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Formation and Perceptual Categorization of Spatial Relationships across Languages

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FORMATION AND PERCEPTUAL CATEGORIZATION OF SPATIAL RELATIONSHIPS ACROSS LANGUAGES

by

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Abstract

Categorical distinctions for spatial relationships differ across languages. Visual statistics gleaned from the environment in conjunction with the labels present in a native language may be used to form semantic categories. The current study makes use of visual statistical learning to train novel category labels for familiar and novel spatial categories present in 4 different continua using fully and minimally overlapping distributions. Prior categorical perception and spatial categorization research suggest the presence of L1 interference in forming novel semantic categories. Visual statistical learning research suggests the ability to track category statistics across visual scenes. Results showed significantly steeper slopes for familiar continua as compared to novel continua for the respective label distributions indicating the presence of L1 interference. The presence of a shallow slope in the novel continua suggests an interaction of the statistics and the L1 interference.

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Formation and Perceptual Categorization of Spatial Relationships Across Languages

Second language (L2) learners are faced with the necessity of adapting to category differences between their native language (L1) and their target language. The same visual input from the environment, such as in the case of spatial relationship between objects in the environment, might be categorized differently in each of these languages. Further, adult L2 learners must manage the interference present from their L1 in learning a second language. These challenges might hinder adult L2 learners as novel category distinctions must be learned alongside the vocabulary used to describe these distinctions. The current study explores the interaction of visual statistics and category labels with existing semantic category information when learning novel categorical distinctions.

The thesis of the current work is that both L1 semantic information and visual cues work together to build semantic relationships in novel category learning. Categorization differences across languages, particularly spatial category differences, will demonstrate the need to form novel categories in second language learning. Statistical learning is one mechanism by which novel word learning might occur. Visual and spatial statistical learning will be discussed in depth as the current study will seek to manipulate visual statistics as a source of category information in spatial category learning. Novel labels will be used to facilitate categorization of spatial continua. Label influence on visual processing will be discussed. Interference of L1 semantic information in L2 learning will then be presented as an alternative source of category information in novel category learning. The formation of novel categories in the current study will be explored through the categorical perception paradigm. Developmental differences in perceptual categorization will demonstrate the differences between infant and adult categorization. Literature pertaining to categorical perception in a second language and spatial categorical perception will provide a background for the novel spatial categories of interest to the current study. Finally, the current study and predictions will be discussed briefly.

Language-Specific Categorical Distinctions

Categorical distinctions can vary across languages for the same environmental stimuli. In terms of color, the label "blue" in English can be applied to a range of wavelengths on the visible spectrum. In Russian, this same range of wavelengths is divided between two labels denoting either lighter blues, "goluboy", or darker blues, "siniy" (Winawer et al., 2006).

Categories of spatial relationships also show differences across languages. Munich, Landau, and Dosher (2001) note an obligatory distinction of "above" and "on" in the English language. In both Korean and Japanese, a locative marker indicating the target object is "top" of the relational object, exists separately of the distinguishing verbs or adverbs and is most often used divorced of clarifying verbs and adverbs. In cases where emphasis is important, it is possible to insert such words that would clarify whether the object "floating" (TTE) or "be floating" (UITE iru) or whether the object is "sticking" (PUTTE) or "be on" (NOTTE iru) in Korean and Japanese respectively. Further distinctions include the obligatory distinction of vertically on or "an" and horizontally on or "auf" in German, optional distinctions in English that fall under the overarching category "on" (Landau, 1996). The concept of containment is represented differently between the English and Korean languages. A single word, "in", is used to describe containment in the English language, however Korean speakers make the distinction between loose and tight containment (Choi, 2006; Choi & Hattrup, 2012; Choi, McDonough, Bowerman, & Mandler, 1999; Landau, 1996). Further, the Spanish word "en" can be used to reference both the containment and contact/ support placement distinctions found in English, Korean, and German (Landau, 1996). One learning mechanism that might allow for L2 learners to adjust to the differences in distinctions between languages is statistical learning.

Statistical Learning

Statistical learning is a very low-level, robust learning mechanism in which the learner passively tracks the statistical frequency of different events in the environment. For example, a learner who has been exposed to a label, such as “dog”, and a visual referent, such as the image of a dog, that co-occur repeatedly in the environment would begin to passively store those instances in their memory and recognize that the pairing occurs with a certain frequency. In this case, the learner would learn the label “dog” refers to the image of a specific class of furry four-legged mammals. This connection between a verbal or written label with a visual referent is of particular interest to this study, though the visual referent will depict a spatial relationship between objects as opposed to a concrete object as in the example. Statistical learning can also refer to the tracking of patterns or co-occurrence frequencies of items in a sequence. Much of the existing research on statistical learning focuses on infants, with relatively fewer studies examining adult learners, even though this mechanism persists throughout adulthood. Developmental research has shown that infants as young as 1-day-old have been found to be sensitive to visual statistics in a habituation task, subject to an age appropriate task design (Bulf, Johnson, &Valenza, 2011). Evidence further supports this sensitivity in older infants (Kirkham, Slemmer, & Johnson, 2002). Humans and other mammals are sensitive to visual statistical differences that can assist in category learning in early infancy, and appear to continue throughout adulthood.

Visual Statistical Learning

Adult studies have demonstrated an ability to use visual statistics in extracting category information. Tokens belonging to a single category, such as “triangles” or “dogs”, share similar features. The frequency with which these features are seen as a collective will eventually lead to the recognition of any token with the shared features as being part of a category. Adult participants were able to track the frequency of visual features across semantic categories of real-world visual scenes such as bathroom scenes, forest scenes, and mountain scenes and were able to use these statistics to track category patterns (Brady & Oliva, 2008). A series of 4 experiments was conducted, varying the use of images and labels across training and testing. A total of 12 scene categories were used throughout the experiments. Experiment 1 followed a classical statistical learning structure in which 4 triplets were made, each containing 3 scene categories. Only a single image was used to represent each category. Participants saw three images consecutively for 300ms, and pressed a button if any of the images were identical. This task was used to keep participants engaged. At testing, participants were shown two image triplets and told to indicate which triplet was familiar. Results indicated participants were able to track the statistics across the 20-min sequence with 86.6% accuracy at testing. A second experiment used multiple exemplars to represent category, and at testing participants selected familiar category sequences, but used exemplars from the category that were not seen during testing. This evaluates how well participants can generalize category co-occurrence (rather than exemplar-based co-occurrence). Participants were less accurate in this task (61.3%). A third experiment used text labels of the category during testing after training with images. Participants were 61.1% accurate in this task, indicating participants were able to transfer categorical knowledge to a lexical task.

The ability to track the similarities in multiple complex exemplars, as seen in the second experiment, mimics the formation of new semantic categories from environmental input. Results of Experiment 3, in which images are associated with category labels at test, indicates statistical learning of image co-occurrences are being stored as general semantic information accessible from multiple modalities. Regardless of category familiarity, Brady and Oliva (2008) demonstrate the ability of adult learners to track statistics across visual exemplars and categories and this kind of learning may contribute to semantic category formation used during lexical access.

