, second and fourth panel. Of the 18 conditional discriminations, 9 were acquired in the first training block, 5 were acquired in two training blocks, and the remaining 4 were acquired in three training blocks. Further, in all blocks that occasioned sub-criterion performances, the level of accuracy was always at least 75% correct. These trial based percentage data are shown in Table 9. In general, these results demonstrated the rapid acquisition of the feature-to-category conditional discriminations.

After the initial acquisition of the conditional discriminations, performances had to be maintained in the presence of decreasing levels of feedback and eventually in the absence of feedback. When feedback was reduced from 100% to 75%, the mastery level of responding was maintained in the first block in 15 of the 18 cases. In the three remaining cases, the initial block showed a transient decrement in accuracy after which mastery was achieved in one or two additional blocks.

When feedback was reduced from 75% to 25%, the mastery level of responding was maintained in the first block in 17 of the 18 cases. In the one remaining case, the initial block showed a decrement in accuracy after which mastery was demonstrated in one additional block.

When feedback was reduced from 25% to 0%, the mastery level of responding was maintained in the first block in 12 of the 18 cases. In the 6 remaining cases, the initial block showed a decrement in accuracy after which mastery was achieved in one additional block. In all cases, however, performances in sub-criterion blocks were never below the level of 75% correct. These trial based percentage data are shown in Table 9. To summarize, each reduction of feedback resulted in the maintenance of the criterion levels of conditional responding. When disruption did occur, there was a rapid recovery of the conditional discriminations at the prevailing level of feedback.

The third and fifth panels of Figure 4 illustrate performances when the previously learned conditional discriminations are combined with the most recently acquired conditional discrimination. Thus, the performances in these phases permitted evaluation of a possible disruptive effect of the inclusion of already-learned conditional discriminations on the maintenance of just-learned conditional discriminations.

Specifically, the data in the third section of each graph corresponds to the combination of the first 2 conditional discriminations, and the data in the fifth section of each graph corresponds to the combination of all 3 conditional discrimination. In the first 6 cases (segment 3), 2 showed maintenance with no disruption while the remaining 4 showed some degree of disruption. Two of the participants showed minor disruption and required 1 block in excess of the minimum at the 100% feedback level but showed no further disruption during each level of feedback reduction. In one case (TF3159SD), there was no consistent pattern in the specific relations that produced incorrect responses. Of the 4 relations in which the incorrect comparisons were chosen, 2 were the most recently acquired conditional discriminations and 2 were the more remotely acquired relations. For the other participant (TF3166DH), however, the 2 relations in which the incorrect comparisons were selected, both selections related to the first acquired conditional discriminations. The remaining 2 disruptions occurred at the 75% feedback. In each case, the decrement in performance was produced by selecting the incorrect comparison on only a single trial within the block.

The data in the fifth section of each panel show the data obtained during the presentation of the combination of all 3 conditional discriminations. Three of the 6 subjects showed some degree of disruption: 1 at the 100% feedback level, 1 at the 75% level and 1 at the 0% level. In each case, the disruption resulted in only a single test block in excess of the minimum required and represented only a single error within the block. These trial based percentage data are shown in Table 9.

To summarize, the data in Figure 5 and Table 9 demonstrate that rate of acquisition of these feature category conditional discrimination was quite rapid. Further, accurate performances were minimally disrupted by the reduction in feedback or by the addition of previously learned relations to blocks containing newly acquired conditional relations.

Equivalence Class Formation

Figure 6 presents the data for participant TF3166DH during the training of the vocation-based equivalence classes. Training and testing blocks are indicated on the abscissa and correspond to the blocks described in the method section. The number of blocks required to meet the % correct criterion is indicated on the ordinate and the height of each bar indicates the number of blocks needed to pass a given phase of class formation. The lower portion of each bar indicates the minimum number of blocks required for training of the baseline conditional discriminations (BL: white bar) and testing of the emergent relations (ERP: checkered bar). The upper portion of each bar (black) indicates the number of blocks in excess of the minimum that were required to meet the mastery criterion. The absence of a black segment on the bar indicates that the % correct criterion was met in the minimum number of blocks required.

For this subject 2 blocks in excess of the minimum required were needed to establish the T1 and T3 baseline conditional discriminations and a single block in excess of the minimum was required to establish the T2 baseline conditional discrimination. Only a single emergent relations probe (E1) required an additional block to meet the mastery criterion. All other trained and emergent relations were demonstrated within the minimum number of programmed blocks.

The formation of both sets of classes for each participant were considered together and are presented in Figure 7. Figure 7 illustrates the performances of all participants during the establishment of the vocation-based (left panels) and nationality-based (right panels) equivalence classes. Each panel has the same format used in Figure 7. Visual inspection of these graphs indicates that each of the baseline conditional discriminations (white bars) were acquired in a small number of blocks with little variability across the baselines within subjects and little variability among all baseline relations across participants. Acquisition of the baseline symbol-feature conditional discriminations then was rapid.

For a given class, the number blocks needed to learn each of the new baseline conditional discriminations did not vary systematically from the number of blocks needed to learn the previously established baseline relations. Therefore, no learning set was observed across the acquisition of the new conditional discriminations. Conversely, the acquisition of one conditional discrimination did not interfere with the acquisition of a subsequently learned conditional discrimination. Further, the baseline relations were maintained with minimal disruption during the reduction of feedback from 75% to 25%, to 0% (data not shown). The actual level of class consistent responding for each block presented during acquisition of the baseline conditional discriminations is presented in Table 10. During the acquisition of baseline conditional discriminations, non-mastery based performances were never below 75% accuracy.

The presentation of the emergent relations probes in Figure 7 (checkered bars) typically produced mastery levels of class indicative comparison selections in the minimum number of test blocks. These performances indicated the immediate emergence of the derived relations. When emergent relations probes did not evoke the mastery level of responding on the first test block, the performances were always at least 75% accurate and were frequently higher.

In general, then, these data demonstrate the immediate or delayed but rapid emergence of 4-member equivalence classes. Baseline conditional discriminations were maintained with minimal, if any, disruption with feedback reduction and untrained relations emerged rapidly with little variability both within and between participants.

Because the vocation-based classes were established prior to the nationality-based classes, it was possible that the formation of the first set of classes might have influenced the formation of the subsequently established equivalence classes. When the two were compared in terms of blocks to acquisition, maintenance of baseline relations, and block needed for the emergence of the derived relations, no systematic differences were noted.

Symbol~Dual Features Tests

Figure 8 illustrates performances of all participants during symbol-dual feature tests and dual feature-symbol in the left and right hand columns, respectively. Each row contains data for a given participant. In most cases, participants always selected the comparison that contained both features acquired by the symbol in the first test block. On the 3 occasions in which that did not occur, that comparison was always selected on the second block. Likewise, participants typically selected the symbol that had been linked by training with the pair of features presented as a sample on the first test block. On the 3 occasions that that did not occur the matching symbol was selected on the second block. There were no systematic differences in test performance across the different types of Co-. Finally, no systematic differences occurred between Voc and Nat Co-s of the symbol-dual feature tests and the dual feature-symbol tests.

The data presented in Table 11 characterizes the graded level of accuracy during both symbol-dual feature and dual feature-symbol tests. These data indicate that when performances were not at the mastery level in the first test block, the performances were always high, with an accuracy level of at least 80% on all trials.

To summarize, separate symbol-single feature relations had been established during the formation of the vocation- and nationality-based equivalence classes. This phase of the experiment evaluated the emergence of relations between the symbol and both acquired features in symbol-dual feature and dual feature-symbol tests. In all cases, these relations were present from first testing, regardless of the negative comparisons used in each test.

Classification Testing

Classification Probe Structure. Due to a programming error, only 32 of the 36 classification probes were assessed. The missing trials would have assessed the relations amongst the 2, 3, 5 and 6 stimuli, all of which would have comprised the last block of classification probes, as seen in Table 8. The loss of these data, however, does not preclude a demonstration of the classification of symbols based on contextual stimuli and the features acquired by the symbols.

Figure 9 is a graphic characterization of a single classification probe used to evaluate control of behavior during a given classification probe. Each classification probe was presented 8 times and each presentation is referred to as a trial. Of the 8 trials, 4 contained the vocation category name, and 4 contained the nationality category name. The order of presentation of the 8 trials was randomized without replacement.

Many aspects of the stimuli included in each probe may control performances on any given classification probe, each of which is referred to as a stimulus control topography (McIlvane & Dube, 2003). Figure 10 presents all possible stimulus control topographies for a single classification probe. The left side of the figure duplicates the set of 8 trials presented for each classification probe as depicted in Figure 9 but includes shading to indicate whether a given trial resulted in the selection of the vocation-based (gray) or nationality-based (checkered) comparison stimulus.

In each row, the two columns indicate patterns of comparison selection that demonstrate the influence of a given stimulus control topography on responding. The right side of the figure provides a description of the stimulus control topographies that are indicated by the pattern of comparison selections depicted in the columns to the left. The stimulus control topography that prevailed during a classification probe was operationally defined as at least 7 out of 8 trials that produced the pattern of responding consistent with each stimulus control topography. In the case where 7 out of 8 trials were consistent with the stimulus control topography specified, the single error could have occurred anywhere in the run of 8 trials presented for a given classification probe.

The two graphs in each row illustrate a specific pattern of responding on a single classification probe. On any given trial, the category name, indicated on the abscissa, is initially presented, (V or N). The category name is followed by the presentation of a sample stimulus and 2 comparison stimuli in a triangular format. The sample stimulus is presented at the vertex of the triangle while the comparison stimuli are presented at the base of triangle. The sample and comparison stimuli are illustrated in the box above the bars on the graph. The sample stimulus contains a vocation-based feature (indicated in blue) and a nationality-based feature (indicated in red). Comparison stimuli are presented in pairs and any given pair of comparison stimuli contains one stimulus that has been associated with the same vocation-based feature and a different nationality-based feature and one stimulus that has been associated with the same nationality-based feature but a different vocation-based feature. Features of a comparison stimulus that differ from the sample stimulus are indicated in black.

The ordinate of the graph indicates the number of trials of a given trial type within the classification probe. Each set of bars represents 4 trials of the same sample/comparison configuration for both the vocation and nationality context cues and each trial is indicated by a box segment of the bar. The shading in each box indicates the selection made during a given trial. Bars shaded in gray indicate selection of the comparison stimulus that shares a nationality-based feature with the sample while the checkered bars indicate selection of the comparison stimulus that shares a vocation-based feature with the sample.

A description of each type of stimulus control topography is shown to the right of the two graphs in each row. The first row indicates joint control of comparison selections by the prevailing category cue and the features acquired by the symbols present in the test trials. This stimulus control topography is represented symbolically as D-Cxt (Experimenter-defined contextual control) and could only be produced if the category names and acquired features of the symbols were acting in concert to exert control over comparison selection. The second row indicates control by the features acquired by the symbols but inverse control by the category names. This pattern of responding could also only be produced if the category names and acquired features of the symbols were acting in concert to exert control over comparison selection but in this case, the Vocation category name resulted in comparison selection based on the acquired Nationality feature while the Nationality category name resulted in comparison selection based on the acquired Vocation feature. This stimulus control topography is represented symbolically as I-Cxt (Inverse contextual control).

The third row indicates control by the vocation-based features and no control by category names. This pattern of responding could not be produced if the category name was acting to indicate that comparison selection should be based on the common feature to which the category name specified. Rather, this pattern of responding would demonstrate preference for selection of the comparison stimulus that shared the same vocation-based feature as the sample. This stimulus control topography is represented symbolically as f-Voc (Feature-based selection: Vocation). The fourth row indicates control by the nationality-based features and no control by the category names. This pattern of responding could not be produced if the category name was acting to indicate that comparison selection should be based on the common feature to which the category name specified. Rather, this pattern of responding would demonstrate preference for selection of the comparison stimulus that shared the same nationality based feature as the sample. This stimulus control topography is represented symbolically as f-Nat (Feature-based selection: Nationality).

Finally, the fifth row indicates no control by either the category name or acquired features. This pattern of responding could not be produced if the category name was acting to indicate that comparison selection should be based on the common feature that the category name specified, nor could it be produced if selection comparison was based on the shared features of a single category. Because the specific stimulus control topography governing comparison selection is difficult to ascertain when more than one error is made on a given classification probe, any classification probe that resulted in 2 or more incorrect comparison selections was considered to be an indefinable stimulus control topography.

Classification test performances. Performances for participants TF3157AL and TF3159SD during classification tests are illustrated in the top and bottom rows of Figure 11, respectively. The left panels show the stimulus control topographies during each of the 32 classification probes. The abscissa lists the classification probes in order of their presentation in Table 8. The ordinate corresponds to the stimulus control topographies illustrated in Figure 9. Thus, this data presentation provides a longitudinal characterization of the stimulus control topographies that emerge in real time with the succession of presentation of the 32 classification probes.

The form of stimulus control evoked by each classification probe was determined by pattern of responding observed in the overall test block. As shown in Table 8, each block contained 2 classification probes each consisting of 8 trials. The patterns of responding to each of the classification probes were compared to the patterns illustrated in Figure 10. The pattern of responding that governed behavior on each classification probe is represented as a dot, above the classification probe indicated on the abscissa, on the line corresponding to the form of stimulus control that governed responding on that probe. For example, in the top panel of Figure 11 (TF3157AL), classification probe 3 has a dot on the line corresponding to f-Nat because during this classification probe the participant responded by exclusively selecting the comparison stimulus that shared a Nationality feature with the sample.

The right panels of Figure 11 provides a summary of the stimulus control topographies aggregated across all 32 classification probes. This figure then provides a cross sectional characterization of the stimulus control topographies that controlled performances, regardless of the order of occurrence. In this case, the stimulus control topographies are indicated on the abscissa, while the classification probes are indicated on the ordinate.

For participant TF3157AL, 24 out of 32 classification probes produced responding that was not consistent with selection based on joint control or control by acquired features. For this participant, neither the acquired features nor the category names controlled responding during the categorization tests.

For participant TF3159SD, the first 16 classification probes occasioned performances that were consistent with either direct joint control by category name and acquired features or by inverse control. Of interest, the first 16 probes alternated systematically between joint control and inverse control. The factors responsible for this alternation, however, are unclear.

After this initial alternation between joint control and inverse joint control by the category names, the performances produced by the remaining classification probes were indicative of random responding. This transition demonstrated the loss of control by either the category name, or the features acquired by the symbols used as sample and comparison stimuli.

