EFFECTS OF PHONOLOGICAL LABEL DIFFERENCES ON CATEGORY LEARNING

- Phonological difference makes conceptual difference –

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ABSTRACT

The present study tested whether the degree of phonological difference between the labels of categories influence category learning and generalization. For this purpose, two experiments were conducted. In the first experiment, participants learned two categories labelled with pseudo-words that were controlled for the degree of difference between the phonetic features of their labels, such that they each pair was maximally different, minimally different, or somewhere in between. These labelled conditions were compared against a no-label control condition. Results showed that participants learned faster and generalized better for categories when category labels differed more.

In the second experiment we tested whether these effects could be attributed to the sound symbolic congruence of the labels to the category members. Results showed that phonological differences influence learning independently from the sound symbolic match. Further we specify a category learning model based on generalized perceptual discriminability of the to-be categorized information, including perceptual features of both items and their labels: Categories are easier to learn when their features (including labels) are easier to discriminate.

Key words: category learning, category labels, phonetic discriminability, Whorfian hypothesis/effects, learning models.

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INTRODUCTION

We represent the world around us via cognitive concepts. Concepts are abstract representations of entities from reality which have been conceptually grouped in broader categories (Murphy, 2002; Sloutsky, 2010). The ability to categorize is not an exclusive property of humans, as animals can also create concepts. Language, on the other hand is an exclusive property of humans. The human ability to use symbols has led some authors to consider humanity as an animal ‘symbolicum’ (Cassirer, 1944).

The relationship between language and concepts has been an object of debate for philosophers and psychologists for centuries, with ideas falling into two broad themes. The first group of authors consider language and concepts to be strictly separate (Fodor 1975; Li & Gleitman, 2002; Gleitman & Papafragou, 2005; Gleitman & Papafragou, 2013; Li, Dunham & Carey, 2009; Klemfuss, Prinzmetal & Ivry, 2012). According to this model, concepts are independent from, and have primacy over language. Language is conceptualized as strictly for communication, and cannot influence the internal composition of concepts. As Gleitman and Papafragou noted: “*thought is first, language is its expression*” (Gleitman & Papafragou, 2005, page 634).

The second group of theories consider language and concepts to be interactive and mutually dependant. Words can provide stability for complex ideas in working memory and also influence the internal composition of the concept (James, 1890; Vygotsky, 1936; Lupyan, 2012; Thierry, 2016). This group of theories is aligned with the *linguistic relativity hypothesis*, which is brought to its extreme in what is known as the Sapir-Whorf hypothesis (Whorf, 1941; Whorf, 1956). This hypothesis considers the linguistic system of the speaker to be a determinant of mind, and proposes that the words and grammatical structures in specific languages determine

the way we think and perceive outside world. A more moderate view is known as the Neo-Whorfian perspective, and holds that different languages can bias cognition and perception as mandatory linguistic encoding of some aspects of reality over others may bias the frequency with which certain concepts or percepts are experienced (Levinson, 2003; Clark, 2003; Gentner & Godin-Meadow, 2003).

Interactions between language and conceptual categories are also addressed in Lupyan's *Language-augmented thought hypothesis* (Lupyan, Rakison, & McClelland, 2007; Lupyan, 2012; Lupyan, & Thompson-Schill, 2012). According to this hypothesis, names are not only used for communication and labelling of concepts, but they also modulate object representation on-line, making the relationship between words and concepts bidirectional. Lupyan tested this hypothesis in experiments in which participants were exposed to either labelled or non-labelled novel categories (Lupyan et al., 2007), and tested on their ability to recognize which items belonged to each category. Results showed that people exposed to labelled categories learned faster and generalized better than people exposed to non-labelled ones.

This finding is consistent with studies of categorisation in infancy, where presence of labels in categorisation tasks facilitates category learning over and above category learning without labels (Quinn, Eimas & Rosenkrantz, 1993; Waxman & Markov, 1995; Xu, 2002; Plunkett & Hu, 2008; Plunkett, Hu & Cohen, 2008; Sloutsky & Lo, 1999; Sloutsky & Fisher, 2004).