Spatial Statistical Learning

The current experiment relies on the assumption that adults are able to track visual category statistics as well as spatial relationships within those images. Fiser and Aslin (2001) provide evidence for statistical learning to track spatial relationships among visual stimuli. The study examined the role of unsupervised statistical learning on spatial configurations along a grid. Experiments 1 and 2 were conducted using a 3x3 grid and each trial put two different complex shapes in two cells. These pairs were referred to as the "base pairs". Of the 6 base pairs, 2 were arranged horizontally, 2 vertically, and 2 diagonally. Participants saw 144 scenes only once during training. These scenes were presented for 2 s each in a sequence that lasted approximately 7 min During testing, participants were presented with a base pair and non-base pair and instructed to indicate which had previously been seen. In Experiment 1, non-base pairs were formed by combining two previously seen shapes in a configuration not seen throughout testing. In Experiment 2, non-base pairs consisted of 2 shapes that may have appeared in the same location during training, but not simultaneously. For example, shape A might appear in the bottom right corner during trial 1, shape B might appear in the space above that in trial 2, but shapes A and B never appeared in those positions on the same trial. Results for both experiments showed participants' recognition for familiar base pairs was significantly above chance (~72% in Experiment 1 and ~60% in Experiment 2). However, false alarms are not reported in this experiment, so the spurious relationships participants might have formed during training cannot be assessed (trials in which participants reported recognizing the trial when it was not shown during training). These experiments indicate participants are able to reliably track visual statistics for the spatial relationships among exemplars. Brady and Oliva (2008) demonstrate people are able to generalize and recognize visual categories based on statistical information, and Fiser and Aslin (2001) demonstrate participants' ability to track spatial relationships among exemplars. The current experiment combines these two concepts and will train categories of spatial relationships with unique labels.

Influence of Labels on Visual Processing

Linguistic labels have been shown to affect visual processing even at the detection level. Lupyan and Spivey (2008) found evidence that priming participants with an auditory label in an object detection task better facilitated detection than a visual cue. Further, in a study using continuous flash suppression (CFS) to mask images, Lupyan and Ward (2013) found evidence for an increase in the threshold of object *detection*, the first level of perceptual processing. Participants were asked to wear cyan/red glasses to view the experiment. A fixation cross was followed by either an auditory cue (the object's label) or white noise. Next, a second fixation cross was shown followed by the masked stimulus. Participants responded by indicating whether or not they saw an object. If participants responded "yes", they were then given a validity prompt asking, "Was the object you saw a ___?". The primary difference between the first two experiments was the type of image used. In Experiment 1, visual stimuli were comprised of 8 gray-scale line-drawings. In Experiment 2, 160 grayscale photographs representing 40 categories were used, 4 exemplars for each category. The results showed that participants correctly detected 49.8% of the presented objects in Experiment 1 and 80.2% in Experiment 2 with valid cues increasing correct detection for both experiments. No differences in false alarms were seen. Results for both experiments indicated a higher overall hit rate for objects preceded by verbal cues, with an increase in correct detection for valid cues.

In the first two experiments, results indicated that only valid labels increased detection (Lupyan & Ward, 2013). Experiment 3 addressed the effect of the degree to which the label matched the stimulus on stimulus detection. Procedure was similar to earlier experiments with visual stimuli consisting of an 11 step square to circle continuum. The labels “square” and “circle” were used. Results indicated an increased hit rate for more prototypical exemplars of each label, suggesting that linguistic labels are affecting low level perceptual processes that may be used to build semantic categories

The results of these studies (Lupyan & Spivey, 2008; Lupyan & Ward, 2013) demonstrate that auditory labels affect low-level perceptual processes. Detection of a more prototypical stimulus is increased when cued by a matching label, indicating category goodness-of-fit is being processed and used at this early level of visual processing (Lupyan & Ward, 2013). The category labels used throughout both experiments correspond to categories found in the English language. Unfortunately, no information on participants’ language background was provided, though it is likely participants were native speakers or relatively proficient L2 speakers of English as both experiments were conducted in English at American universities. This brings about a potential question of interference from the L1 when learning an L2 that requires novel semantic categories to be formed.

L1 Influence in L2 Learning

Native-language has been shown to not only decrease sensitivity to novel categories, but to also interfere in the encoding of new labels and categories in L2 learning. Semantic interference was found in reaction time data of a novel word learning study (Finkbeiner & Nicol, 2003). Participants were trained on 32 novel vocabulary words representing 4 categories, 8 words belonging to each category. Participants were assigned to one of two between-subject conditions. In the "related" condition, participants learned semantically related words together in the same block. In the "unrelated" condition, words were scrambled within a block. For both conditions, a total of 4 blocks of 8 words were formed and each block was presented 4 times during training. Participants who learned the vocabulary words within their semantic groupings were significantly slower in translating these words than those who learned them in a random order. This result was true of both L1-L2, forwards, and L2-L1, backwards, translation. These differences in reaction times appear to indicate an increase in L1 interference when words are trained in semantic groupings. This is possibly due to the increase in semantic information present due to the connection between the words and the overarching category label. Additional semantic information tied to the category label would serve to increase interference beyond what is inherent in the individual word labels.

Finkbeiner and Nicol (2003) demonstrate the influence of L1 semantic category information when learning a second language. When L2 learning is structured in a manner which emphasizes L1 semantic categories, there is a negative effect on L2 learning as learners must adapt and reconcile the L1 category information with the novel labels and information unique to the L2. Spatial categories are one such area. In learning novel spatial categorical distinctions, learners are required to adapt the spatial category information from the L1 to form the L2 category distinctions.

Categorical Perception

The formation of novel spatial categories requires collapsing the category information from two L1 categories to form a single L2 spatial category, or the division of a single L1 category into two novel categories. One such example is the division of the English “on” into the novel “vertical on” and “horizontal on” placement categories. Spatial relationships such as these form a spatial continuum. Perceptual categorization is the distortion of a continuum into qualitatively distinct categories. As in the “on” example, the perceptual categorization of a continuum can vary from language to language. The points at which a category transitions into a different category, such as the point where “vertical on” becomes “horizontal on”, are called category boundaries.

Early research on this phenomenon centered around the perceptual categorization of speech with an emphasis on the discrimination across phoneme boundaries (Liberman, Harris, Hoffman, & Griffith, 1957; Liberman, Harris, Kinneym, & Lane, 1961). Initially, it was suggested that speech was unique in this discrimination of categories from a continuum and was in line with the Motor Theory of Speech Perception (Liberman, Cooper, Harris, & MacNeilage, 1962; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Liberman et al. (1961) found evidence of this uniqueness by using a series of artificial speech and non-speech (“control”) sounds to test participant ability to discriminate across category boundaries. A common ABX discrimination task was used in which two sounds are played sequentially followed by a third sound that matches either the initial or the second sound. It was noted that trials using the control audio stimuli remain at or near chance while speech trials tended to show a distinct peak.

Subsequent research demonstrating categorical perception in non-speech auditory stimuli fell in contrast to the assumption that categorical perception was a phenomenon unique to speech. Musicians were asked to label a series of tonal intervals with the categories “fourth”, “tritone”, and “fifth” (Siegle & Siegle, 1977). Participant data demonstrated sharp category boundaries indicating categorical perception along a musical continuum. Burns and Ward (1978) further demonstrated similarities in the perception of musical intervals and stop consonants when tested using comparable procedures.

Pastore et al. (1977) proposed a model of categorical perception that could account for the presence of the phenomenon across modalities. This model was referred to as a common-factor model of categorical perception. Following this model, any point along a continuum that contained any strong source of differing information such as a sensory or perceptual threshold would promote the formation of a category boundary. This model was tested using visual flickering light stimuli varying along a continuum by flicker frequency.