Although the performances shown by both subjects were different, it is unlikely that the absence of the expected performances resulted from a breakdown in the symbol-dual feature relations because they had been demonstrated immediately prior to the classification test. Rather, it is more likely that these performances were related to a breakdown in the feature-category relations. For this reason, the testing procedure was revised for the four remaining subjects. Specifically, the feature-category relations were retrained immediately prior to the presentation of the classification probes for the 4 remaining participants.

Figure 12 presents the data for the feature-category retraining that preceded the classification probes for the remaining 4 participants (TF3156YK, TF3163MT, TF3166DH and TF3168UP). The format of this figure is identical to that used in Figure 4 and demonstrates that some initial reacquisition of the relations was required for all of the 4 subjects. Although the number of blocks in excess of the minimum required to meet criteria was minimal, these data suggest that some breakdown in the trained relations had occurred. Sub-criterion performances, as shown in Table 9, were also comparable to the initial feature-to-category name training.

The fact that some retraining was needed to reestablish the feature-category relations provides some support for the view that the absence of these relations might have accounted for the inconsistent performances during the classification probes conducted with participants TF3157AL and TF3159SD. Figures 13-14 present the results of the classification tests for the subjects who received this feature- category retraining. Figure 13 presents the performances on the classification probes for TF3166DH and TF3168UP. Although these subjects were exposed to the feature-category re-training, each demonstrated a form of control that was different from that seen with the two prior subjects. For subject TF3166DH, despite the demonstration that all prerequisite relations were intact, the classification probes resulted in comparison selections that were based on the acquired vocation feature on 6 of the 32 tests, or the acquired nationality features on 11 of the 32 tests. The remaining 5 blocks for this participant indicated either random responding (4 blocks) or inverse contextual control (1 block). The performances of this participant did not indicate any joint control by category names and acquired features.

In contrast, participant TF3168UP exhibited an unusual pattern of joint control by the category names and features acquired by the symbols. This subject demonstrated a pattern of responding consistent with the experimenter-defined classes on some blocks (15 out of 32) but inverse control on other blocks (15 out of 32). Similar to TF3159SD, this participant also alternated systematically across classification probes. In this case, TF3168UP demonstrated a dual alternation in that responding on the first 2 probes were consistent with joint control by the category names and acquired features and the next 2 probes were consistent with inverse joint control. This interleaved pattern of D-Cxt and I-Cxt continued throughout the series of classification probes. Although it is unclear what produced this shift in comparison selection, it would appear that the relations between the acquired features and the category names were switched during the classification tests such that the vocation category name resulted in comparison selection based on the acquired nationality-base feature while the nationality category name resulted in comparison selection based on the acquired vocation-based feature.

Figure 12 presents the results of the classification probes for two of the participants who also received feature-category retraining immediately prior to the classification probes, TF3159YK and TF3163MT. For both participants, the initial classification probes did not evoke performances that were indicative of classification based on joint control by the category names and the acquired features of the symbols. For participant TF3159YK, performance during the initial classification probes indicated control by the Vocation-based features with no control by the category names. With successive classification probes, performances shifted to joint control by the category names and acquired features of the symbols. For Participant TF3163MT, performances on all but two classification probes indicated joint control by the category name and acquired features of the symbols.

These data demonstrated that the class membership of a given symbol varied according to the prevailing category name in the absence of feedback and in the absence of the features previously acquired by the symbols. The probability of accurate responding based on chance on any trial within the set of 32 classification probes was 0.5. Thus, assuming that performance on any trial was independent of performance on any other trial, the likelihood of completely accurate performance (all 8 trials of the 32 classification probes or 256 trials) during the final classification test is 8.64e-78.

Participant TF3156YK responded consistent with a D-Cxt stimulus control topography on 231 of the 256 trials. The likelihood of this level of accuracy occurring as a result of random responding is equal to 2.66e-43. Participant TF3163MT responded consistent with a D-Cxt stimulus control topography on 248 of the 256 trials. The likelihood of this level of accuracy occurring as a result of random responding is equal to 3.54e-63.

Within participant demonstration of contextual control. For one of the two participants mentioned above, TF3163MT, two follow-up tests were conducted to determine the effects of the presence of the category names on the performances evoked by the classification probes. Further, these tests allowed us to assess whether the presentation of the conflict tests in the absence of a category name resulted in a decrement or breakdown in subsequent control by the category names. Thus, although these follow-up tests contained the same sample and comparison pairs as the classification probes, these tests were conducted in the absence of the category name. Thus, on any given trial a classification probe was presented in the absence of a category name to assess what might control responding on these ambiguous trials. These data are shown in Figure 15.

During these test trials, the absence of the category names resulted in virtually exclusive control by the acquired Nationality-based features. Following these performances, this subject was re-exposed to the category tests containing the category names and once again, virtually all of the classification probes engendered performances that indicated joint control by the category name and acquired features of the symbols. To summarize, the three testing cycles constituted a presence-absence-presence or ABA evaluation of the effects of the category names on the classification of stimuli into different equivalence classes based on the features shared by sample and comparison stimuli. The results of the three testing conditions demonstrated, on a within-participant basis, that the classification of symbols was determined by the joint control of the category names and the features acquired by 9 stimuli that were members of equivalence classes. It should also be noted that the performances in all three cycles of testing were conducted in the absence of feedback. Thus, the control of class assignment by contextual stimuli and the acquired features of the stimuli being assigned to classes was maintained with repeated presentation of test trials in the absence of feedback.

Discussion

Summary

The present experiment studied the conditions needed to induce the classification of all of the symbols in a set into different equivalence classes based on (a) the presence of category labels which function as contextual stimuli, (b) specific features that are members of different categories (feature-category relations), and features from different categories that have been acquired by each of the symbols (symbol-feature relations). Two of the 6 subjects classified each of the nine symbols in the experiment into one of two different equivalence classes based on the category name presented during each classification probe and the features acquired by the symbols during training. In addition, that assignment occurred in the absence of the features that had been acquired by the symbols. Finally, all of the class assignments occurred in the absence of direct feedback. Thus, in the presence of the Vocation based contextual cue, the classes were 123p, 456w, and 789c. In the presence of the Nationality based contextual cue, the classes were 147a, 258f, and 369g.

The membership of one symbol in two different equivalence classes can be illustrated with the following example. When presented with the category name vocation in a classification test, Renoir was assigned to a class of painters based on training that established Renoir as a painter. When, however, presented with the category name nationality in a classification probe, Renoir was assigned to a class of French citizens based on training that established Renoir as French.

The global reclassification of symbols into different equivalence classes based on acquired features and the prevailing category names represents a rather significant extension of the findings of earlier studies. These studies demonstrated the contextually controlled switching of class membership of a single stimulus in an equivalence class. The influence of the contextual stimulus reflected discrimination reversal training with the stimuli that switched class membership that was conducted in the presence of the contextual stimuli prior to the class switching tests.

Factors that Influenced Symbol Classification.

Although the main finding of the experiment is summarized above, the experiment was conducted in many phases. Each was used to establish one of the stimulus control repertoires that was a prerequisite of the classification repertoire mentioned above. A fuller understanding of the behavioral processes that influenced the emergence of symbol classification control by contextual cues and features acquired by those symbols can be discerned by a consideration of the performances established in each phase of the experiment. Each will be described below.

Feature-category relations. The experiment began with the establishment of **c**onditional relations between three stimuli referred to as features and a category name. This was done for two different categories. The stimuli presented as samples were used as the features while the comparison stimuli served as comparisons. Thus, feature-category relations were established using a comparison-as-node or many-to-one training structure. In addition, the establishment of the various conditional discriminations was conducted in a serial manner. The acquisition of the conditional discriminations was very rapid, as would be expected given the use of a comparison-as node-training structure and the serial form of training (Fields & Verhave, 1987).

The apparent robustness of the feature-category conditional discriminations was suggested by the fact that the inclusion of previous and recently learned conditional discriminations did not disrupt the relational performances occasioned by either of the conditional discriminations. Although the feature-category relations were not disrupted under these conditions, other data raise questions about the retention of these relations. Specifically, after the formation of the vocation- and nationality-based equivalence classes and testing for the relations between the dual features and the symbols, retraining was needed to reinstate the feature-category relations. It is possible, then, that the inclusion of feature cues in the vocation- and nationality-based equivalence classes could have disrupted the previously established feature-category relations.

Equivalence class formation. Three 4-member vocation based equivalence classes were established using nine stimuli referred to as symbols. Each class consisted of three symbols representing the names of individuals and a feature that corresponded to one of three vocations. Following the formation of these vocation-based equivalence classes, the same set of nine symbols then formed three other equivalence classes based on acquired nationality based features. All of these equivalence classes were established very rapidly by all participants. All of the vocation based and nationality based equivalence classes were established using the simple-to-complex protocol (Adams, Fields & Verhave, 1993) and each had a comparison-as-node training structure (Buffington, Fields & Adams, 1997). In addition, training and testing were conducted using a multiple negative comparison trial format (Adams, Fields & Verhave, 1999; Harrison & Green, 1990). Each of these procedural factors is known to facilitate the formation of equivalence classes. The combined usage of these procedures probably accounted for the rapid formation of the equivalence classes in the present experiment.

Separation of vocation- and nationality-based equivalence classes with no contextual cues. As noted above, although each symbol was a member of a vocation-based and a nationality-based equivalence class, the two classes remained separated from each other. This occurred even though each symbol was associated with vocation-based and nationality-based features. The source of the separation of classes is controlled by the distribution of features acquired by the stimuli in the emergent relations probes. This can be illustrated by considering a representative equivalence probe that contains the 1, 2 and 5 symbols as the sample, positive comparison, and negative comparison, respectively.

This probe evaluates an equivalence relation between two symbols in the Vocation based class: 1 as the sample and 2 as the positive comparison. The sample 1 had acquired the features (p) and (a), the positive comparison 2 had acquired the features (p) and (f), and the negative comparison 5 had acquired the features (w) and (f). Thus, the sample and positive comparison (1 and 2) share the same acquired vocation based feature (p). In contrast, the sample and negative comparison (1 and 5) contain different vocation based features: (p) for the sample and (w) for the negative comparison. Therefore, by attending to the vocation-based features acquired by the symbols in the equivalence probe, it is possible for a subject to conditionally select the comparison that is from the same class as the sample stimulus.

The situation is markedly different with regard to the nationality-based features acquired by the 1, 2, and 5 symbols. Both the positive and negative comparisons (2 and 5) contained the same nationality based feature (f). Therefore, differential selection of the positive comparison was not possible if a subject attended to the nationality based features that had been acquired by the symbols during the establishment of the baseline conditional discriminations.

Virtually all of the emergent relations probes produced class consistent comparison selections, which documented the formation of vocation based and nationality based equivalence classes. These performances could have occurred only if a subject was under the discriminative control of the vocation based features during the tests that evaluated the emergence of the vocation based classes and to the nationality based features during the tests that evaluated the emergence of the nationality based classes. One final note, the performances evoked by the symbols in the equivalence probes had to be under the conditional discriminative control of features that had been acquired by the prevailing samples and comparisons. This occurred even though those features were not physically present at the time of testing.

This separability of equivalence classes based on acquired features has not been observed before. It may, however, be germane to equivalence classes in real life settings. The stimuli in real life equivalence classes are linked to many defining features yet the classes containing those features do not coalesce even in the absence of explicit contextual or instructional stimuli. It is likely that the combination of features in the set of comparisons act as discriminative stimuli for selective control by features that are different in each comparison stimulus in a set.

Interference in the formation of equivalence classes. In the present experiment, vocation based classes were formed before the nationality based classes. Because both sets of classes contained the same nine symbols, the features acquired by the symbols during the formation of the vocation-based equivalence classes could have interfered with the formation of the second set of equivalence classes. That, however, was not the case. The baseline conditional discrimination for the nationality-based equivalence classes were learned at the same rate as the baseline relations for the previously learned vocation-based classes. In addition, all of the derived relations emerged immediately. Perhaps the absence of an interference effect was due to the discriminative function served by the commonality of the features acquired by the comparisons in the conditional discriminations that were the baselines of each type of equivalence class.

Symbol-Dual Feature Relations. During the formation of the equivalence classes, relations were established between each symbol and one feature stimulus in each of two different and orthogonal stimulus sets (nationality and vocation). The dual feature-symbol tests evaluated whether a participant would identify the relation between each stimulus and the pair of features that had been established on a separate basis. All subjects passed these tests, regardless of the complexity of the negative comparisons used in the test trials.

These tests were conducted immediately prior to the classification tests. Thus, the relations between each symbol and its acquired features were intact at the time of the classification tests. Failures of the classification tests then could not be attributed to the absence of the relations between the symbols and their acquired features.

Classification test outcomes for two participants. At the conclusion of the symbol-dual feature and dual feature-symbol test, all of the subjects had acquired all of the conditional relations that were logically needed to classify the symbols based on the contextual function of the category cues and the features acquired by the symbols. When two subjects were then presented with the classification probes, one responded in an unsystematic manner, which demonstrated a lack of control by the category names and a lack of control by the features acquired by the symbols. The other subject showed some evidence of joint control based on category names and the features acquired by the symbols at the start of testing. By the second half of classification testing, however, responding devolved to an unsystematic pattern of comparison selection.

As mentioned above, the emergence of contextual control of class membership of the symbols during the classification tests requires that all previously trained conditional relations be intact. Immediately before the classification test, the participants were not given a review of the feature-category relations. Thus, the failure of classification could have been due to a breakdown of the feature-category relations that had been established at the start of the experiment.

Retraining of feature-category relations. To prevent this potential source of failure, feature-category retraining was conducted with the four remaining subjects immediately prior to the presentation of the classification probes. Notably, as many errors were made during feature-category retraining as had occurred during the initial training of these relations. These results suggested that the feature-category relations might not have been intact at the time of classification testing with the first two participants. Thus, the failures of classification could have been due to a breakdown of the feature-category relations.

It is also possible that the failure of the classification tests was ***not*** due to the breakdown of the feature-category relations at the time of classification testing. During the establishment of the feature-category relations, the category cues were always presented as comparisons and never as sample stimuli. During the classification tests, the category cues were always presented as samples and never as comparisons. For contextually controlled classification of symbols to occur as expected, the category cues would have to function as samples instead of the comparison functions they served during training (I.e., the features and categories would to be symmetrically related to each other).