James (James, 1890) first noted two roles for labels in the categorization process: As 'disparate associates', labels first increase the overall difference between category members; and second enhancing the perception of existing differences. He gives the example of discrimination between two varieties of wine: the flavour of the wines can be associated with the situations in

which we tasted them. Since these situations are different, the context can help to drag apart our experience of the flavours of the wines. Formally, if concepts B and C are difficult to discriminate, but A and D are easier to discriminate, then if A is associated with B and D is associated with C, then AB and CD will be more easily discriminated than B and C alone (James, 1890, page 511). Figure 1, illustrates these relationships, where horizontal distance between items represents the degree of difference between them.

Figure 1: Simplified model of James' hypothesis: horizontal distance represents level of difference between entities

In this case, A and D could be previous experiences related to the concepts. Apart from experiences, James claims that role of A and D could be taken by words, or more specifically, the names of the concepts. Since *“the names [of wines] differ far more than the flavours, [the names] help to stretch these latter farther apart”*.

This idea was further specified within behaviourist psychology, by Miller and Dollard (1941). Describing higher mental processes through learning, they considered that generalization can be induced by specific responses that produce a common cue (in behaviourist terminology). Meaning, once we have the same name for the different things, these names will increase the

overall similarity of these different things. They give an example of a tribe surrounded by enemy tribes who are very diverse. If they name them all as “enemies”, they will be readily generalized as members of the same opposing group. On the other hand, if the individual tribes are given names that are “highly distinctive”, these names will “lessen the generalization” (Miller, 1948), meaning, they will increase distinctiveness between different tribes.

This claim was experimentally tested with children (Birge, 1941, from Miller & Dollard, 1941) in an experiment where children identified two different objects easier as the members of the same category if those objects shared the same name.

Further research in this area using behaviourist methods was conducted by Rossman and Goss (1951). In an experiment where participants previously learned names (highly distinctive syllables) for objects which were highly similar, they performed much better in the categorisation learning task compared to the groups which did not learn, but just saw labelled objects (in 1 or 4 trials). This confirmed Miller’s hypothesis that highly different verbal responses lead to faster concept formation.

The aim of this paper is to test how the learning of categories is influenced by the degree of phonological difference in verbal labels applied to categories of objects: Will learning be faster and more easily generalized for categories with phonologically dissimilar labels compared to the categories with phonologically similar labels? This research question follows directly from James’/Miller’s hypothesis: If distinctive elements (i.e., names) associated with two concepts contribute discriminability to these concepts, then where those elements are more distinct we could expect the differentiation to be larger between them. Meaning, categories labelled with

labels that are more phonologically distinct would be learned more effectively than to the same categories labelled by labels that are less phonologically distinct.

Additionally, if James' hypothesis is correct, we could expect a range of label differences would lead to a range of effects on concept learning and generalization. Since it is difficult to test behaviourally all possible variations of the label differences, we created a series of word pairs differing in their degree of phonological difference, ranging from maximal difference (all phonemes differ), to minimal difference (only one phoneme differs – a minimal pair), with an intermediate word pair showing a moderate difference. If our learning paradigm shows that concepts named with moderately different labels are learned and generalized better than those named with a minimal difference, but worse than those with maximal difference, we can conclude that the degree of phonological difference corresponds to the ease of learning along a continuum of phonological differences.

Labels with phonological gradations are compared to a condition with no labels, to find out they differ from a scenario in which only the visual properties of the category members are available, with no associated information to guide category learning. In this way we can unpack the effects of different features of labels on category learning. It is expected that condition with maximally different labels will be learned more effectively than a silent condition, as in Lupyan et al. study (2007), and that the other degrees of phonological difference will fall between these extremes.

For this purpose, experiment with categorization task was designed in which participants were trained to classify different exemplars as members of novel categories. The design and materials were based on the YUFO classification task implemented by Lupyan and colleagues (Lupyan et al., 2007), implemented in a novel approach/avoid task, and accompanied by novel

labels, finely controlled for their phonological features. In the current study, we use a feature-based model of phonology to describe differences between words-forms used as labels.

EXPERIMENT 1

In this experiment, participants took part in a category learning task where YUFO categories (Gauthier, James, Curby, & Tarr, 2003) were presented in different labelling conditions, ranging from no label (silent), to maximally different labels.