One view of categorical perception of particular note to this study is the view that the perception of categories along a continuum is relative to the language of the viewer. Roberson, Davies, and Davidoff (2000) argue the concept that categorical perception, in particular the perception of color categories, is linguistically relative as opposed to innate in a replication of Heider’s (1972) research on universal color categories. Over a series of 6 experiments, Roberson et al. (2000) explored the naming, memory, and categorical perception of the color spectrum with speakers of 3 different languages: English, Dani, and Berinmo. It is important to note that the Dani language only has 2 basic color terms while the Berinmo language only has 5. Most relevant to the current research is Experiment 5 during which two groups of participants, one made up of monolingual Berinmo speakers and the other made up of native-English speakers, were taught to sort a series of color stimuli into two categories. Participants were required to learn two sets of color distinctions. A portion of the participants were required to learn the nol to wor color continuum found in the Berinmo language and the yellow to green color continuum found in the English language, while the remaining participants learned the blue to green color continuum native to English and the green1 to green2 continuum that was novel for both languages. Results were analyzed in pairs using 2(English – Berinmo) x 2 (nol-wor/yellow-green or green-blue/green1-green2) ANOVAs. For the nol-wor and yellow-green learners, participants were faster to learn the category distinction found within their own language. Berinmo learners in the green-blue (novel) and green1-green2 (novel) conditions performed similarly on both continua, while the English learners in the same condition performed better on the blue-green (familiar) continuum as opposed to the green1-green2 (novel) continuum. These results support the idea that the perception of color categories is relative to the categories recognized in a person's primary language. These differences in category perception are not unique to color, and can be found in target concepts such as spatial relationships as well. Given that the differences in categorical perception transfer to other concept areas across languages, it is likely the difficulties in learning novel category distinctions will transfer as well.

Research has indicated similar patterns of discrimination and categorization across a variety of continua, including color (Bornstein, Kessen, & Weiskopf, 1976; Winawer et al., 2006) facial expressions (Cheal & Rutherford, 2011; De Gelder, Teunisse, & Benson, 1996; Lee, Cheal, & Rutherford, 2015), and lexical tones (Bidelman & Lee, 2015). Categorical perception is pervasive across different modalities and helps organize, label, and encode the environment around us. However, the degree to which categories are distorted toward a prototype, and the influence of the variance in and frequency of exemplars one is exposed to remains a broad question in this area.

Developmental Differences in Categorical Perception

Humans have been shown to be capable of distinguishing certain category boundaries from infancy. Aslin, Pisoni, Hennessy, and Perey (1981) found infants from English speaking backgrounds as young as 6 months were able to discriminate between phonemes along a voice onset time continuum that encompassed phoneme category boundaries both found and not found in the English language. This sensitivity to novel category boundaries diminishes in time as infants are increasingly exposed to their native language. Werker and Lalonde (1988) found infant sensitivity to novel phoneme boundaries to diminish by the time infants were 11-13 months old. Further, infants as young as 9-months-old have appear to be capable of recognizing visual categorical differences along a happy-angry continuum (Lee et al., 2015), though this sensitivity did not generalize to other facial continua.

The ability to distinguish across category boundaries is an important skill that is present in multiple modalities from a young age. Unlike infants, adult learners do not have the advantage of sensitivity to novel category boundaries in certain modalities. Adult L2 learners are uniquely challenged with the need to alter their perception of category boundaries along a continuum to adapt to the differing boundaries of their target language whether this difference is in voice-onset-times or in color and spatial categories not distinguished in the L1.

Second-Language Categorical Perception

The capability of infants as young as 6- to 12-months old to perceive category boundaries (Aslin et al., 1981; Lee et al., 2015) is important in gathering the information necessary to build semantic categories. Particularly in regards to phonemic categorical perception, adults show a diminished capability to distinguish between categories not found in their native language (Aslin et al., 1981) even for those speakers who exhibit a nativelike command of their L2 (Stölten, Abrahamsson, & Hyltenstam, 2013). Some evidence has been found, however, to indicate that perceptual training of adults on non-native phoneme continua can help L2 learners improve identification and production of the non-native continuum (Bradlow, Pisoni, Akahane-Yamada, & Tohkura, 1997). While L2 learners did not reach native-like consistency over the 45 sessions that made up the perceptual learning portion of the experiment, the improvement seen indicates the potential to train learners to recognize categorical distinctions that do not exist in the learner's current semantic knowledge or native language.

Spatial relationships are one such area where L2 learners potentially face the challenge of learning new categorical distinctions. As previously discussed, spatial category boundaries can differ widely across languages (Landau, 1996) requiring L2 learners to define new sub categories of a native spatial distinction or recognize the combining of spatial categories into a novel overarching category. For example, L2 learners of German with an English L1 would be required to recognize the familiar category "on" as being two distinct categories with novel labels within the German language (auf and an). On the other hand, L1 German speakers learning English as an L2 would need to recognize a single novel label as being sufficient to cover both distinct "on" categories present in German. In a study of placement verb use L1 Danish to L2 Spanish and L1 Spanish to L2 Danish adult learners, evidence was found to indicate the difficulty existed both in switching from a system in which an overarching category label has precedence (Spanish) to one where the use of subordinate categories is required (Dutch) as well as switching from subordinate prevalent to overarching prevalent (Cadierno, Ibarretxe-Antuñano, & Hijazo-Gascón, 2015).

Spatial Categorical Perception

The potential for spatial categories to be perceived with differing boundaries across languages, such as the German categories “an” and “auf” merging to form the English “on” (Landau, 1996), demonstrates that spatial continua can be carved into different linguistic categories. The ability to understand and adapt to a differing spatial structure is necessary when learning a second language and is helpful when traveling or transitioning into a new environment where appropriate labels need to be recognized and used in conversation. The presence of existing L1 category information can cause difficulties in learning a second language (Finkbeiner & Nicol, 2003).

Recognition of spatial categories is possible from infancy. Infants as young as 3 months have been shown to be capable of recognizing distinct spatial relationships when tested using a familiarization-novelty preference procedure (Quinn, 1994). Additionally, infants between 9 and 14 months old have been shown capable of recognizing category boundaries along a spatial continuum that do not exist within their native language (McDonough, Choi, & Mandler, 2003). Similar to what occurs in phoneme discrimination (albeit later in development), older infants appear to lose this ability in favor of forming language specific spatial categories (Choi et al., 1999). This inability to distinguish non-native category boundaries appears to persist into adulthood as English speaking adults were also unable to differentiate novel spatial stimuli (McDonough et al., 2003).

Current Study

The current study seeks to explore the use of visual statistics in training novel labels for both familiar and novel spatial relationship continua. Semantic categories formed in the L1 have been shown to be persistent and can cause interference during L2 learning (Finkbeiner & Nicol, 2003). The simple presence of category labels has been shown to affect visual processing as early as detection of visual stimuli (Lupyan & Spivey, 2008; Lupyan & Ward, 2013). This interference from pre-learned categories and labels presents an obstacle to forming new category distinctions as is required of L2 learners. Statistical learning as a mechanism allows for statistical information to be tracked across exposures to allow the recognition of categorical similarities. Research has indicated the potential to track category statistics even across complex, true to life scenes (Brady & Oliva, 2008). Given the sensitivity of statistical learning, it is possible that use of such methodologies will assist L2 learners in discriminating novel category boundaries and learning labels for these newly distinguished categories. Further, the use of a visual statistical learning methodology to train novel labels for familiar and novel categorical distinctions will provide insight into how these spatial and linguistic cues integrate to form meaning over the life span.

Participants were trained on continua that varied in familiarity and label distribution using novel labels. We hypothesize the distribution of the visual statistics in conjunction with the novel labels will influence the semantic networks. Participants completed both a categorization task and a discrimination task upon completion of the training phase.