With regard to the remaining four subjects, the retraining of the feature-category relations ensured that they would be active at the time of classification testing. Thus, any failures seen with these four subjects could not be ascribed to the absence of the feature-category relations. Retraining, however, did not address the issue of symmetricality of the features and the category cues. Although failure of symbol classification could not be attributed to the absence of feature-category relations, this manipulation did not rule out failure based on nonsymmetricality.

The effect of feature category retraining can be adduced by a comparison of the classification test performances of these two subjects who did not have such retraining and the four subjects who did., The two subjects who did not have feature-category retraining responded unsystematically to most of the classification probes. The subjects who received retraining rarely responded unsystematically to the classification probes. Some of the performances were indicative of control by context and features direct and inverse, others responded to nationality-based features or vocation-based features. In all cases, however, at least some form of stimulus control governed performances. Therefore, the retraining of the feature-category relations prompted control by some topography.

Classification test outcomes after feature-category retraining. After feature-category retraining, the classification probes presented to participant TF3166DH produced responding that was in accordance with the features in one category but was not in accordance with the category stimuli presented during the test trials. For this participant, the absence of contextual control could not be attributed to the absence of the relations between each category cue and its related feature stimuli. Further, failure could not be attributed to a breakdown in symbol feature relations because the performances were highly consistent with the presence of features in a particular category. Failure, then, had to reflect the absence of joint control of responding by contextual stimuli in combination with the features acquired by the symbols.

When participant TF3168UP was presented with the classification probes, the performances were indicative of contextual control and the features acquired by the symbols. These data also were somewhat puzzling since there was a completely systematic alternation of direct contextual control and inverse contextual control across pairs of classification probes presented in a test block. The variables responsible for this double alternation are not yet apparent. Nevertheless, the data do show some of the predicted contextual control.

When the last two subjects (TF3156YK and TF3163MT) were presented with the classification probes, they classified the symbols into different equivalence classes that were in accordance with the prevailing contextual cue and the features acquired by each symbol. These participants then demonstrated the emergence of six different equivalence classes, the membership in each being governed by the prevailing contextual cue and a particular set of category features. This sort of emergent performance reflected joint control by contextual cues and selective discriminative control by features that had been acquired by symbols, even though the symbols were not present at the time of classification (Iversen, 2006). As noted in the results, there was only a miniscule likelihood of these performances occurring by chance.

One of these subjects (TF3163MT) was exposed to an ABA test of contextual control. He showed the abovementioned performance when the contextual cues were presented (the A condition) and responding in accordance with the features in Nationality category in the absence of the contextual cues (the intervening B condition). These performances showed the classification of symbols based on contextual control and features acquired by symbols was not disrupted by the presentation of the classification probes in the absence of the contextual cues and in the absence of feedback.

Conclusion. The present experiment identified the behavioral repertoires that are necessary for the classification of a set of symbols into different equivalence classes based on features acquired by those symbols but not present at the time of classification. The results demonstrate that the establishment of at least 3 prerequisite repertoires are required: 1) the establishment of relations between a category name and exemplars of that category, 2) the establishment of relations between the symbols and their category-based features and 3) the maintenance of relations between the symbols and their acquired features in the absence of the acquired features. Although these repertoires appear to be necessary, they were not sufficient since only some of the participants in the study passed the final classification test.

These findings represent a significant advancement in our understanding of how stimuli can function as members of different equivalence classes. Although previous research had demonstrated that contextual cues could govern the membership of a single stimulus in different equivalence classes, the control exerted by the contextual cues was always based on a direct contingency between the contextual cue and the stimulus that was switching class membership. The present experiment extended these findings and demonstrated that contextual cues can also govern the membership of all of the stimuli in a set by indicating which previously acquired features of each stimulus, should be attended to during classification, even though those features were not physically present at the time of classification. As mentioned above, this emergent repertoire did not occur with all participants. Additional research will be needed to elucidate procedures that enhance the reliability and generality of symbol classification based on contextual cues and the features acquired by the symbols.

Table 1: Stimuli used in the current experiment. The first column indicates the cue type and the successive columns indicate the metaphorical names, the symbolic representations, the actual stimuli used (CVC's) and their numerical representations, respectively.

Cue Type	Names	Symbolic	Stimuli
Category Names	Nationality	N	@@@@
	Vocation	V	####
Vocation-Based Features	Painter	p	JEV
	Writer	w	YUT
	Composer	c	DOP
Nationality-Based Features	American	a	ZEP
	French	f	GUQ
	German	g	COV
Symbols	Pollock	1	LEQ
	Renoir	2	ZOJ
	Bosch	3	BAF
	James	4	CAZ
	Voltaire	5	MEV
	Goethe	6	ROL
	Gershwin	7	POV
	Debussy	8	YAR
	Beethoven	9	GEP

Table 2a: Feature-Category relations and stimuli used for their establishment. The direction of the trained relation is shown in the far left column and is followed by the symbolic representations and the metaphorical representations of the trials used for training. Details regarding the order of training are provided in the text.

Relation	**Symbolic**			**Metaphorical**		
	Sa	Co+	Co-	Sa	Co+	Co-
p→V	p	V	N	Painter	Vocation	Nationality
w→V	w	V	N	Writer	Vocation	Nationality
c→V	c	V	N	Composer	Vocation	Nationality
a→N	a	N	V	American	Nationality	Vocation
f→N	f	N	V	French	Nationality	Vocation
g→N	g	N	V	German	Nationality	Vocation

Table 2b: Feature –Category Relations. Trial configurations in each training block (T) and testing block (M) used to establish Feature-Category relations. Blocks were presented as ordered in the left column. Details regarding the randomization of trials within each block are provided in the text.

		Symbolic			**Metaphorical**		
Blk	Type	Sa	Co+	Co-	Sa	Co+	Co-
T1	Training	p	V	N	Painter	Vocation	Nationality
		a	N	V	American	Nationality	Vocation
T2	Training	w	V	N	Writer	Vocation	Nationality
		F	N	V	French	Nationality	Vocation
M2	Testing	p	V	N	Painter	Vocation	Nationality
		w	V	N	Writer	Vocation	Nationality
		a	N	V	American	Nationality	Vocation
		f	N	V	French	Nationality	Vocation
T3	Training	c	V	N	Composer	Vocation	Nationality
		g	N	V	German	Nationality	Vocation
M3	Testing	p	V	N	Painter	Vocation	Nationality
		w	V	N	Writer	Vocation	Nationality
		c	V	N	Composer	Vocation	Nationality
		a	N	V	American	Nationality	Vocation
		f	N	V	French	Nationality	Vocation
		g	N	V	German	Nationality	Vocation

Table 3a: Baseline conditional discriminations used to establish "Vocation"-Based equivalence classes. Numbers refer to the names of individuals. Letters refer to Vocations.

Symbolic Representation of Equivalence Class	**Trained Relations**
Class 123p	**1→p 2→p 3→p**
Class 456w	**4→w 5→w 6→w**
Class 789c	**7→c 8→c 9→c**

Table 3b : Baseline conditional discriminations used to establish "Nationality"-Based equivalence classes. Numbers refer to the names of individuals. Letters refer to Nationalities.

Symbolic Representation of Equivalence Class	**Trained Relations**
Class 147a	**1→a 4→a 7→a**
Class 258f	**2→f 5→f 8→f**
Class 369g	**3→g 6→g 9→g**

Table 4: Blocks of training and testing trials used to establish three "Vocation"-Based equivalence classes. The far left column (BLK) lists the designation assigned to the block and is described in the text. Subsequent columns indicate the sample and comparison pairs used during the blocks that correspond to the different vocation-based equivalence classes. No Sa or Co+ listed in a row indicates that the Sa and Co+ were identical to those presented in the line above. Each trial within a block was presented 4 times regardless of block type or, within training trials, during feedback reduction.

				Equivalence Class					
			123p			**456w**			**789c**
BLK	**Sa**	**Co+**	**Co-**	**Sa**	**Co+**	**Co-**	**Sa**	**Co+**	**Co-**
T1	1	p	w	4	w	p	7	c	p
			c			c			w
S1	p	1	4	w	4	1	c	7	1
			7			7			4
T2	2	p	w	5	w	p	8	c	p
			c			c			w
S2	p	2	5	w	5	2	c	8	2
			8			8			5
MS1		**COMBINES ALL TRIALS INCLUDED IN T1, T2, S1 & S2**							
E1	1	2	5	4	5	2	7	8	2
			8			8			5
	2	1	4	5	4	1	8	7	1
			7			7			4
M1		**COMBINES ALL TRIALS INCLUDED IN T1, T2, S1, S2 & E1**							
T3	3	p	w	6	w	p	9	c	p
			c			c			w
S3	p	3	6	w	6	3	c	9	3
			9			9			6
MS2		**COMBINES ALL TRIALS INCLUDED IN T1, T2, T3, S1, S2 & S3**							
E2	1	3	6	4	6	3	7	9	3
			9			9			6
	2	3	6	5	6	3	8	9	3
			9			9			6
	3	2	5	6	5	2	9	8	2
			8			8			5

ME1	**COMBINES ALL TRIALS INCLUDED IN T1, T2, T3, E1 & E2**
M2	**COMBINES ALL TRIALS INCLUDED IN T1-T3, S1-S3 & E1-E2**

Table 5: Blocks of training and testing trials used to establish three "Nationality"-Based equivalence classes. The far left column (BLK) lists the designation assigned to the block and is described in the text. Subsequent columns indicate the sample and comparison pairs used during the blocks that correspond to the different vocation-based equivalence classes. No Sa or Co+ listed in a row indicates that the Sa and Co+ were identical to those presented in the line above. Each trial within a block was presented 4 times regardless of block type or, within training trials, during feedback reduction.

Equivalence Class

		147a			**258f**			**369g**	
BLK	**Sa**	**Co+**	**Co-**	**Sa**	**Co+**	**Co-**	**Sa**	**Co+**	**Co-**
T1	1	a	f	2	f	a	3	g	a
			g			g			f
S1	a	1	2	f	2	1	g	3	1
			3			3			2
T2	4	a	f	5	f	a	6	g	a
			g			g			f
S2	a	4	5	f	5	4	g	6	4
			6			6			5
MS1		**COMBINES ALL TRIALS INCLUDED IN T1, T2, S1 & S2**							
E1	1	4	5	2	5	4	3	6	4
			6			6			5
	4	1	2	5	2	1	6	3	1
			3			3			2
M1		**COMBINES ALL TRIALS INCLUDED IN T1, T2, S1, S2 & E1**							
T3	7	a	f	8	f	a	9	g	a
			g			g			f
S3	a	7	8	f	8	7	g	9	7
			9			9			8
MS2		**COMBINES ALL TRIALS INCLUDED IN T1, T2, T3, S1, S2 & S3**							
E2	1	7	8	2	8	7	3	9	7
			9			9			8
	7	1	2	8	2	1	9	3	1
			3			3			2
	4	7	8	5	8	7	6	9	7
			9			9			8

ME1	**COMBINES ALL TRIALS INCLUDED IN T1, T2, T3, E1 & E2**
M2	**COMBINES ALL TRIALS INCLUDED IN T1-T3, S1-S3 & E1-E2**

Table 6: Assessment of Symbol-Dual feature relations. Condition varied based on the "Nationality"- and "Vocation"-based features shared between the Co+ and Co-. The + and – signs correspond to shared "Nationality"-based and shared "Vocation"-based features, respectively.

		Type of Co-		
Sa	**Co+** +/+	**V-no N-no** -/-	**V-yes N-no** -/+	**N-yes V-no** +/-
1	ap	fw gw fc gc	fp gp	aw ac
2	fp	aw gw ac gc	ap gp	fw fc
3	gp	aw fw ac fc	ap fp	gw gc
4	aw	fp gp fc gc	fw gw	ap ac
5	fw	ap gp ac gc	aw gw	fp fc
6	gw	ap fp ac fc	aw fw	gp gc
7	ac	fw gw fp gp	fc gc	ap aw
8	fc	ap gp aw gw	ac gc	fp fw
9	gc	ap fp aw fw	ac fc	gp gw

Table 7: Assessment of Dual feature-Symbol relations. Tests varied by the type of Co- presented with the Sa. The V and N correspond to "Nationality" and "Vocation"; The sign following the letter (+ or -) indicates if the Co- shared that class-based feature with the sample stimulus. Trials were presented a minimum of 4 times in the absence of feedback. Details regarding the comparison pairs and the order of testing are provided in the text.

		Type of Co-		
Sa	**Co+**	**V-/N-**	**V+/N-**	**N+/V-**
ap	1	5 6 8 9	2 3	4 7
fp	2	4 6 7 9	1 3	5 8
gp	3	4 5 7 8	1 2	6 9
aw	4	2 3 8 9	5 6	1 7
fw	5	1 3 7 9	4 6	2 8
gw	6	1 2 7 8	4 5	3 9
ac	7	2 3 5 6	8 9	1 4
fc	8	1 3 4 6	7 9	2 5
gc	9	1 2 4 5	7 8	3 6

Table 8: Classification Probes. The 36 classification probes used to evaluate the classification of the symbols based on prevailing category name and the acquired vocation-based and nationality-based features of the symbols. Each row contains information for one of the classification probes. The first column indicates the block number that contained the classification probes. The second column contains the category name that is presented during a probe. The second, third and fourth columns indicate the names presented in each classification probe and specify the features associated with each name. The second column indicates the sample while the next two columns indicate the comparisons.