Method

Participants

The participants were 80 second year elementary psychology students (10 males), who participated in the experiment as part of their course credit⁶. Participants were randomly divided into four groups, who were presented with visual stimuli accompanied by (1) *no labels*. (2) *minimally different labels*; (3) *moderately different labels*; (4) *maximally different labels*. One participant was excluded from analysis due to misunderstanding the task instructions.

Materials

The experiment was designed in the program SuperLab 4.0. The screen was a 21” LCD, with a visual angle of 12.23° (distance 70cm). Participants used standard keyboard arrow buttons (directing left and right) for their responses. Each participant received auditory stimuli via headphones.

⁶ The present research was ethically approved by the Serbian psychological association from the University of Nis (Ethical approval document number 3/16).

Visual Stimuli. The YUFO stimuli list of ‘aliens’ was used (Gauthier et al., 2003, downloaded from: <http://sapir.psych.wisc.edu/stimuli2/>, on June-2015). The aliens were originally designed to fall into two groups on the basis of statistical distribution of a number of visual features, including head shape, base foot shape, and limb characteristics. One group of YUFOs had a somewhat rounded base and flatter, rounder heads (Upper stimuli in Figure 2).

Eight members of each category were used as training stimuli (Upper left, Lower left of Figure 2). An additional four stimuli from category were added to the stimulus set for the test block (Upper right, Lower right, Figure 2).

Figure 2: YUFO stimuli (from Gauthier et al., 2003) in two categories (top and bottom). Left: Training exemplars; Right: novel exemplars added during test.

Audio Stimuli. For the labels, we used pseudo-words to label items in the different categories, and varied the degree of phonological difference between the labels across conditions. *Minimally different* labels differed only in the identity of a single consonant, which differed only in the place of articulation, yielding the minimal pair spelled *džoset* and *đoset* in the Latin script of Serbian, and transcribed in the International Phonetic Alphabet (IPA) as /dʒoset/ vs /dʑoset/. These words differ by a small difference in the place of articulation of the voiced affricate at the start of the word: /dʒ/ versus /dʑ/ (post-alveolar and retroflex, respectively). Although this contrast is unfamiliar to speakers of English and other Western European languages, it is phonemic in contemporary Serbian, meaning that the contrast would normally signal a difference between the meaning of two words. *Maximally different* labels differed in their syllable structure (CVCV vs VCVC), and a minimum of two phonological features for every speech segment (voicing and place of articulation of consonants; tongue backness and lip rounding of vowels), yielding the pseudo-word pair *ketsi* and *ubom* (IPA: /ketsi/ and /ubom/).

In between these extremes were *moderately different* labels that shared a syllable structure (CVCVC), but where 4 of the 5 speech segments differed by a small degree in a single phonological feature (voicing or manner of articulation of consonants; one-step change in height of vowels) yielding the pseudo-word pair *đosiš* and *đuzetč* (IPA: /dʑosiʃ/ – /dʑuzetʃ/). In this case, the sonority of the two words barely differ (one word contains a voiceless affricate and a voiced fricative, the other a voiced fricative and a voiceless fricative). We predicted this would place the difference between the two labels somewhere in between the pseudo-word minimal pair (*minimum difference* labels), and the pair where sonority differences and congruence were maximized (*maximum difference* labels). In the no label condition, images were presented in

silence. Table 1 shows the degree of phonological difference in each of the label pairs in Experiment 1.

Table 1

Feature-based analysis of word pairs in Experiment 1. Ones (1) indicate presence of the feature difference. Pluses and minuses indicate presence (+) or non-presence (-) of specific feature.

	Maximum Difference						Minimum Difference						Medium Difference				
	k	e	ts	i	#		dʒ	o	s	e	t		dʒ	o	S	i	ʃ
	#	u	b	o	M		dʒ	o	s	e	t		dʒ	u	Z	e	tʃ
Consonant Features																	
Place	1		1		1		1						1				
Manner	1		1		1												1
Voice	1		1		1										1		
Vowel Features																	
Height		1		1										1		1	
Backness		1		1													
Rounding		1		1													
Sonority																	
Word 1	-		-				+		-		-		+		-		-
Word 2			+		+		+		-		-		+		+		-
Total Difference					19						1						5

All auditory stimuli were spoken by a female native speaker of Serbian, and digitally recorded and edited in Sound Forge 7.0 programme (.wav stereo file). Labels were approximately of equal length (around 700ms).