We predict one of three theoretical outcomes: L1 dominant, statistic dominant, or non-learning. A L1 dominant outcome is most likely in the event that the L1 semantic category information provides the primary source of information for the participant during training. This would manifest in the categorization data as steep category boundaries for familiar continua regardless of label distribution, while novel continua would be at chance across all steps with a linear slope near 0. See Figure 1 for example categorization graphs. It is important to note that the novel continua in this outcome would technically fall under the "non-learning" umbrella as

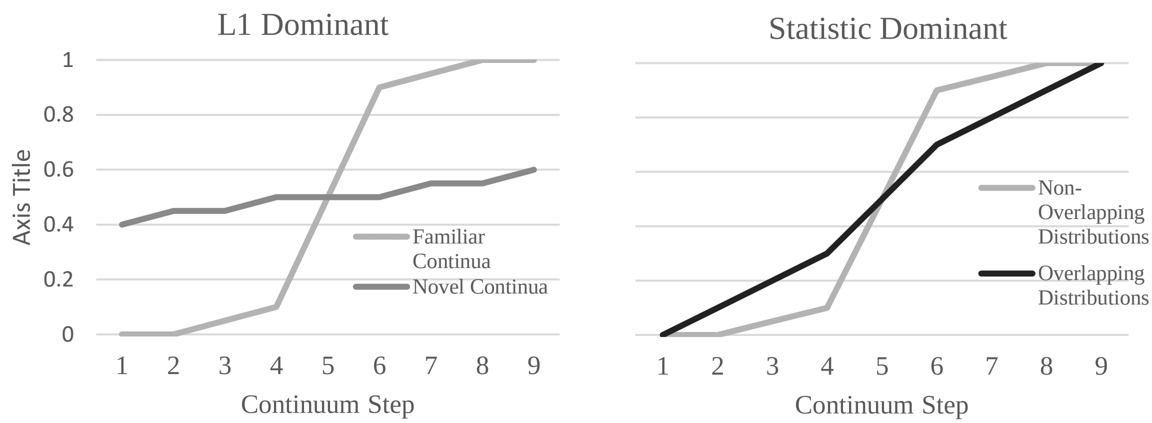

Figure 1. Visual representation of possible categorization task outcomes.

participants would not be demonstrating any grasp of the novel labels, however this outcome differs from the aforementioned non-learning outcome as the "at chance" results only apply to 2 of the 4 continua. In discrimination data, familiar continua will show a sharp increase around the middle step, as seen in curve A on Figure 2, while novel continua should once again remain uniform across all steps as seen in curve B. This outcome falls in line with the theory of linguistic relativity as discussed in Robinson et al. (2000) and their similar study using color categories. The differences in category learning are reliant upon the categories present in the participant's L1, in this case English.

A statistic dominant outcome would occur should category learning rely more heavily on the frequency of the label distributions. This outcome is in line with the Fiser and Aslin (2001) indication that learners are capable of tracking spatial category frequency and distributions across trials and the Brady and Oliva (2008) findings that people are capable of generalizing category information in labeling category exemplars. Categorization results for a statistic dominant outcome should follow a similar pattern to the label distributions. See Figure 1 for example categorization predictions. A non-overlapping label distribution, regardless of familiarity, should present as a steep category boundary around the 5th step of a 9 step continuum

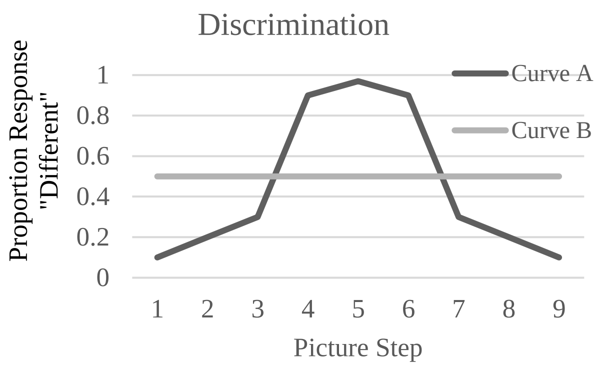

Figure 2. Visual representation of possible discrimination task outcomes.

with a plateau in the curve at each end, while an overlapping label distribution will have a shallower slope across the entire continuum. In the discrimination data, the non-overlapping continua should present with a sharp increase at the middle of the continuum, such as curve A in Figure 2, while the overlapping continua will remain more uniform across all step pairs as in curve B.

The third possible outcome is that participants will not show category learning. This would likely be due to task error or task difficulty, such as participant inability to map the novel labels onto the spatial stimuli. In the categorization data, a non-learning outcome would manifest similarly to the novel L1 dominant outcome in which frequency of the label chosen is close to or at chance across all continuum steps and a slope hovering near 0 for all 4 continua regardless of familiarity or label distribution. In Figure 1, the Novel continua line under the L1 dominant panel illustrates the predicted pattern for all four conditions for the non-learning potential outcome.

Finally, it is possible that both the L1 and statistic dominant accounts will play a role in novel category learning. Prior research has shown strong effects of both existing L1 information (Finkbeiner & Nicol, 2003; Roberson et al., 2000) and statistical learning (Brady & Oliva, 2008; Fiser & Aslin, 2001), lending credence to the possibility of a combined effect in learning novel categorical distinctions.

Method

Participants

Thirty-nine participants were recruited from the University of Memphis subject pool. A total of 33 participants (*M* = 19.48, *SD* = 1.70) were included in the data. Six participants did not meet the minimum inclusion criteria of being right handed or ambidextrous (2) and monolingual English speakers (4). Data on other levels of language exposure were collected to allow researchers to control for prior exposure to the novel spatial continua. Prior exposure was limited to courses in Spanish or French to fulfill high school and college requirements (12 participants) and short term study abroad trips (3 participants).

Materials

Four continua depicting simple shapes in continuous spatial relationships were designed in a photo manipulation program. Each continuum consisted of 9 steps across which shapes gradually transitioned from one spatial relationship to another. Figure 3 depicts an example 1st, 5th, and 9th step in the “vertical on” to “horizontal on” continuum. See Appendix A for further examples.

Figure 3. 1st, 5th, and 9th steps of the vertical on/ horizontal on continuum.

The continua were separated into two categories: familiar continua and novel continua. The 2 familiar continua depicted spatial distinctions found in the English language, above/ below and on/ off, while the novel continua depicted spatial distinctions not native to the English language, horizontal on/ vertical on and loose containment/ tight containment. The distinction between vertical and horizontal "on" placement is one found in the German language, while the distinction between loose and tight containment is made by Korean speakers.

Eight artificial preposition labels were created, corresponding to steps 1 and 9 on each continuum. Artificial prepositions were chosen by forming a selection pool of approximately 16 2 syllable potential pseudowords. Final pseudoword stimuli were chosen by consensus of 6 members of the Language and Behavior Lab during a regular lab meeting. A neighborhood density calculation performed using IPHOD, an online phonological calculator, indicated each pseudoword had equal to or fewer than 2 real word phonological neighbors (Vaden, Halpin, & Hickok, 2009).

Audio tokens were recorded in Praat (Boersma & Weenink, 2013), so that each word was heard within an English sentence describing the context of the image. For example, the sentence corresponding to Figure 3 exemplars was, "the red rectangle is **defas** (**zetak**) the black surface". See Appendix B for the artificial prepositions used in the study with the English definitions. An audio editing program was used to equalize the length of the audio clips by adding silence to the end of the shorter sentences. Final audio clips were 3700 ms in length.

Two steps depicting a gray circle resting on the and slightly to the right of the peak of a pink triangle and the artificial labels “ginzar” and “dinlat” were used to provide an example of each task. The sample sentence. “The gray circle is ginzar the pink triangle,” was written out as an example sentence, but no audio example was played for the example trials.