	Probe	Cx	Sa	Co+	Co-
Block 1	1	V	1-ap	2-fp	4-aw
		N	1-ap	5-fw	2-fp
	2	V	5-fw	4-aw	2-fp
		N	5-fw	2-fp	4-aw
	3	V	2-fp	1-ap	5-fw
		N	2-fp	5-fw	1-ap
	4	V	4-aw	5-fw	1-ap
		N	4-aw	1-ap	5-fw
Block 2	5	V	1-ap	2-fp	7-ac
		N	1-ap	7-ac	2-fp
	6	V	8-fc	7-ac	2-fp
		N	8-fc	2-fp	7-ac
	7	V	2-fp	1-ap	8-fc
		N	2-fp	8-fc	1-ap
	8	V	7-ac	8-fc	1-ap
		N	7-ac	1-ap	8-fc
Block 3	9	V	1-ap	3-gp	4-aw
		N	1-ap	4-aw	3-gp
	10	V	6-gw	4-aw	3-gp
		N	6-gw	3-gp	4-aw
	11	V	3-gp	1-ap	6-gw
		N	3-gp	6-gw	1-ap
	12	V	4-aw	6-gw	1-ap
		N	4-aw	1-ap	6-gw
Block 4	13	V	1-ap	3-gp	7-ac
		N	1-ap	7-ac	3-gp
	14	V	9-gc	7-ac	3-gp
		N	9-gc	3-gp	7-ac
	15	V	3-gp	1-ap	9-gc
		N	3-gp	9-gc	1-ap
	16	V	7-ac	9-gc	1-ap
		N	7-ac	1-ap	9-gc

Block 5	17	V	2-fp	3-gp	8-fc
		N	2-fp	8-fc	3-gp
	18	N	9-gc	8-fc	3-gp
		N	9-gc	3-gp	8-fc
	19	V	3-gp	2-fp	9-gc
		N	3-gp	9-gc	2-fp
	20	V	8-fc	9-gc	2-fp
		N	8-fc	2-fp	9-gc
Block 6	21	V	4-aw	5-fw	7-ac
		N	4-aw	7-ac	5-fw
	22	V	8-fc	7-ac	5-fw
		N	8-fc	5-fw	7-ac
	23	V	5-fw	4-aw	8-fc
		N	5-fw	8-fc	4-aw
	24	V	7-ac	8-fc	4-aw
		N	7-ac	4-aw	8-fc
Block 7	25	V	4-aw	6-gw	7-ac
		N	4-aw	7-ac	6-gw
	26	V	9-gc	7-ac	6-gw
		N	9-gc	6-gw	7-ac
	27	V	6-gw	4-aw	9-gc
		N	6-gw	9-gc	4-aw
	28	V	7-ac	9-gc	4-aw
		N	7-ac	4-aw	9-gc
Block 8	29	V	6-gw	5-fw	9-gc
		N	6-gw	9-gc	5-fw
	30	V	8-fc	9-gc	5-fw
		N	8-fc	5-fw	9-gc
	31	V	5-fw	6-gw	8-fc
		N	5-fw	8-fc	6-gw
	32	V	9-gc	8-fc	6-gw
		N	9-gc	6-gw	8-fc
Block 9*	33	V	3-gp	2-fp	6-gw
		N	3-gp	6-gw	2-fp
	34	V	5-fw	6-gw	2-fp
		N	5-fw	2-fp	6-gw
	35	V	2-fp	3-gp-	5-fw
		N	2-fp	5-fw	3-gp
	36	V	6-gw	5-fw	3-gp
		N	6-gw	3-gp	5-fw

*Data not recorded due to a programming error. See text for details.

Table 9. Feature-Category Training. Subject id, feedback level (FB) and block number are indicated in far left columns. The remaining columns represent each stage of training and testing. Lower case letters represent the features (p = painter, w = writer, c = composer, a = American, f = French, g = German) and upper case letters represent the category names (V = vocation, N = nationality). Arrows indicate the direction of the training and testing with the arrowhead pointing to the stimulus that served as the sample in a matching-to-sample format. Numbers in the cells indicate the percent correct within the block.

Subject	FB	Block	p -> V	a -> N	w -> V	f -> N	p -> V <- w	a -> N <- f	c -> V	g -> N	c ↓ p -> V <- w	g ↓ a -> N <- f
TF3157AL	100	1	100	75	100	100	100	100	100	75	100	100
		2	100	100					100	75		
		3							100	100		
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	75	100	100	100	100	100	100	100	100
		2	100	100								
	0	1	75	100	100	100	100	100	100	100	100	100
		2	100	100								
TF3159SD	100	1	100	50	75	25	75	75	75	75	92	100
		2	100	100	75	100	100	100	100	100	100	100
		3			100	100						
	75	1	100	100	100	100	100	100	75	100	100	100
		2							75	100		
		3							100	100		
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	100	75	100	100	100	100	100	100
		2			100	100						
TF3156YK	100	1	75	25	100	50	100	100	100	100	100	100
		2	100	100	100	100						
	75	1	100	100	100	100	100	87	100	100	100	100
		2					100	100				
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	100	100	100	100	100	100	100	100
TF3163MT	100	1	100	100	100	100	100	100	75	100	100	100
		2							100	75		
		3							100	100		
	75	1	75	100	100	100	87	100	100	100	100	100
		2	100	100			87	100				
		3					87	100				
		4					100	100				
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	75	100	100	100	100	100	100	75	100	100
		2	100	100					100	100		
TF3166DH	100	1	100	100	75	100	75	100	75	100	100	100
		2			75	100	100	100	100	100		
		3			100	100						
	75	1	100	100	100	75	100	100	100	100	100	92
		2			100	100					100	100
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	75	100	100	100	75	100	100	100
		2			100	100			100	100		
TF3168UP	100	1	75	50	100	100	100	100	100	75	100	100
		2	100	100					100	100		
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	100	100	100	100	100	100	92	100
		2									100	100

Table 10. Equivalence class training and testing. Block names (which correspond to Tables 4 and 5), feedback level (% FB), % correct to reach passing criteria (% Correct), stimulus sets within a block (Set #) and the minimum number of blocks required to reach criterion (Min Req) and actual number of blocks required to meet criterion are identified in the first 8 columns. Individual participant data for the "Vocation"-based and "Nationality"-based equivalence classes re identified in subsequent columns. Numbers within the cells indicate the percent correct during the block. Yellow indicates that the actual % correct was below minimum criterion.

Block Name	% FB	% Correct Crtierion	Set #	Min Req	Blocks	"Vocation"-Based Classes						"Nationality"-Based Classes					
						TF3157AL	TF3158SD	TF3156YK	TF3163MT	TF3166DH	TF3168UP	TF3157AL	TF3158SD	TF3156YK	TF3163MT	TF3166DH	TF3168UP
T1	100	100	1	1	1	93	100	97	87	93	100	100	89	97	100	97	89
					2	100		100	97	95		100	89	100		97	97
					3				97	100			93			100	95
					4				91				97				97
					5				91				97				100
					6				95				100				
					7				97								
					8				97								
					9				100								
	75	100	1	1	1	100	95	100	100	100	100	100	100	100	95	100	100
					2		100								100		
	25	100	1	1	1	100	95	100	95	100	100	100	100	100	100	100	100
					2		100		100								
	0	100	1	1	1	100	100	100	100	100	100	100	100	100	100	100	100
S1	0	100			1	100	100	100	91	100	100	100	97	97	100	100	100
					2				93				97	100			
					3				100				100				
T2	100	100	1	1	1	83	91	91	100	83	100	91	91	100	100	100	91
					2	91	100	100		100		91	100				91
					3	100						100					91
					4												100
	75	100	1	1	1	100	83	100	83	100	100	100	100	100	100	100	100
					2		91		100								
					3		100										
	25	100	1	1	1	100	83	100	100	100	100	100	100	100	100	100	100
					2		91										
					3		100										
	0	100	1	1	1	100	100	100	100	100	100	100	100	100	100	100	100
S2	0	98	1	1	1	100	97	100	93	100	97	100	100	100	100	100	97
					2		100		89		100						100
					3				98								
MS1	0	98	1	1	1	100	100	100	95	97	97	100	97	98	95	100	100
					2				100	100	100		100	100	98		
E1	0	95	1	1	1	97	95	100	91	91	97	100	97	98	100	95	100
					2				97	100							
			2	1	1	100	100	100	97	100	100	100	98	100	97	97	97
M1	0	95	1	1	1	99	96	100	95	100	100	100	100	100	97	97	98
			2	1	1	99	97	100	95	100	100	100	100	100	95	100	100
T3	100	100	1	1	1	91	83	91	83	75	91	100	83	91	83	75	83
					2	100	100	100	100	100	100		100	100	91	83	100
					3										100	100	
	75	100	1	1	1	100	100	100	83	100	100	100	91	91	100	100	100
					2				75				100	100			
					3				100								
	25	100	1	1	1	100	91	100	75	100	100	100	100	100	100	100	100
					2		100		100								
	0	100	1	1	1	100	100	100	83	100	91	100	100	100	100	100	100
					2				100		100						
S3	0	98	1	1	1	100	95	100	98	100	100	100	98	100	95	100	98
					2		100								100		
MS2	0	98	1	1	1	100	97	100	95	100	100	100	100	100	100	100	100
					2		100		94								
					3				100								
E2	0	97	1	1	1	98	100	97	100	98	100	100	100	100	97	80	97
				2	2	100	100	100	97	100	97	100	100	100	100	100	98
					3											100	
			2	1	1	100	100	100	100	98	100	100	100	100	100	94	98
				2	2	100	100	100	94	100	100	100	100	100	89	100	98
					3				97						97		
			3	1	1	100	100	100	91	100	100	100	100	100	91	100	98
				2	2	100	100	100	94	100	100	100	100	100	94	86	98
					3				100						100	97	
					4				97						94		
					5										94		
					6										97		
M2	0	95	1	1	1	100	100	100	87	100	100	100	100	100	95	97	97
				2	2	100	100	100	97	100	100	100	100	97	93	97	100
					3										100		
			2	1	1	100	100	100	97	100	100	100	97	97	95	97	100
				2	2	100	100	100	91	100	97	100	100	100	100	100	100
					3				97								
			3	1	1	100	100	97	91	100	100	100	97	100	87	97	100
				2	2	100	100	100	89	100	97	100	100	100	91	100	97
					3				97						87		
					4				100						95		
					5				100						89		
					6										100		

Table 11. Symbol-Feature and Feature-Symbol tests. Participants are identified in the first column followed by the number of blocks to reach the percent correct criterion (minimum of 97% correct) and the number of sets within each block. Subsequent columns indicate whether the Co- shared no features with the sample (None), a "Vocation" feature with the sample (Vocation) or a "Nationality" feature with the sample (Nationality). Numbers within the cells indicate the percent correct in the block. Yellow highlighting indicates that the percent correct criterion was not met in that block. Data are shown for Symbol-Feature tests and for Feature-Symbol tests as described in the text.

			Symbols --> Features			Features --> Symbols		
			Matching Feature in Co-			Matching Feature in Co-		
Participant	Block	Set	None	"Vocation"	"Nationality"	None	"Vocation"	"Nationality"
TF3157AL	1	1	98	97	83	100	97	92
	2				100			
	1	2	98	100	100	100	97	100
TF3159SD	1	1	98	94	94	98	100	97
	2			94	100	95		
	3			94				
	4			100				
	1	2	100	100	97	100	100	97
TF3156YK	1	1	98	97	100	100	100	100
	2	2	100	100	100	100	100	100
TF3163MT	1	1	100	94	100	98	94	100
	2			91			91	
	3			94			94	
	4			94			88	
	5			92			97	
	6			97				
	1	2	100	100	100	98	100	100
TF3166DH	1	1	100	83	100	100	100	97
	2			97		94		
	1	2	100	100	97	97	100	100
TF3168UP	1	1	100	100	63	98	86	80
	2				72		100	100
	3				88			
	4				97			
	1	2	100	100	97	98	100	97

Table 12. Feature-Category Re-training. Subject id, feedback level (FB) and block number are indicated in far left columns. The remaining columns represent each stage of training and testing. Lower case letters represent the features (p = painter, w = writer, c = composer, a = American, f = French, g = German) and upper case letters represent the category names (V = vocation, N = nationality). Arrows indicate the direction of the training and testing with the arrowhead pointing to the stimulus that served as the sample in a matching-to-sample format. Numbers in the cells indicate the percent correct within the block.

Subject	FB	Block	p -> V	a -> N	w -> V	f -> N	p -> V <- w	a -> N <- f	c -> V	g -> N	c ↓ p -> V <- w	g ↓ a -> N <- f
TF3156YK	100	1	75	100	100	75	87	100	75	100	92	100
		2	100	100	100	100			100	100	100	100
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	100	100	100	87	100	100	100	100	100
		2					100	100				
	0	1	100	100	100	100	100	100	100	100	100	100
TF3163MT	100	1	100	100	100	75	100	100	50	100	92	100
		2			100	100			100	100	100	100
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	100	100	87	100	100	100	100	100
		2					100	100				
TF3166DH	100	1	100	100	50	50	100	100	100	100	100	100
		2			100	100						
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	100	100	100	100	100	100	100	100	100
	0	1	100	100	100	100	100	100	100	100	100	100
TF3168UP	100	1	75	100	75	100	100	100	100	100	100	100
		2	100	75	100	100						
		3	100	100								
	75	1	100	100	100	100	100	100	100	100	100	100
	25	1	100	100	100	100	100	87	100	100	100	100
		2					100	100				
	0	1	100	100	100	100	100	100	100	100	100	100

Figure Captions

Figure 1: Six potential equivalence classes based on either "Vocation" or "Nationality" illustrated with a) with metaphorical names, b) symbolic representation and c) symbolically. Classes based on "Vocation" are ringed in blue and classes based on "Nationality" are ringed in red.

Figure 2: Explanation of conflict classification test. a) Conflict classification test presented in the absence of a category name. b) Conflict classification test presented in the presence of a category name. c) Tabular example of a conflict classification trial. Please note that a) is an ambiguous test because during training, 1 – ap has been associated with both comparison stimuli. Stimuli 1-ap and 2-fp were trained as members of the same "Vocation"-based equivalence class while stimuli 1-ap and 4-aw were trained as members of the same "Nationality"-based equivalence class. Thus, responding on this trial should be equally distributed between both comparisons. In the presence of the category name, however, the trial becomes disambiguated. Thus, in the presence of the category “Vocation”, the participant should choose the comparison that comes from the same "Vocation"-based class and in the presence of the cue “Nationality”, the participant should choose the comparison that comes from the same "Nationality"-based class. The features acquired by the stimuli are indicated in the parentheses and are not present at the time of testing.

Figure 3. Trial configuration of an equivalence test during Nationality-based classes that were the second set of equivalence classes trained. Metaphorical stimuli are shown in black and features of the stimuli are shown in color (blue = vocation feature; red = nationality feature). In this case, comparison selection cannot be based on the previously

acquired Vocation based featured because a) the vocation feature of both comparison stimuli are the same (writer) and b) the vocation feature shown is not the vocation feature that had been previously acquired by the sample. Please note that the features were not present during testing.

Figure 4. Performance or TF3156YK during feature-category training. Data are presented for each phase of training and the specific relations trained and tested are indicated in the boxes above each segment. Lower case letters represent the features (p = painter, w = writer, c = composer, a = American, f = French, g = German) and upper case letters represent the category names (V = vocation, N = nationality). Each arrow connects two stimuli that were the sample and comparison in a conditional discrimination with the sample at the tail of the arrow and the comparison at the head of the arrow. Feedback level during each stage of training and testing is indicated on the x-axis and number of trials to the % correct criterion is indicated on the y-axis. The lower segments of each bar (gray) indicate the minimum number of blocks required for training or testing while the upper segments (black) indicate the number of blocks in excess of the minimum required to reach criterion. The absence of a black bar indicates that the % correct criterion was met in the minimum number of blocks required.