Design and procedure

The experiment was divided into two phases: *training* and *test*. Participants were told that they were participating in a categorization task in which they play the role of a cosmonaut exploring a new planet. There are two types of creature on the planet: good creatures and bad creatures. In each trial an alien appears in the centre of the screen, followed by a picture of the cosmonaut. If they think the alien is a good creature, they should approach it by pressing the arrow key pointing towards the creature. Otherwise, they should avoid it by pressing the arrow key pointing away. In the instructions it was explained that previous missions had named the two types of creatures, and on each trial, the labels would be presented after deciding whether to avoid or approach the alien. Participants were instructed to pay special attention to the names, as their knowledge would be tested at the end of the experiment (in the silent condition, this instruction was omitted).

In the *training phase* for each trial (Figure 3), a randomly selected alien was presented in the centre of the screen, followed by an image of the cosmonaut, who could move towards or away from the alien. In decision-making studies of this kind, there is often a confound of response hand (i.e., left/right) with the category under investigation (i.e., avoid/approach), meaning that participants might be systematically faster to make one kind of decision than the other, depending on handedness. To remove this confound, the cosmonaut appeared on the left or right side of the screen, and participants used both hands to ‘avoid’ and ‘approach’ the alien in different trials. After selection, participants received auditory feedback to signal if their selection was correct (bell) or incorrect (buzzer), while the alien remained on the screen throughout the trial. Following auditory feedback, participants heard the name of the alien category. It is important to note that labels are completely redundant to the task, since participants did not need to hear the labels learn which aliens belong to the ‘good’ or ‘bad’ category. The training phase

consisted of nine blocks, each of which presented the entire set of training stimuli. The training phase consisted of nine blocks (in each block the entire list of stimuli was presented once – 16 per block). The entire training lasted around 8 minutes.

Figure 3: Trial structure in the training phase (phase I)

As in the original study (Lupyan et al, 2007), the *test phase* was designed to find out if participants extracted feature-based information about the previously seen aliens in such a way that they could remember the trained items and generalize to new members of the same category. In addition to the eight stimuli from the training phase, additional test stimuli were added (four previously unseen members of each category), resulting in a total of 12 trials for category per block. There were four blocks in the test phase. Trials in the *test phase* were the same as in the *training phase*, except without auditory feedback and labels. Trials were presented on the screen up to the response of the participant. Entire test phase lasted approximately 4 minutes. As

participants performed the task, reaction times and percentage of correct responses were recorded and subsequently analysed.

Predictions and analysis

Most studies that use a pair of items to label two different categories used labels that are phonologically distinct (e.g. “leebish” and “grecious” in Lupyan et al., 2007). We predicted that learning could be more or less effective if the labels have larger or smaller phonological distance, respectively, resulting in a graded learning effect across different labelling conditions. In particular, we predicted worse responses in the minimal pair condition (minimum difference), best performance in the condition with the largest phonological difference (maximum difference), and performance falling in between these extremes for the moderate difference condition (middle difference). No label was used as a control condition, and in line with previous research on the effectiveness of labels in similar learning paradigms (Lupyan et al., 2007), we predicted that learning would be worse in the silent condition than in the labelled conditions. Regarding reaction times, in line with previous studies (Lupyan et al., 2007) we predicted that there would be no difference across these four experimental conditions.

To test whether labelling condition makes a difference on performance in this task we compared the accuracy of participants using a mixed ANOVA with repeated measures design, comparing accuracy during the different test phases (training, test), for participants in the four different labelling conditions.

Results and discussion

Accuracy was computed as the percentage of correct avoid/approach decisions in each block of the study. Accuracy rates for participants in the four groups are presented in Table 2, and shown unfolding across the blocks of the study in Figure 4.