Procedure

The experiment was created using Psyscope, a Mac OS based experiment design software (Cohen, MacWhinney, Flatt, & Provost, 1993). The experiment consisted of a passive training phase, a categorization task, and a discrimination task. Each continuum was trained using either a fully overlapping label distribution or a non-overlapping label distribution. Participants were each trained using the overlapping distribution for 1 of the novel and 1 of the familiar continua. The remaining novel and familiar continua were trained using the non-overlapping distribution. It is important to note that the non-overlapping distribution does have one point of overlap at the 5^{th} step of the continuum. See Figure 4 for example distributions. Continua conditions were within-subject with continua label distributions counterbalanced across 2 lists. See Appendix C for continua distribution chart.

Training. Participants were provided with verbal and written instructions before each section of the experiment. Prior to training, participants were instructed to sit in front of a Mac computer while wearing headphones and were informed there would be 2 types of trials during the course of training. The majority of the trials would consist of a single step of a continuum

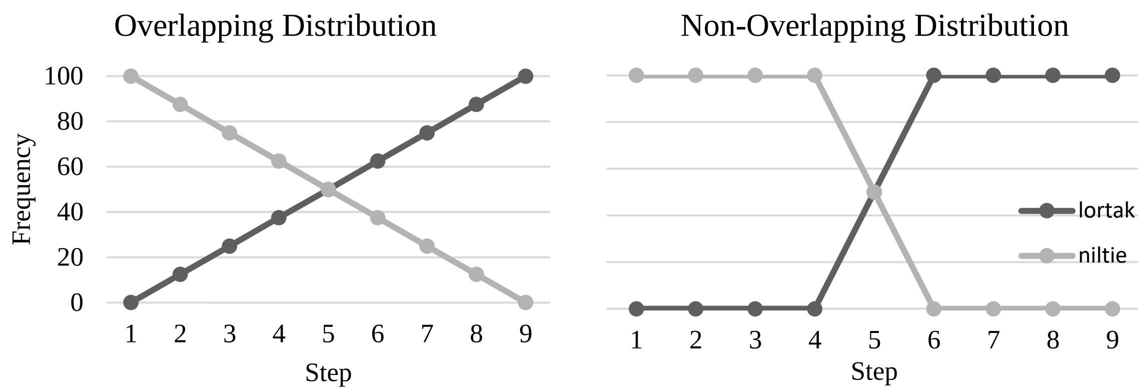

Figure 4. Non-overlapping and overlapping distributions of lortak and niltie labels across a 9 step continuum.

being displayed with a label shown in writing underneath the image. An audio sentence describing the image would then play over the headphones. An example was presented with the sentence in writing. Trials were set to advance after 3700 ms. The length of time was determined by the longest audio token and was held constant to allow equal exposure to visual stimuli across trials. Due to the label distributions, at least 1 step on each continuum was trained as having 2 possible options. A passive training approach, during which participants were trained without feedback, was selected to avoid an interaction between feedback and the manipulation of label distributions for these more ambiguous points.

The second type of trial consisted of a categorization task that was meant to ensure participant attention to the experiment. Trials consisted of a single step from a continuum with both labels for that continuum displayed below the image. Participants were instructed to use the letter keys “a” and “l” to choose the label that best fit the image shown. The side on which each label was presented was pseudorandomized by list. Participants were informed that these trials were timed and they should respond as quickly as possible while making sure to read the labels carefully before choosing as they would not always be on the same side.

Trial order during training was pseudorandomized by list with categorization trials occurring at regular intervals. A total of 432 training trials, 12 per continuum step, and 21 categorization trials were presented during the training phase. Categorization trials were spaced at intervals of 17 to 23 training trials throughout each list. Exact position of the categorization trials was pseudorandomized separately for each list.

Upon completing the training portion of the study, participants were instructed to retrieve the researcher. The researcher informed the participant they would be given a couple of minutes to rest before starting the testing portion of the experiment. Participants were then offered candy while they were waiting as some research has indicated that glucose can improve self-control, including attentional self-control, during research tasks (Sanders, Shirk, Burgin, & Martin, 2012). It was noted in the participant log if participants accepted or rejected the candy with only 4 participants declining the offer. The researcher then left the room for approximately 2 min before returning to begin the testing portion of the experiment.

Testing. Participants were informed that there were two tasks to complete for the testing phase and that they should alert the researcher once they reached a second set of instructions. Response option and response time data were collected for all testing trials.

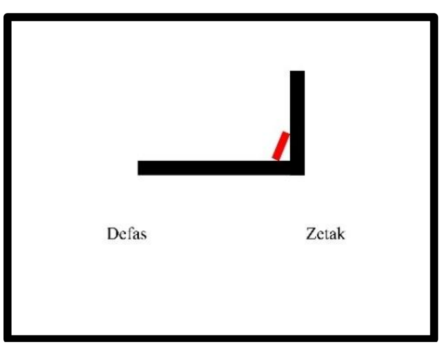

Figure 5. An example trial for the categorization task.

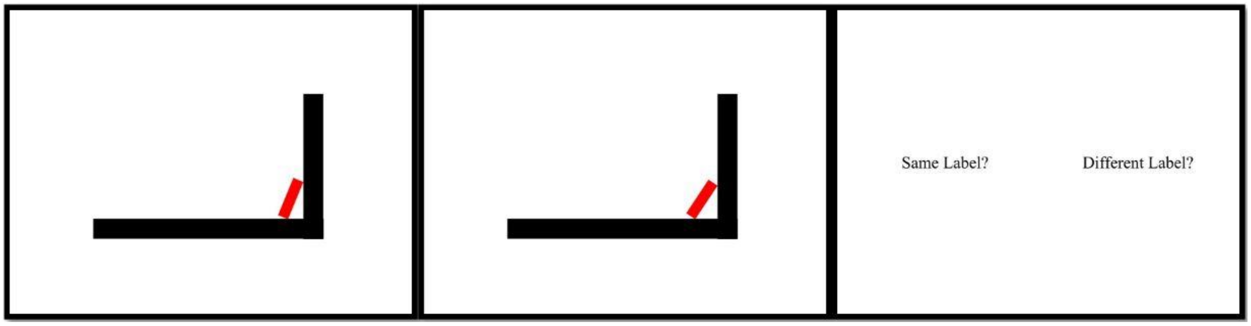

Figure 6. An example trial sequence for the discrimination task.

The first task was a categorization task identical to the categorization trials completed during training with the exception that the task would not be timed. Participants were shown a single step from a continuum with both continuum labels shown beneath the image. Label side was pseudorandomized by list. Participants were instructed to use the “a” and “l” keys to indicate label choice. See Figure 5 for an example categorization task trial. Trials in the categorization task were randomized within blocks. Each block contained trials from a single continuum. Blocks were presented in a random order. Randomization was performed using the randomization features within the Psyscope program. The categorization task contained a total of 288 trials, 8 trials per continuum step.

Participants were asked to alert the researcher upon reaching the second set of instructions within the testing portion of the experiment. The researcher then verbally explained the instructions for the discrimination task. Participants were shown two continuum steps sequentially before seeing a screen that presented the options “Same Label?” and “Different Label?”. See Figure 6 for an example trial sequence for the discrimination task. Each continuum step was shown for 500 ms with a 50 ms fixation point displayed between. The time was initially set at 300 ms per continuum step as is consistent with the stimulus time used in Brady and Oliva (2008) for the discrimination of visual scenes, however brief pilot testing indicated a need to increase the duration to 500 ms.   There was no time limit for participant response, however response time was recorded. The trials for this task were again presented by blocks, with each block containing all trials for a single continuum. The response options changed sides by block, with 2 blocks having the “Same Label?” option displayed on the left side of the screen and the remaining 2 blocks have the “Same Label?” option displayed on the right. These options were counterbalanced by list. Each continuum step was presented 4 times for a total of 128 trials.