Figure 5. Performances of all participants during feature-category training. A full description of the presentation format is provided in Figure 1.

Figure 6. Performance of TF3166DH during the establishment of two, 4-member equivalence classes. Training and testing blocks are indicated on the x-axis and correspond to the blocks described in Tables 4 and 5. The number of blocks required to meet the % correct criterion is indicated on the y-axis. The lower segments of each bar

indicate the minimum number of blocks required for training (white bar) and testing (gray bar) blocks. The upper segment of each bar indicates the number of trials in excess of the minimum that were required to meet the % correct criterion. The absence of a black bar indicates that the % correct criterion was met in the minimum number of blocks required.

Figure 7. Performances of all participants during the establishment of two, 4-member equivalence classes. The graphs in the left panel represent performances during the establishment of the "Vocation" based equivalence classes. The graphs in the right panel represent performances during the establishment of the "Nationality" based equivalence classes. A full description of the presentation format is provided in Figure 3.

Figure 8. Performances of all participants during feature-symbol and symbol-feature tests. The graphs in the left panel (Symbols → Features) represent testing of the trained relations in a format consistent with the direction of the training. During these tests, the sample stimulus consisted of the symbol stimuli, denoted in Table 1 as 1 – 9, and comparison stimuli were compound stimuli comprised of both a "Vocation" feature and a "Nationality" feature, denoted in Table 1 as p, w, c and a, f, g. The positive comparison (Co+) on each trial consisted of a compound stimulus containing the "Vocation" feature and "Nationality" feature to which the symbol had been trained during the establishment of the equivalence classes. Test type varied based on the negative comparison (Co-) presented: a) None – the Co- did not contain any features that had been trained to the sample symbol, b) Vocation – the Co- contained the same "Vocation" feature that had been trained to the sample symbol but contained a different "Nationality" feature and c) Nationality – the Co- contained the same "Nationality" feature that had been trained to

the sample symbol but contained a different "Vocation" feature. The graphs in the right panel (Features → Symbols) represent the symmetrical property of the relations tested in the Symbol → Feature tests described above. The number of blocks required to meet the % correct criterion is indicated on the y-axis. The lower segments of each bar indicate the minimum number of blocks required for training (white bar) and testing (gray bar) blocks. The upper segment of each bar indicates the number of trials in excess of the minimum that were required to meet the % correct criterion. If no black bar present, participant met the % correct criterion in the minimum number of blocks required.

Figure 9. Illustration of a single classification test probe. On any given trial, the context cue, V = "Vocation" or N = "Nationality", is presented as indicated on the x-axis. The context cue is followed by the presentation of a sample stimulus and 2 comparison stimuli. The sample stimulus contains a "Vocation" feature (indicated in blue) and a "Nationality" feature (indicated in red). Comparison stimuli are presented in pairs and any given pair of comparison stimuli contains one stimulus that has been associated with the same "Vocation" feature and a different "Nationality" feature and one stimulus that has been associated with the same "Nationality" feature but a different "Vocation" feature. Features that differ from the sample stimulus are indicated in black. The y-axis indicates the number of trials of a given type within the block. Each set of bars represent 4 trials of the same sample/comparison configuration for both the "Vocation" and "Nationality" context cues.

Figure 10. Overview of the stimulus control topographies that may emerge during categorization test. The graphs on the left indicate the different patterns of responding that might be seen during assessment of the contextually controlled categorization

repertoire. The format of the graphs correspond to the illustration presented in Figure 9 and a description of the predominant stimulus control topographies is presented to the right of each graph.

Figure 11. Performances of TF3157AL and TF3159SD during the classification tests. The left panels show the stimulus control topographies during each of the 32 trial types. The x-axis corresponds to trial type based on order of testing and the y-axis corresponds to the stimulus control topographies illustrated in Figure 10. The right panel provides a summary of the stimulus control topographies during all 32 classification probes. In this case, the probes are indicated on the y-axis while the stimulus control topographies are indicated on the x-axis.

Figure 12. Performance on feature-category re-training. Data are presented for the 4 participants who received the feature-category retraining. All stages of re-training and testing are indicated in the boxes above each segment. Lower case letters represent the features (p = painter, w = writer, c = composer, a = American, f = French, g = German) and upper case letters represent the category names (V = vocation, N = nationality). Arrows indicate the direction of the training and testing with the arrowhead pointing to the stimulus that served as the sample in a matching-to-sample format. Feedback level during each stage of training and testing is indicated on the x-axis and number of trials to the % correct criterion is indicated on the y-axis. The lower segments of each bar (gray) indicate the minimum number of blocks required for training or testing while the upper segments (black) indicate the number of blocks in excess of the minimum required to reach criterion. The absence of a black bar indicates that the % correct criterion was met in the minimum number of blocks required.

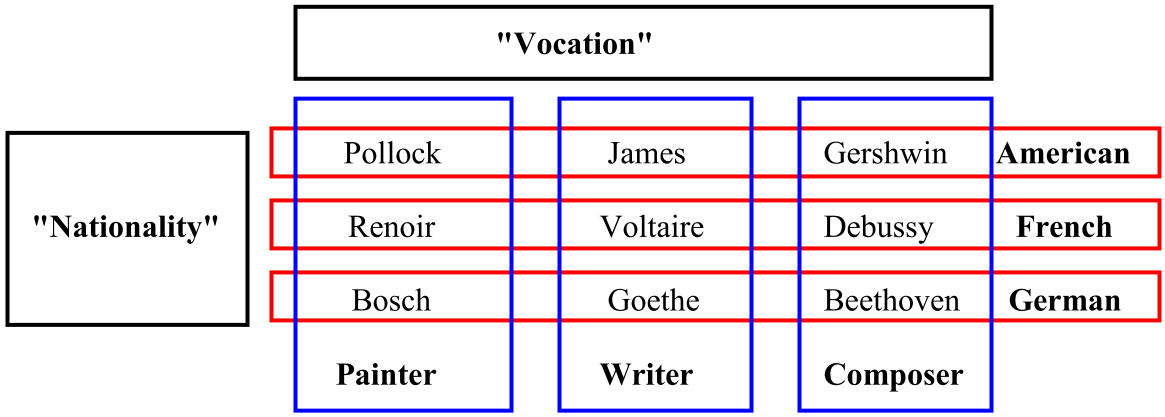
Figure 13. Performances of TF3166DH and TF3168UP during classification tests. The left panels show the stimulus control topographies during each of the 32 classification probes. The x-axis corresponds to the probe based on order of testing and the y-axis corresponds to the stimulus control topographies illustrated in Figure 10. The right panel provides a summary of the stimulus control topographies during all 32 probes. In this case, the test trails are indicated on the y-axis while the stimulus control topographies are indicated on the x-axis.

Figure 14. Performances of TF3156YK and TF3163MT during classification tests. The left panels show the stimulus control topographies during each of the 32 classification probes. The x-axis corresponds to the probe based on order of testing and the y-axis corresponds to the stimulus control topographies illustrated in Figure 10. The right panel provides a summary of the stimulus control topographies during all 32 probes. In this case, the test trails are indicated on the y-axis while the stimulus control topographies are indicated on the x-axis.

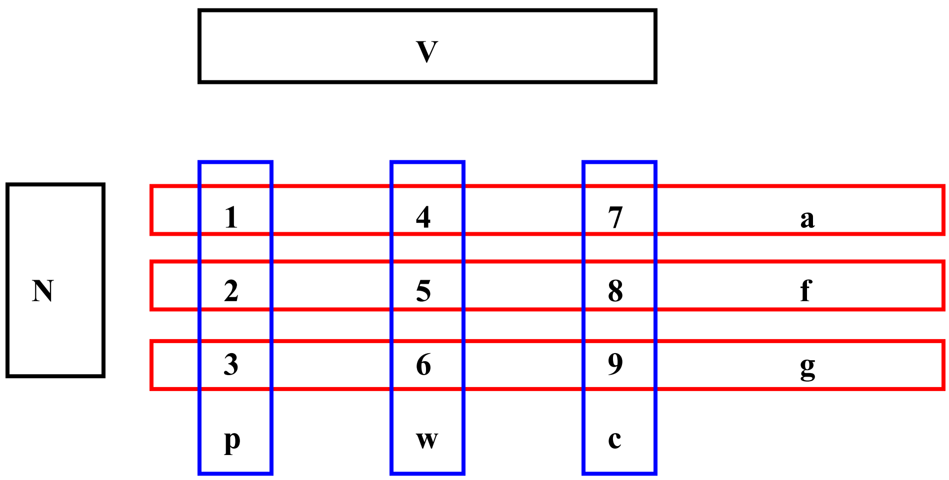
Figure 15. Performance of TF3163MT during ABA classification tests. The top row indicates performance during the first set of classification probes that were conducted in the presence of the category names. The second row indicates performances during classification tests in which the category name was not present. Finally, the third row indicates performances on the second test in which category names were presented. In each row, the left panels show the stimulus control topographies during each of the 32 classification probes. The x-axis corresponds to the probe based on order of testing and the y-axis corresponds to the stimulus control topographies illustrated in Figure 10. The right panels of each row provide a summary of the stimulus control topographies during

all 32 probes. In this case, the test trails are indicated on the y-axis while the stimulus control topographies are indicated on the x-axis.

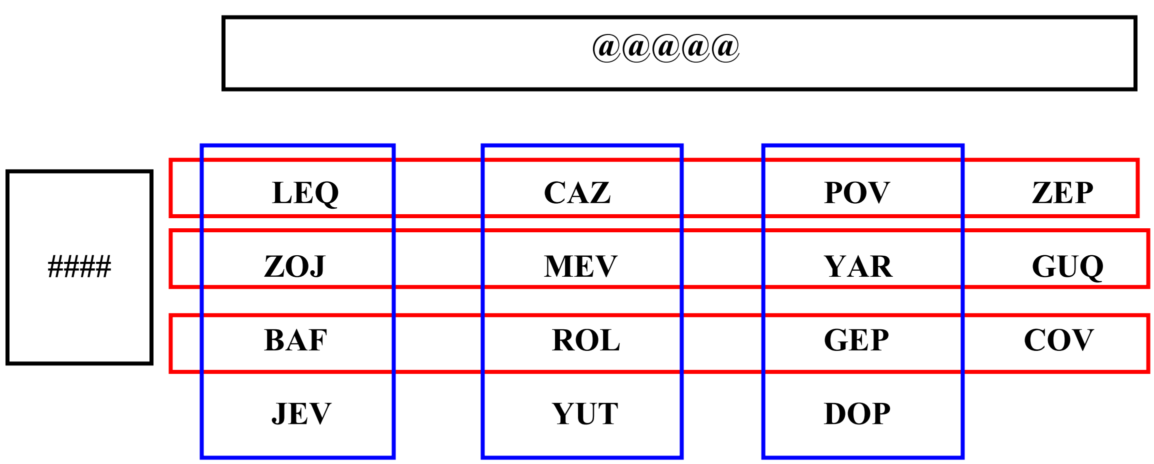
a)


"Vocation"
"Nationality"
Pollock
James
Gershwin
American
Renoir
Voltaire
Debussy
French
Bosch
Goethe
Beethoven
German
Painter
Writer
Composer

b)


V
N
1
4
7
a
2
5
8
f
3
6
9
g
p
w
c

c)


@@@@@
####
LEQ
CAZ
POV
ZEP
ZOJ
MEV
YAR
GUQ
BAF
ROL
GEP
COV
JEV
YUT
DOP

a) Conflict Classification Probe

Pollock
(American Painter)

Renoir **James**
(French Painter) **(American Writer)**

==

b) Solvable Classification Probe

"NATIONALITY"

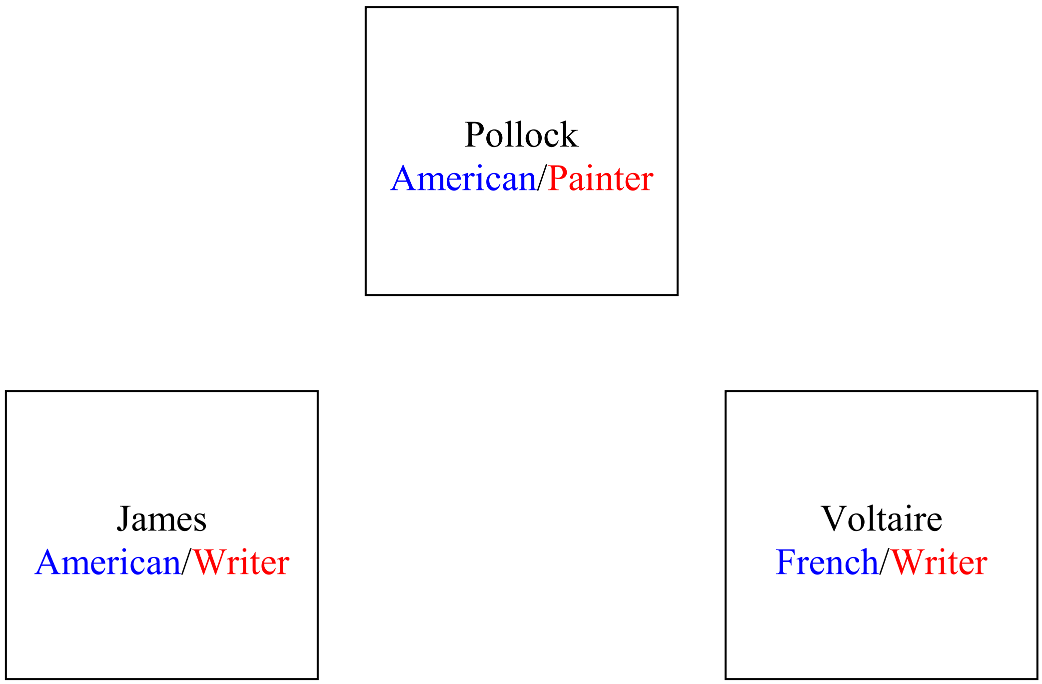
Pollock
(American Painter)