Table 2

Percentage of correct responses in Experiment 1

Label condition	N	Training			Test		
		M (%)	SD	95% CI	M (%)	SD	95% CI
Maximally Different	19	71.71	12.62	[79.11, 85.44]	79.33	12.22	[83.04, 87.85]
Moderately Different	20	82.50	7.27	[71.83, 81.21]	85.47	5.26	[76.36, 87.28]
Minimally Different	20	76.84	10.44	[65.57, 77.02]	82.19	11.77	[73.14, 84.38]
No labels	20	73.33	11.51	[67.75, 77.97]	74.43	16.40	[66.55, 80.88]

A two-way mixed-design ANOVA was conducted with Labelling condition as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test). There was a significant main effect of Labelling condition ($F(3,75) = 3.411$, $p = .022$, $\eta^2 = .120$), a significant main effect of Phase ($F(1,75) = 32.849$, $p < .001$, $\eta^2 = .305$), and a significant Group x Phase interaction ($F(3,75) = 3.610$, $p = .017$, $\eta^2 = .305$). Post-hoc power analysis was conducted with $\beta = .880$ (Faul, Erdfelder, Lang, & Buchner, 2007).

To unpack the interaction between group and phase, one-way ANOVAs were conducted separately for each experimental phase, with a Group as a between-subjects factor. There were significant differences observed between labelling conditions in both the training phase ($F(3,75) = 3.987$, $p = .011$, $\eta^2 = .138$) and the test phase ($F(3,75) = 2.996$, $p = .036$, $\eta^2 = .107$).

Figure 4: Percentage of correct responses (with 1 standard error within the respective block) over phases and blocks in Experiment 1

In a planned comparison for each of the experimental phases, with Bonferroni correction for multiple comparisons was applied generating the adjusted alpha-level of 0.0083 (adjusted for 6 comparisons). As predicted, in the training phase, accuracy was significantly higher in the maximally different label condition than in the minimally different label condition (mean-difference = 10.790, $p = .002$) and in the silent condition (mean-difference = 9.167, $p = .008$). Other pairwise differences were not significant. In the test phase, the silent condition was significantly different compared to the maximal (mean-difference = -11.042, $p = .005$), and the middle different condition did not reach the corrected alpha level for significance (mean-difference = -7.761, $p = .046$). The other comparisons were non-significant.

The observed differences between training and test phase (within-subject differences) demonstrate that learning occurred, since participants performed better in the test phase after than in the entire training phase, when concept formation was still in progress.

To understand the interaction between Phase and labelling condition we removed the silent condition from the ANOVA. In this analysis we observed the main effect of phase ($F(1,56) = 46.313$, $p < .001$, $\eta^2 = .453$) and the main effect of labelling ($F(2,56) = 3.634$, $p = .033$, $\eta^2 = .115$), but without the interaction with condition ($F(3,56) = 2.935$, $p = .061$, $\eta^2 = .095$). This suggests that the interaction was driven by the performance of participants in the silent condition for whom there was a smaller difference between training and test than for the other groups.

Regarding reaction times analysis, data were transformed (inversed transformation) and trimmed to two standard deviations above the means. A two-way mixed-design ANOVA was conducted with Group as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test). Results showed that there was no significant main effect of Group ($F(3,75) = 1.913$, $p = .135$, $\eta^2 = .071$). However, there was a significant main effect of Phase ($F(1,75) = 6.347$, $p = .014$, $\eta^2 = .078$). Additionally, there was no significant Phase x Group interaction ($F(3,75) = .899$, $p = .446$, $\eta^2 = .035$).

These results showed that participants did not differ between groups in the selection speed. However, participants responded faster in the test phase compared to the training phase, since they already knew most of the stimuli in the test condition and took them less time to make a selection.

These results support the hypothesis first articulated by James, that inherent differences between exemplars belonging to different categories can be enhanced by the perceptual differences provided by verbal labels, and the degree of difference in the verbal labels is a

powerful feature providing differentiation. The observed differences demonstrate that participants learned and generalized better in the maximal difference condition compared to the minimal different condition. Additionally, since the middle difference group lies between minimal and maximal difference levels, we can conclude that there is a continuum of effects of label difference on category learning, and this continuum can be inferred directly from the number of phonological features that differ between two labels, just as we predicted. Finally, data revealed that even though there are no significant differences between the minimally and middle different labels on category learning compared to the silent condition in the training phase, effects of minimally and middle condition are obvious in the test phase where there is interaction between minimal and silent condition. These findings also align with Lupyan's hypothesis that labels affect generalization, since the labels become associated with the category structure (and its typical feature representation), regardless of the degree of the phonological similarity between category labels. However, we found that the degree of the phonological difference used in the label differentiation is an important factor for the success of the generalization of the categories.