Upon completion of the discrimination task, participants were asked a series of questions by the researcher to confirm study eligibility and provide data to control for prior language exposure. Participants were specifically asked if they had studied any language(s) other than English for more than 3 years. If participants responded in the affirmative, they were asked to specify which language(s) and the context in which they were learned. Participants were then asked if they had studied or lived abroad in a country whose primary language was not English. If participants responded in the affirmative, they were asked to specify the country and/ or primary language as well as the length of time they spent in the country.

Results

Response time data were collected for both categorization (M = 1655.02 ms, SD = 2507.52 ms) and discrimination trials (M = 904.60 ms, SD = 1100.33 ms). Trials with response times greater than two standard deviations from the mean were excluded from analysis. A total of 225 or 2.37% of categorization trials and a total of 244 or 5.78% of discrimination trials were excluded from analysis.

Categorization

Aggregate categorization curves by condition were plotted for proportion response to step 9 label by continuum step. See Figure 7 for aggregate categorization curves by condition.

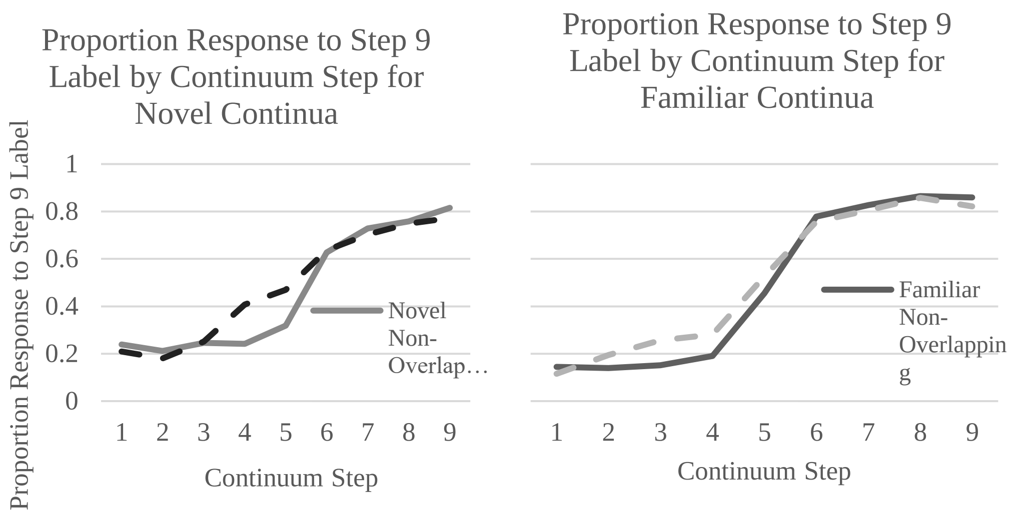

Figure 7. Categorization curves with proportion of response to step 9 label across continuum steps separated by familiarity.

Individual participant data for steps 4 through 6 were fit to a linear function with the formula $y = mx+b$. See Figure 8 for participant slope values for steps 4-6. A two-way ANOVA for the slope (m) was run with continuum condition as a within-subject variable and list as a between-subject variable. The continuum condition was measured on 4 levels: novel overlapping (*M* = 0.12, *SD* = 0.20), novel non-overlapping (*M* = 0.19, *SD* = 0.23), familiar overlapping (*M* = .24, *SD* = .22), and familiar non-overlapping (*M* = .29, *SD* = .19). A significant effect of condition was found, $F(3,93) = 7.039$, $p < .001$. The observed power was .98. Additional paired samples *t*-tests were run to determine pairwise effects. The familiar non-overlapping condition showed a significantly steeper slope than the novel non-overlapping condition, $t(32) = -3.01$, $p < .05$. Likewise, there was a significant difference between the overlapping distributions with the familiar overlapping condition showing a significantly steeper slope than the novel overlapping condition, $t(32) = -3.05$, $p < .05$. There was a marginally significant difference in slope between the novel continua, with the non-overlapping condition having the steeper slope, $t(32) = -1.99$, $p = .056$. No difference in slope was seen between the familiar overlapping and non-overlapping conditions, $t(32) = -1.30$, $p = .202$. No effect of list was seen, $F(1,31) = .014$, $p = .907$.

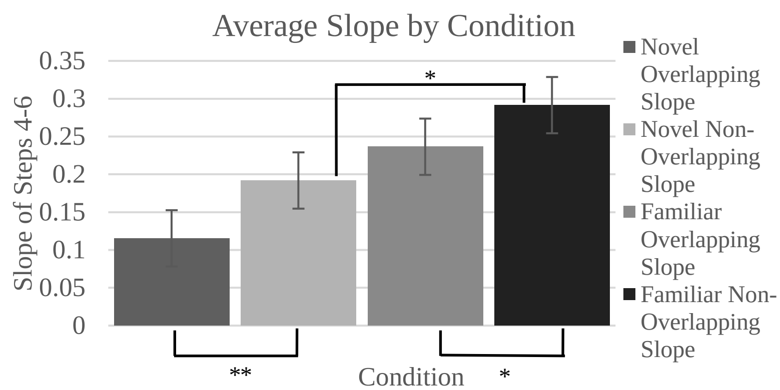

Figure 8. Average slope of a line fit to the data for continuum steps 4-6 by condition. Single star indicates significance, p<.05. Double star indicates marginal significance, p = .056.

Discrimination

Discrimination task responses were analyzed for the proportion of responses indicating two steps on a continuum had “different” labels. Proportion of “different” responses were plotted against step pairings for each continuum, and an average response value across all step pairings was taken for each participant for each condition. See Figure 9 for graph of proportion of “different” responses across step pairings. A two-way ANOVA for average proportion was run with continuum condition as a within-subject variable and list as a between-subject variable. There was a main effect of condition, $F(3,93) = 6.76$, $p < .001$. However, there was also a between-subjects effect of list, $F(1,31) = 19.20$, $p < .001$. For graph of data separated by list, see Appendix C.

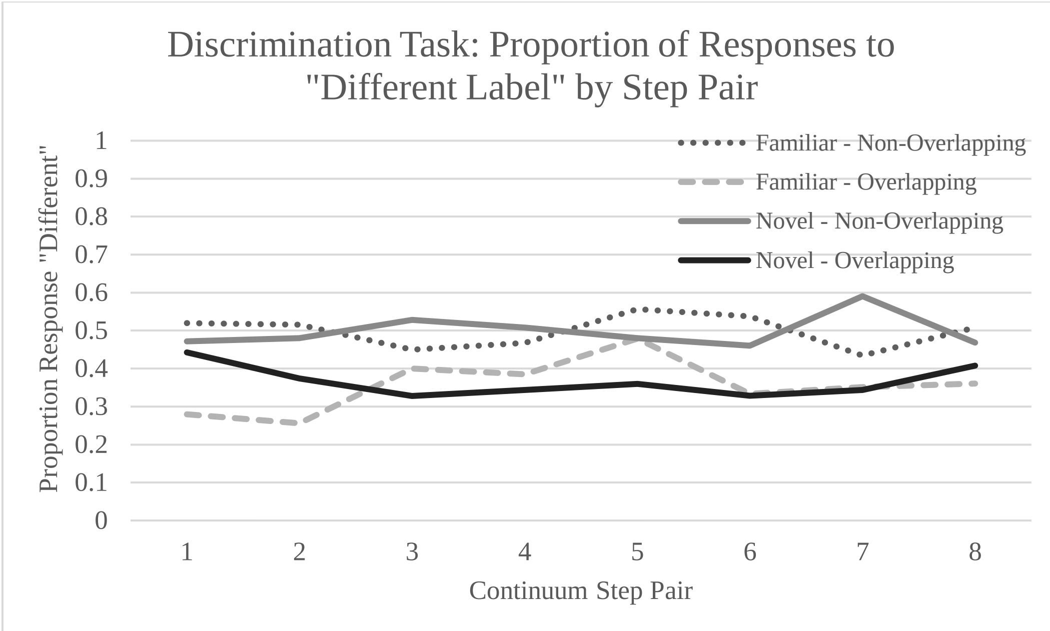

Figure 9. Discrimination task data for the proportion of responses to "Different Label" by continuum step pair collapsed across lists.