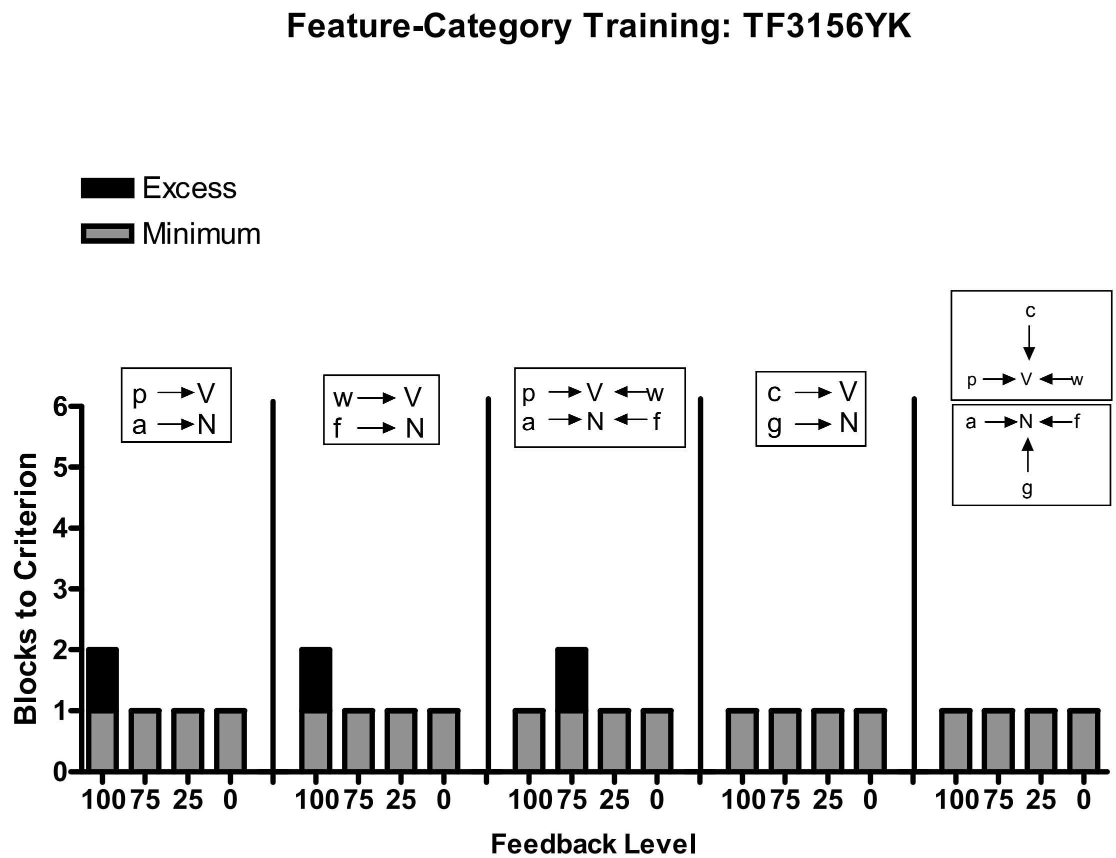
Renoir **James**
(French Painter) **(American Writer)**

==

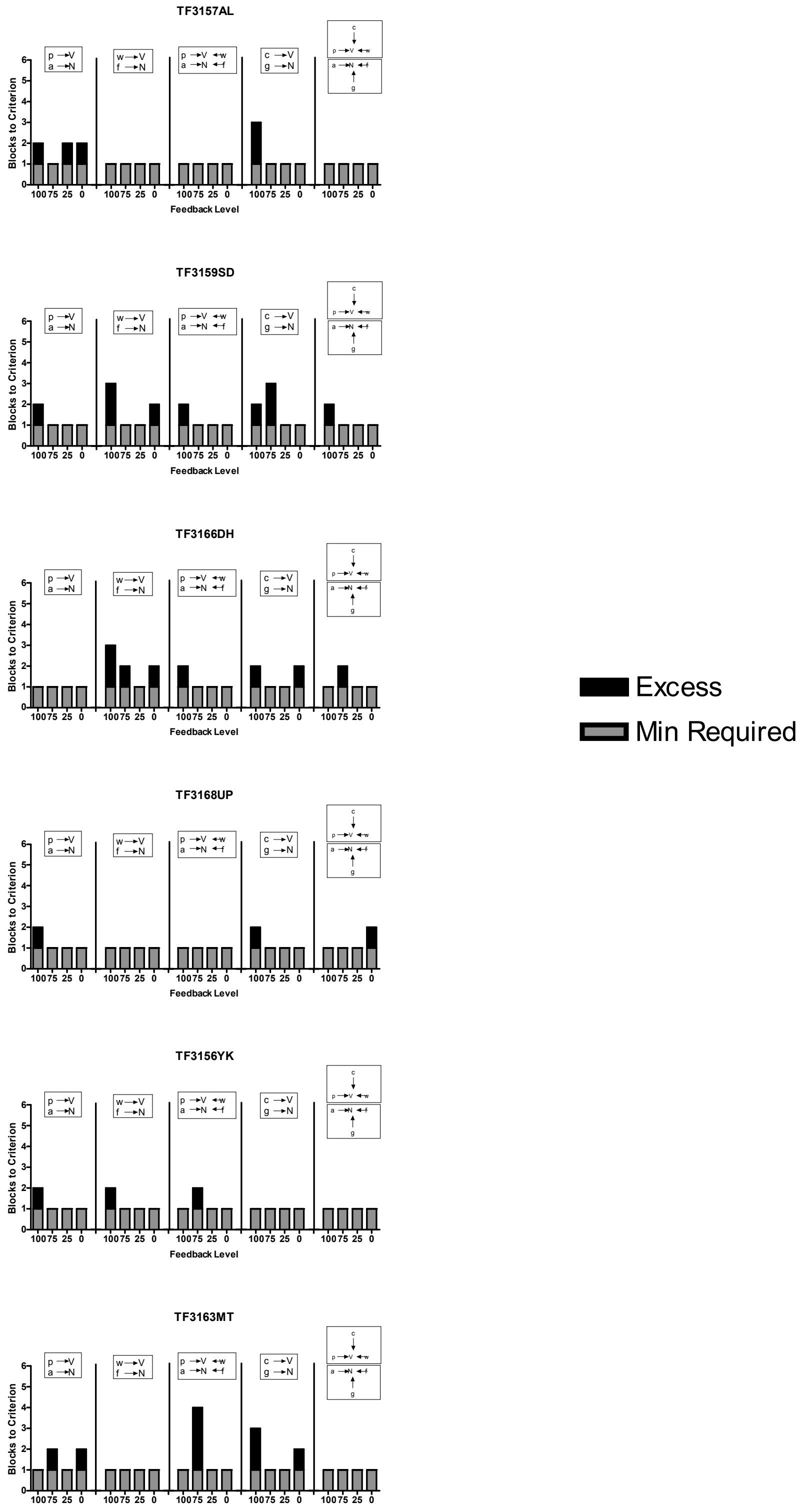
c) Symbolic and Metaphorical Representations of Solvable Classification Probe

Context/ Category	Symbolic Sa	Co+	Co-	Metaphorical Category	Sa	Co+	Co-
V	1	2	4	Vocation	Pollock	Renoir	James
N	1	4	2	Nationality	Pollock	James	Renoir

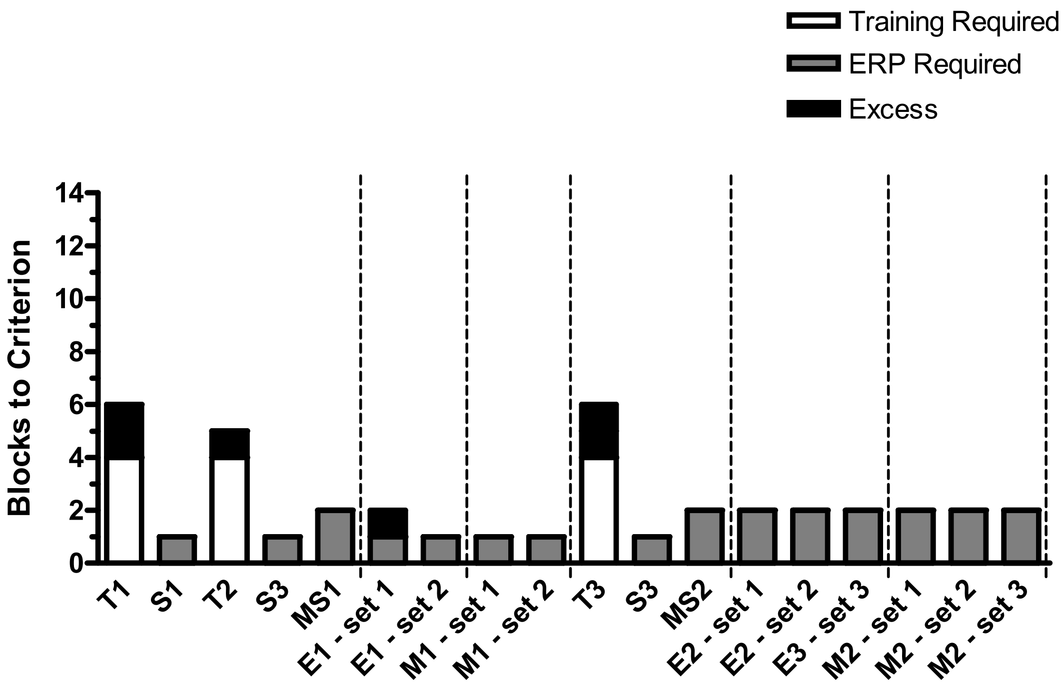

Pollock
American/Painter
James
American/Writer
Voltaire
French/Writer

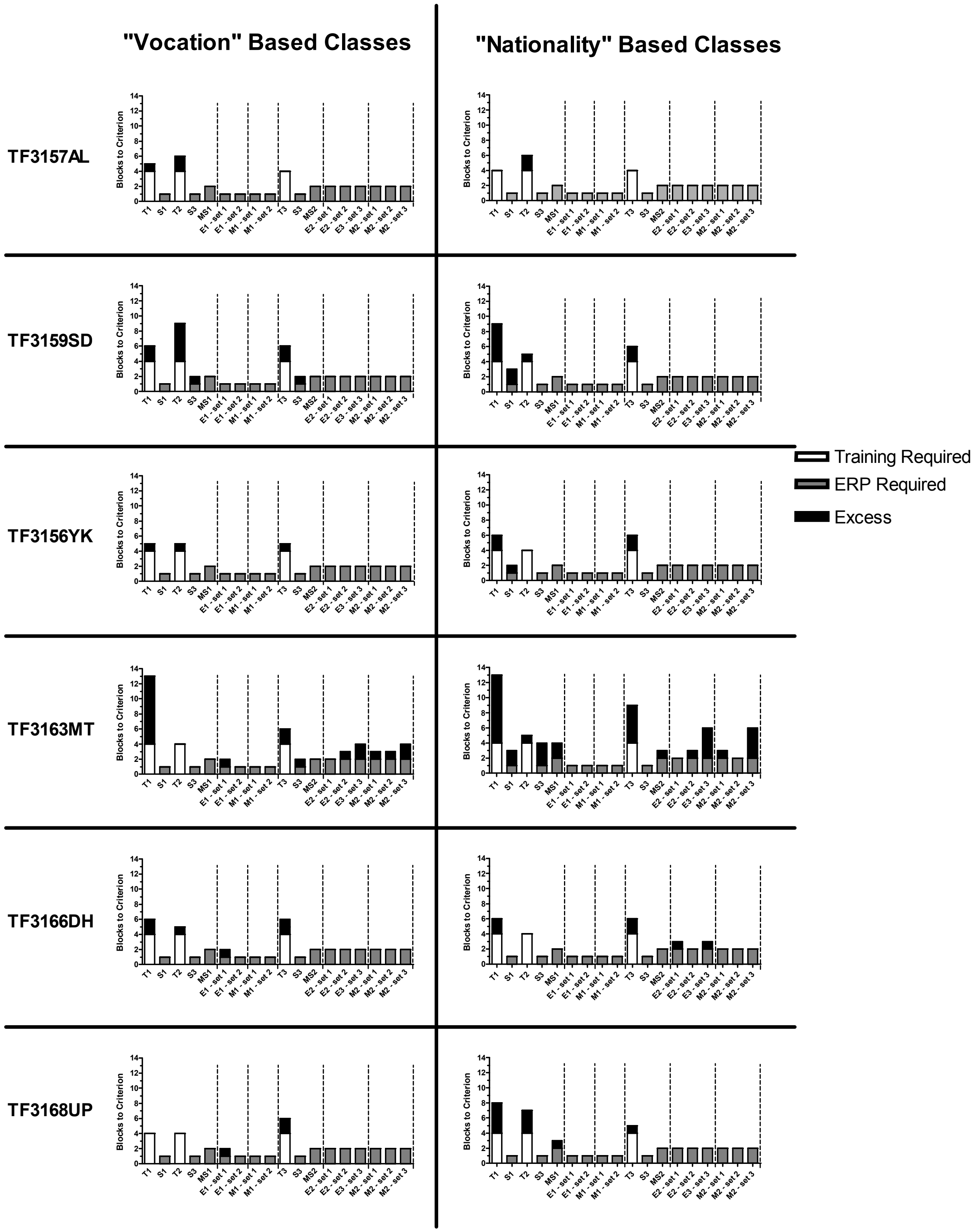

Feature-Category Training: TF3156YK
Excess
Minimum
Blocks to Criterion
Feedback Level
p → V
a → N
w → V
f → N
p → V ← w
a → N ← f
c → V
g → N
c
p → V ← w
a → N ← f
g
100 75 25 0

Feature-Category Training: All Subjects

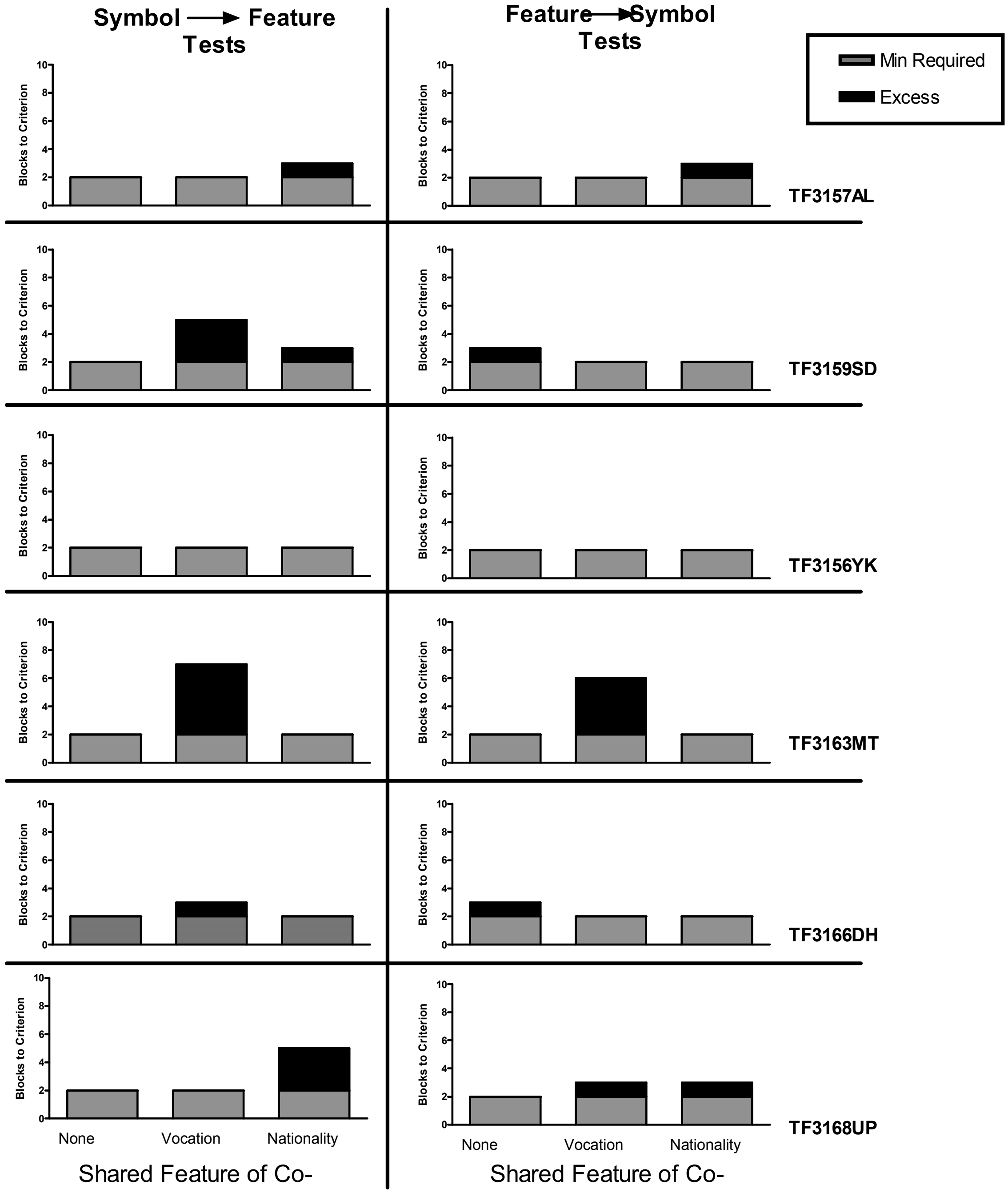


4-member Equivalence Class Formation: TF3166DH

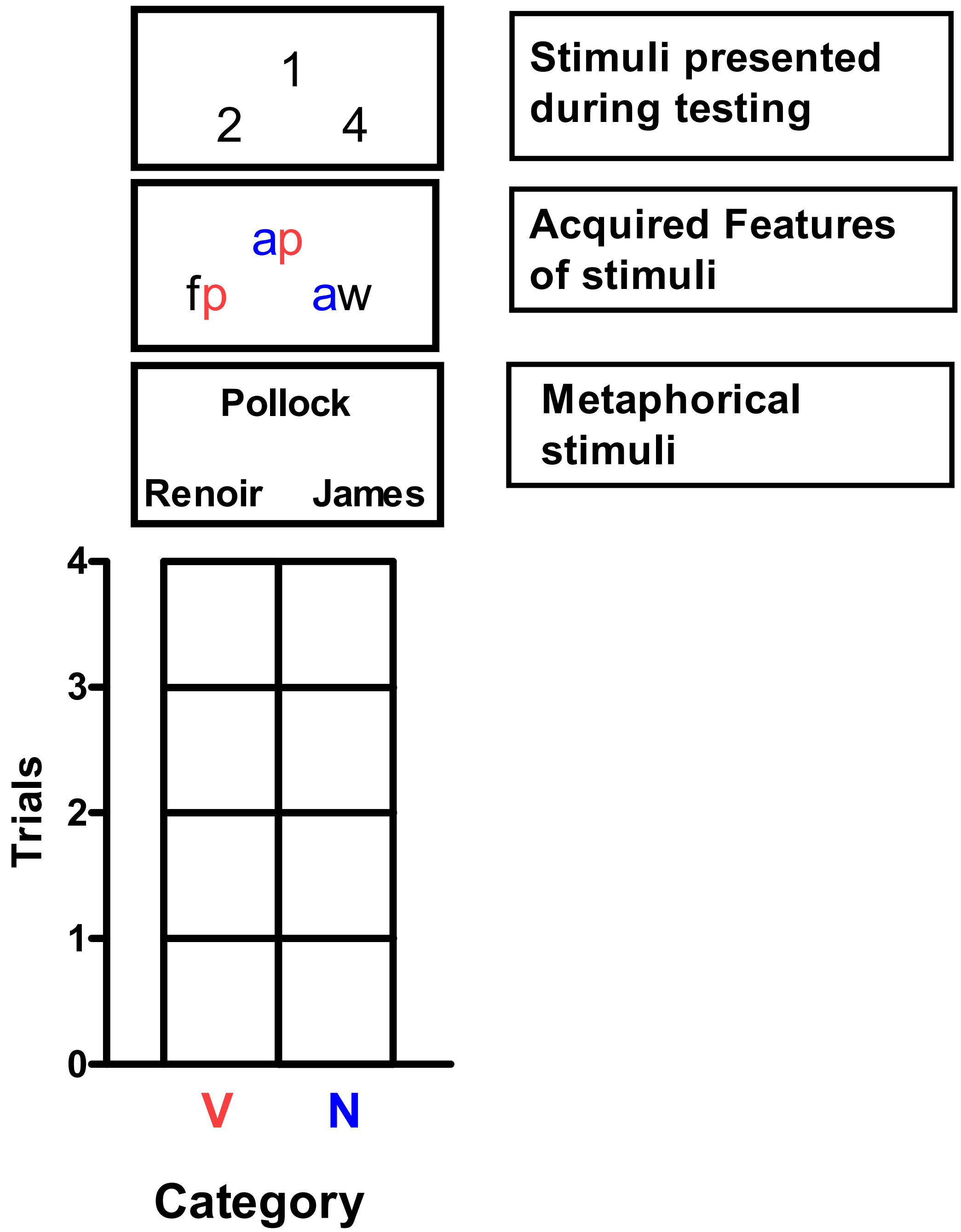



"Vocation" Based Classes
"Nationality" Based Classes
TF3157AL
TF3159SD
TF3156YK
TF3163MT
TF3166DH
TF3168UP
Blocks to Criterion
Training Required
ERP Required
Excess

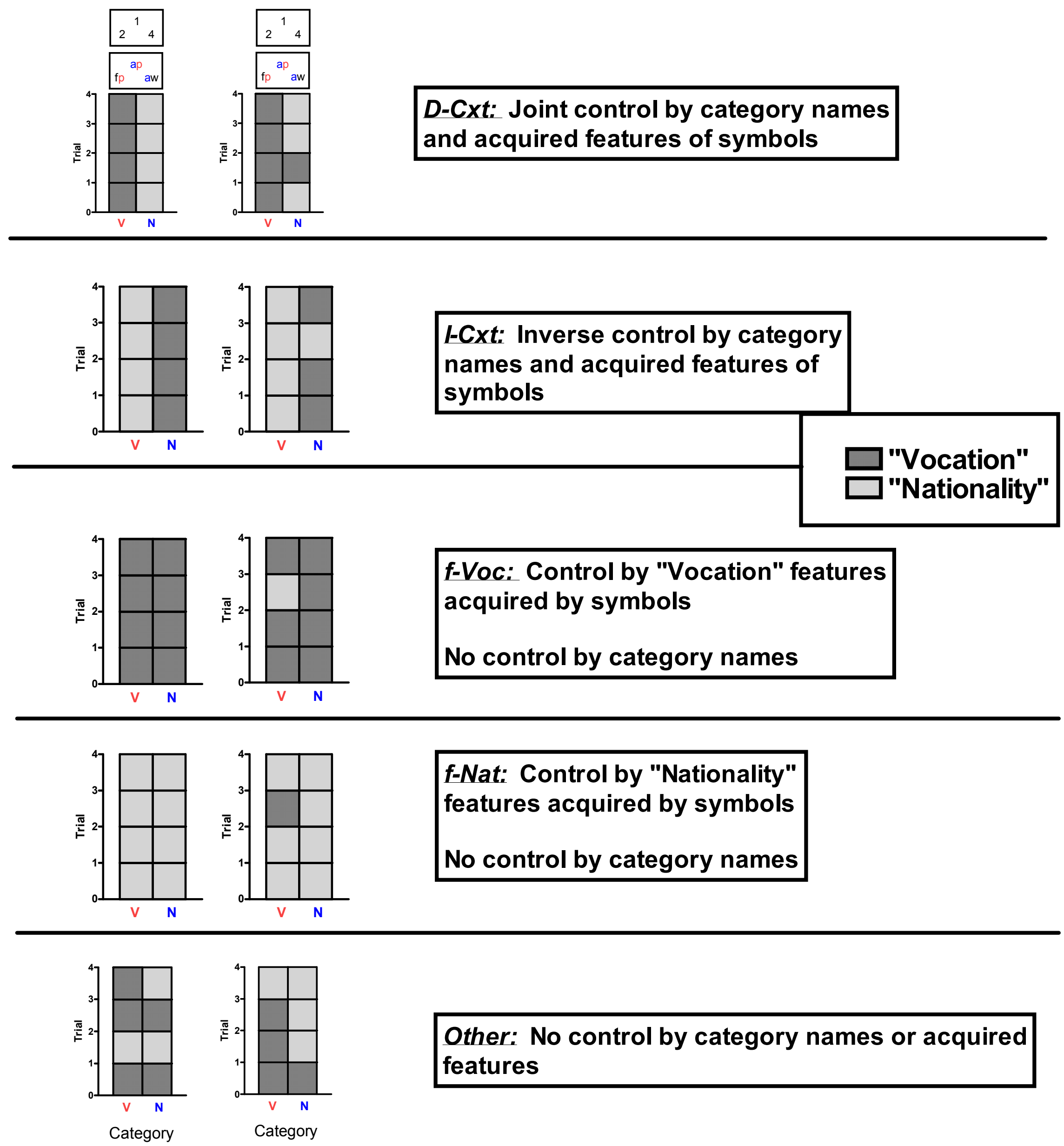
Symbol-Dual Feature and Dual Feature-Symbol Tests: All Subjects