Discussion

The categorization results appear to indicate the presence of both an L1 dominant and statistic dominant outcome for categorization data. More specifically, it appears that L1 semantic category information overrode the frequency distribution of the novel labels for the familiar continua, while the frequency distributions appear to be the primary source of information in learning the novel continua. There was further indication of a L1 category influence for the novel continua, primarily for the non-overlapping label distribution. A visual representation of these results can be found in the categorization curves in Figure 8.

The familiar non-overlapping continua were a baseline measure as it most closely mimics a categorical perception task without training. The continuum is one which exists in the English language and the label distribution is minimally altered and only overlaps at a single point.

Both the familiar non-overlapping and the familiar overlapping continua formed a steep slope with no significant difference between the slopes by label distribution. This most closely corresponds to the predicted results for familiar continua in a L1 dominant outcome in which native language (L1) semantic category information is the primary source of information for category learning.

On the other hand, the novel continua closely follow the expected results for a statistic dominant outcome. There is a marginally significant difference between the non-overlapping and overlapping slopes for the novel continua, with the non-overlapping continuum having a steeper slope than the overlapping continuum. It is also important to note that neither of the novel continua have a slope of or near 0, which would indicate a lack of learning for that continuum and would be consistent with both the non-learning and L1 dominant theories.

One result that appears to indicate the presence of L1 influence for the novel continua is the significant difference in slope between the familiar non-overlapping and novel non-overlapping continua. Given a purely statistic dominant outcome, the slopes for each of these should not show any significant differences. The presence of L1 category information appears to have interacted with the distribution statistics with the result of a shallower slope than would be obtained through the influence of the distribution statistics alone.

Given the apparent difference in primary information source for the familiar and novel continua, L1 vs statistics, the significant difference in slope between the familiar overlapping and novel overlapping continua is to be expected. This difference, with the familiar overlapping continuum having the steeper slope, does support the conclusion that the familiar and novel continua differed in primary information sources during training. This could be attributable to an apparently more amorphous nature of the novel spatial relationships as opposed to the familiar relationships. In the absence of pre-existing information that is consistent with the task, in which participants are presented with 2 label options and required to choose the label that “best fits” the image, participants would be required to rely on the alternative information found in the statistical distributions.

These results provide valuable insight into the formation of new category boundaries when learning a second language. In line with the Roberson et al. (2000) finding with regard to learning novel and familiar color distinctions, participants were better able to categorize familiar continua regardless of novel labels or label distribution statistics in training. This appears to indicate a level of concreteness from those category distinctions that exist in the L1 and are thus supported by pre-existing category information, while the more amorphous novel continua rely on environmental cues such as visual statistics of frequency distributions in the formation of novel category boundaries.

An interesting note is that the novel categorical distinctions appear to be learned with only minimal interference from the overarching category information from the native language. For example, there appeared to be minimal interference from category information pertaining to the English category "on" in forming the novel "vertical on" and "horizontal on" distinctions. Future research should address whether the amorphous nature of the novel categories remains when collapsing across category boundaries to form a single category such as in the case of combining the English "in" and "on" to form the Spanish "en".

An error in the discrimination task design coupled with a between subject effect of list on the results obtained limit the usability of these results in addressing participant ability to discriminate between categories along the learned continua. Due to each continuum containing at least 1 point of overlap, it is feasible that the "correct" answer for every single continuum step pair is "Same Label". In future iterations of this study, an even numbered continuum in which there is no perfectly centered middle step might be used to eliminate this problem. This would prevent any label distribution from having a point where each label is presented exactly 50% of the time. In other words, there will always be a label that "best fits" each step providing a natural discrimination point between the two middle steps.

For the data obtained, there was a between subject effect of list indicating an interference of the specific continua-distribution pairings during the discrimination task. Appendix C provides the specific continuum as well as the familiarity and label distribution by list. Figure 9 contains the aggregate discrimination data for both lists, however Appendix D contains a graphical breakdown of these data by list. Participants were asked to indicate whether the two images that flashed consecutively on screen were represented by the "same label" or "different labels". Results were calculated as the proportion of the time a participant chose the "different label" response option. The visual representation of the list 1 discrimination data indicates that participants, on average, were at or below a .5 proportion of responses as "different". This is to be expected given the design of the task.

The qualitative discrimination data for list 2 contain only 2 categories with an average proportion of .5 or less across all step pairings. Unsurprisingly, both overlapping continua remain below the .5 line as the label distributions would likely increase the chance of a "same label" response. On the other hand, the non-overlapping distributions both remain at or above the .5 mark for all steps for list 2. No significance testing has been performed for these data, however the presence of the non-overlapping continua falling above the .5 line is interesting. Of the 9 step continuum, a non-overlapping label distribution contained 4 consecutive steps that shared a single label, a center step that was represented by both labels equally, and a final 4 consecutive steps that shared a single label. Given this distribution, low proportions of responses as "different label" would likely be expected. One explanation is that participants in list 2 chose not to pay attention to continuum step labels and instead answered the question "are these two steps different?" for each step pairing.

It is difficult to predict exactly what, if any, effect of continuum-distribution pairing drove the between-subject effect with the current design also strongly influencing the data. One possible account for this effect is the availability or lack of visual cues to the transitioning between continuum endpoints that are present for each continuum. In the novel continua, for example, the vertical on – horizontal on continuum shapes remain touching for all steps in the continuum, though the angle at which the red rectangle is placed against the black surface differs. For the loose containment – tight containment continuum, the black box changes size to move the edge closer to the orange rectangle, or to change the tightness of fit for the containment shapes. See Figure 3 and Appendix A Figure A1for a visual representation of these continua. A possible solution would be to increase the distance in the discrimination step pairings from 1-step pairings to 2-step pairings. An increase in the distance between the continuum steps would allow the differences between the steps to be more noticeable.

Apart from adjusting the discrimination task to better fit the visual stimuli and same-different response options chosen for this experiment, there are several avenues to continuing this research. As mentioned previously, a priority of this research avenue should be in addressing the combining of multiple L1 categories to form an overarching L2 category such as the Spanish "en". Replications of this study using different spatial continua are also necessary in supporting the findings of this initial study.

A separate yet closely related avenue of research is to explore the influence of statistical distributions and L1 category information on novel category formation across modalities. Visually, Roberson et al. (2000) provides an example of such a study with color, though without the manipulation of label distributions. Such distinctions as the categorical differences in “blue” color terms in Russian (Winawer et al., 2006) might be trained using similar methodologies to provide insight into what mechanisms play a role in learning novel color categories. While color is a logical choice for subsequent continua to explore, other options such as facial expressions (Lee et al., 2015) might be studied in a similar manner.

Cross-linguistic exploration of this research would also be beneficial. The current study provides evidence that is specific to English L1 speakers. Studies involving L1 speakers of different languages and studies of bilingual or multilingual speakers, using language appropriate continua, would provide more stable insight into the influence of visual statistics and L1 semantic information on novel category learning.

Finally, future research should address novel category learning in speakers of visual languages such as American Sign Language. It is possible that speakers of such languages will rely more on visual statistical information due to the visual nature of the L1, though this might not necessarily be the case.

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Appendix A

1st, 5th, and 9th Steps of Continua Stimuli

Figure A1. 1st, 5th, and 9th steps of the tight/ loose containment continuum.

Figure A2. 1st, 5th, and 9th steps of the above/ below continuum.

Figure A3. 1st, 5th, and 9th steps of the on/ off continuum.

Appendix B

Pseudoword Stimuli with English Definitions

Table B1

Continuum endpoints and their English definitions.

Novel Step 1	**Novel Step 9**	**English Step 1**	**English Step 9**
Defas	Zetak	On (Vertical)	On (Horizontal)
Lortak	Niltie	On	Off
Trulta	Gullna	Tight Containment	Loose Containment
Corlad	Meedla	Above	Below

Appendix C

Continuum Condition by List

Table C1

Continuum condition by list.

Continuum	**Familiarity**	**List 1 Distribution**	**List 2 Distribution**
Above – Below	Familiar	Overlapping	Non-Overlapping
On – Off	Familiar	Non-Overlapping	Overlapping
Vertical On – Horizontal On	Novel	Overlapping	Non-Overlapping
Loose Containment – Tight Containment	Novel	Non-Overlapping	Overlapping

Appendix D

Discrimination Task Data by List

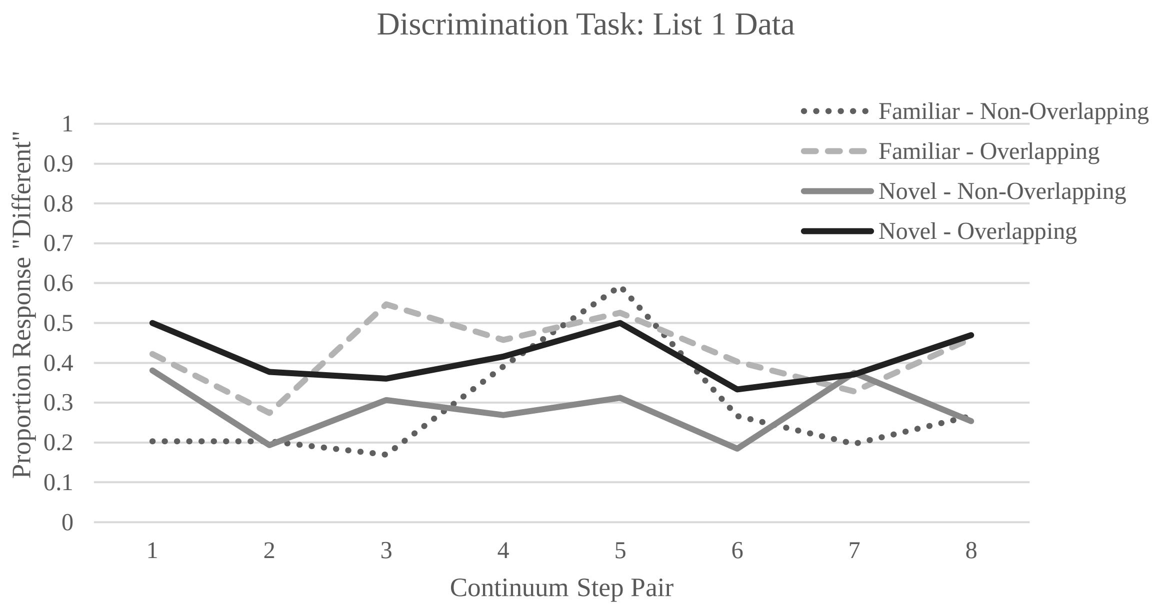

Figure D1. Proportion of responses to “Different Label” by continuum step pair for List 1 participants only.

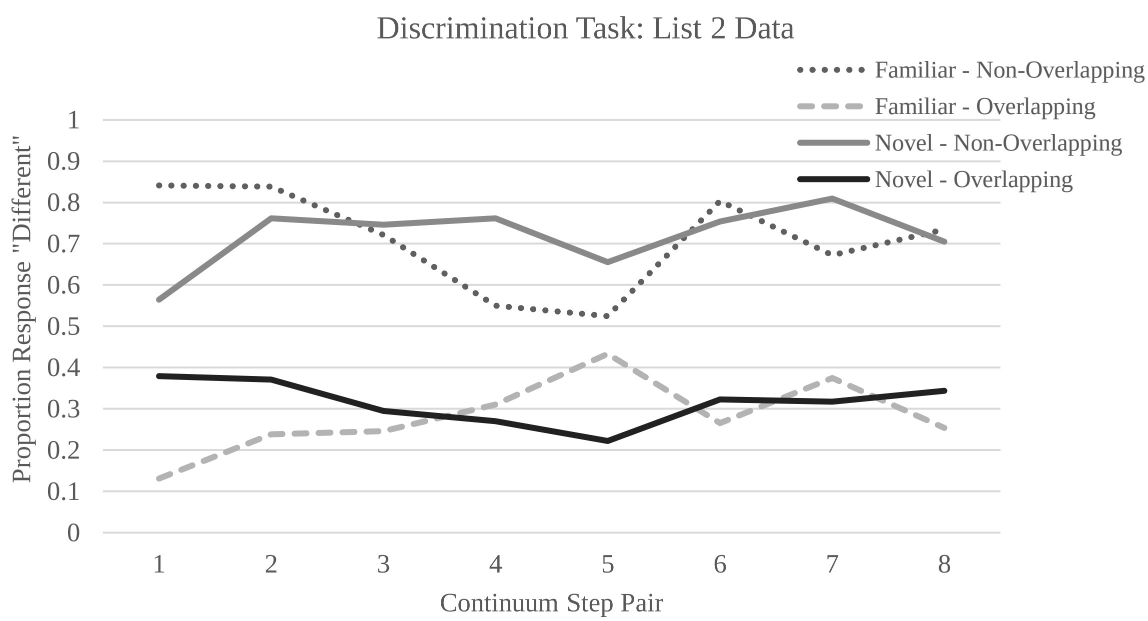

Figure D2. Proportion of responses to “Different Label” by continuum step pair for List 2 participants only.

From: Beverly Jacobik (bjacobik) **On Behalf Of** Institutional Review Board
Sent: Tuesday, July 05, 2016 5:36 PM
To: Stephanie Marie Huette (shuette) <shuette@memphis.edu>
Subject: IRB Approval 2810

Hello,
The University of Memphis Institutional Review Board, FWA00006815, has reviewed and approved your submission in accordance with all applicable statuses and regulations as well as ethical principles.
PI NAME: Stephanie Huette
CO-PI:
PROJECT TITLE: Perception of language
FACULTY ADVISOR NAME (if applicable):
IRB ID: #2810
APPROVAL DATE: 7/1/2016
EXPIRATION DATE: 7/1/2017
LEVEL OF REVIEW: Expedited
Please Note: Modifications do not extend the expiration of the original approval
Approval of this project is given with the following obligations:
1. If this IRB approval has an expiration date, an approved renewal must be in effect to continue the project prior to that date. If approval is not obtained, the human consent form(s) and recruiting material(s) are no longer valid and any research activities involving human subjects must stop.
2. When the project is finished or terminated, a completion form must be completed and sent to the board.
3. No change may be made in the approved protocol without prior board approval, whether the approved protocol was reviewed at the Exempt, Exedited or Full Board level.
4. Exempt approval are considered to have no expiration date and no further review is necessary unless the protocol needs modification.
Approval of this project is given with the following special obligations:

Thank you,

James P. Whelan, Ph.D.
Institutional Review Board Chair
The University of Memphis.
Note: Review outcomes will be communicated to the email address on file. This email should be considered an official communication from the UM IRB.