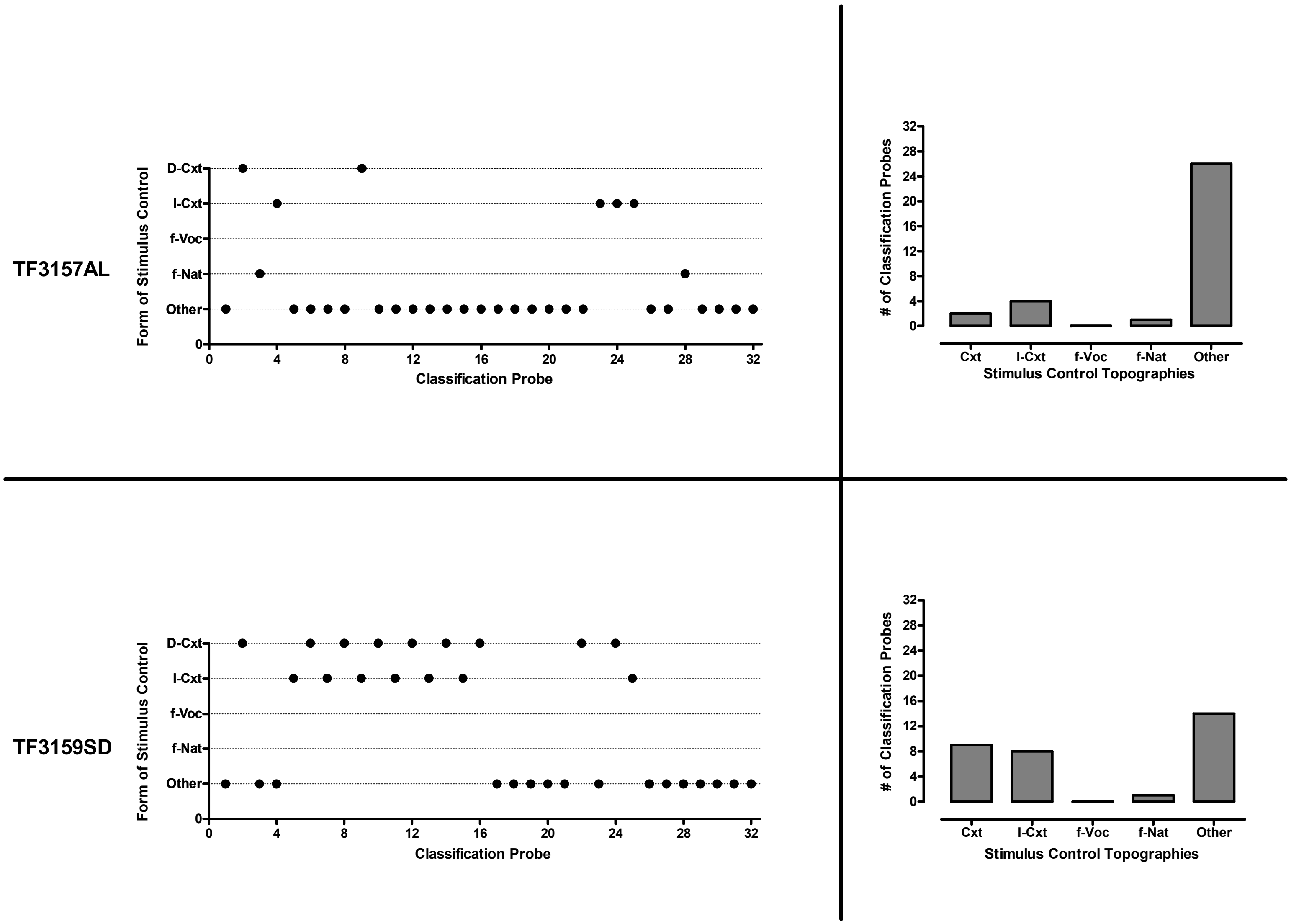
Classification Test Probe I



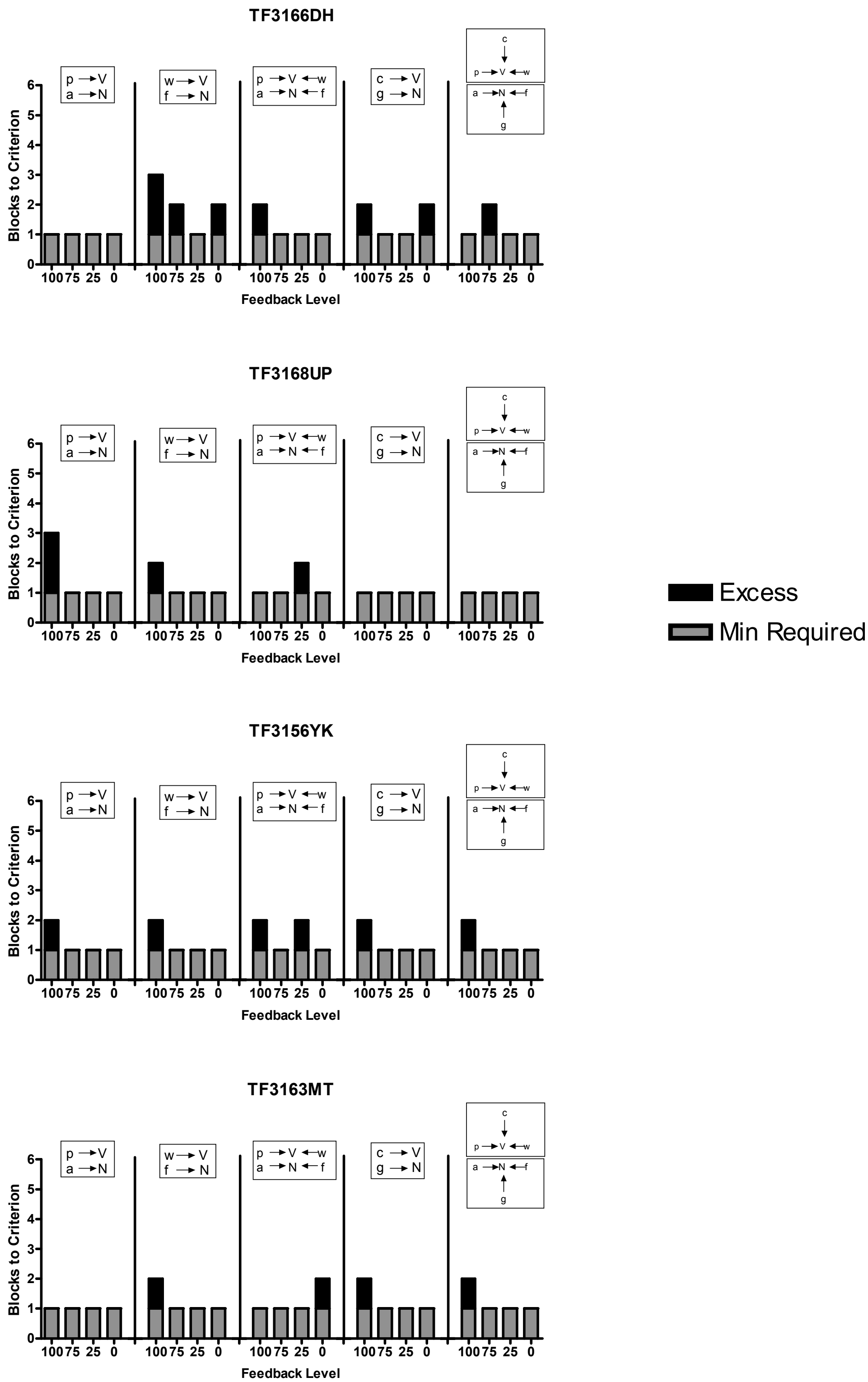
Outcomes of Symbol Classification Probes: Features Absent During Testing



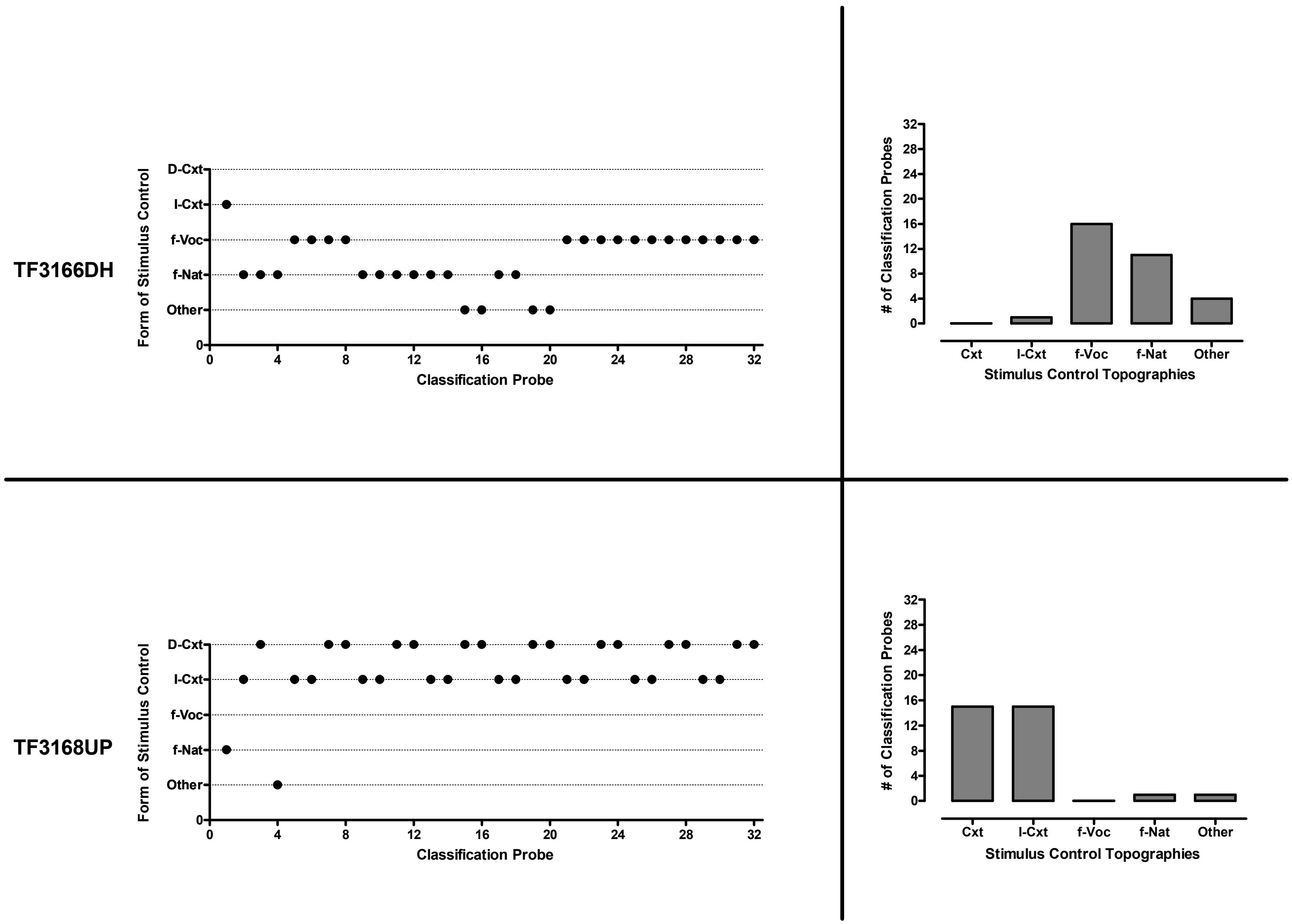
Classification Test Performances: TF3157AL & TF3159SD



Feature-Category Re-Training: All Subjects

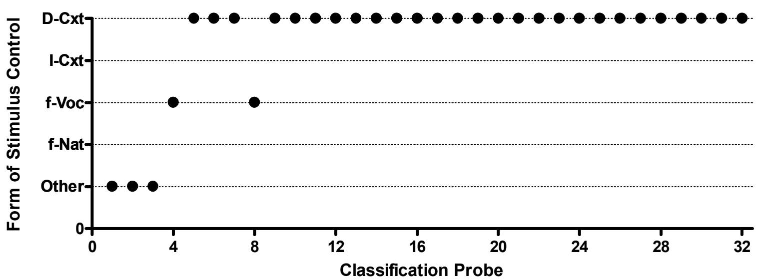


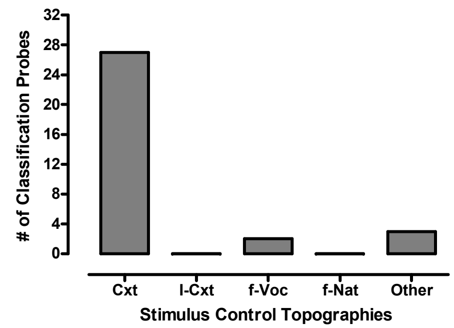
Classification Test Performances: TF3166DH &TF3168UP



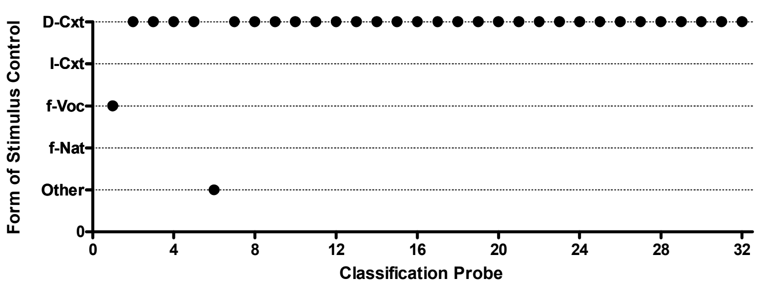
Classification Test Performances: TF3156YK & TF3163MT

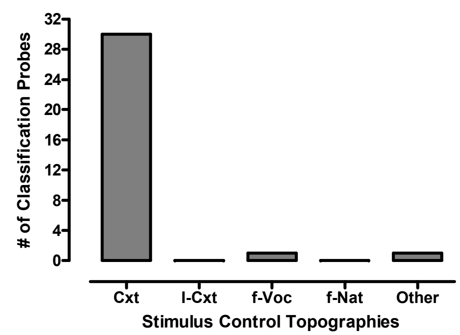
TF3156YK



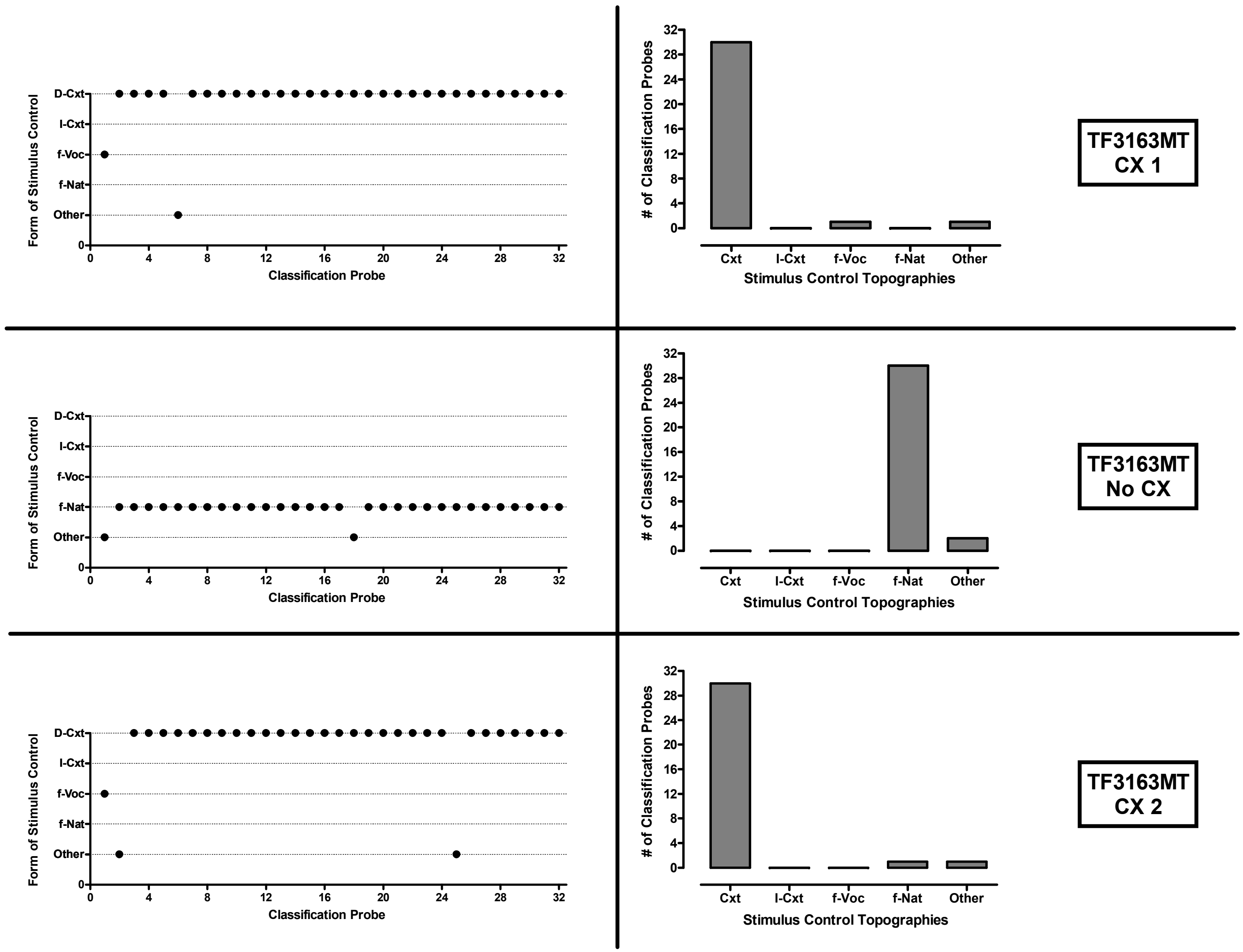


TF3163MT





ABA Classification Probes: TF3163MT



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