EXPERIMENT 2

In Experiment 1 we obtained results supporting the hypothesis first proposed by James – that perceived differences in the verbal labels contribute to the salience of a categorical discrimination (as demonstrated by the accuracy of learning which items belonged to which categories). However, the tokens in the maximally different pair were comprised of segments that matched each other internally in their pattern of cross-modal associations (the direction of their congruence). As such, there is another possible source of differentiation available to the

listener is whether the sounds themselves have some kind of inherent match to the items in one of the categories. The consonants and vowels in the maximally different label pair shared a pattern of sound symbolic congruence (i.e., *ketsi* is canonically ‘sharp’ sounding while *ubom* is canonically ‘rounded’ sounding in Serbian). This means an alternative reason for the standout success of this word pair may have been a low-level match between the sound-symbolic associations of the labels and the visual shapes of the category that they were paired with, relative to the other label pairs.

Some previous studies (for example, Sučević, Savić, Popović, Styles, & Ković, 2015), have shown that sound symbolism can influence conceptual representation. Furthermore, another previous study that used the YUFO stimuli (Lupyan & Casasanto, 2015) showed effects of sound symbolic congruence (“spikey” label with “spikey” aliens vs “spikey” label with “rounded” aliens), meaning that participants learned faster and generalized better when the word-pairs had a congruent match between the label and visual category, compared to incongruent match. Their study also contained a norming study that showed that participants classified the first group of aliens as “rounded” (top two rows in figure 2) and the second group of aliens as “spikey” (lower two rows in figure 2).

Given the possibility that the congruence of the word-forms to the items in the to-be-learned categories may have contributed to the previously observed effect, the aim of the second study was to test whether cross-modal congruence produced a learning effect that was stronger than the learning effect produced by phonological differentiation. In the previous study, the Maximum Difference labels had been paired with the categories of aliens that mismatched the canonical cross-modal associations of the segments (*ketsi* – rounder aliens; *ubom* – spikier aliens). In the current study, we introduced a pair of labels that differ by a similar degree in

phonology, but with minimal cross-modal associations (*citech* and *nudžoz*, IPA: /citetʃ/ vs /nudʒoz/). We compare performance in the low-association condition to a condition where the original Maximally Different labels were paired with the congruent categories (*ketsi* – spikier aliens; *ubom* – rounder aliens). This comparison allows us to establish whether sound symbolic congruence between the labels and objects adds anything to the category learning effect over and above the discriminability of the labels.

Method

Participants

The participants were 40 second year elementary studies psychology students (around 20 years of age, 10 males), who participated in the experiment as part of their course credit, and who did not take part in the previous experiment. Participants were randomly divided into two groups. In the first group, participants were presented with maximally different verbal labels without sound symbolism, while in the second group with maximally different labels with sound symbolism which were congruent with visual stimuli (aliens). Results for one participant were excluded from the further analysis, since she incorrectly understood the instructions.

Material and stimuli

Materials and stimuli were identical to the previous experiment, with the exception of the labels, as shown in Table 3. These labels were designed to contain segments that differ as much as the segments in the previous maximally different condition, but without the sound-symbolic grouping within each word. The consonants in the new labels differ by at least two features (voicing and manner and the vowels differ by backness and lip rounding). The resulting words were *citech* and *nudžoz* (IPA: /citetʃ/ vs /nudʒoz/). Note that these words did not differ in their

syllable structure as the maximally different word pair did, and all consonants were selected to lack strong sound-symbolic associations in Serbian (Ilić, Ković & Janković, 2012).

As in the previous study, *Maximally different* labels differed in the syllable structure (CVCV vs VCVC), two phonological features of every speech segment, (voicing and place of articulation of consonants; tongue backness and lip rounding of vowels) yielding the pseudo-word pair *ketsi* and *ubom* (IPA: /ketsi/ and /ubom/). The grouping of phonemes into words was done to maximize the difference in sonority (low sonority *ketsi*, high sonority *ubom*) to further maximize the perception of difference between the words. Note that these two words align with known patterns of sound-symbolic congruence in Serbian (Ković, Sučević & Styles, 2017) (i.e., *ketsi* more ‘spikey’ sounding and *ubom* more ‘rounded’ sounding).

Table 3

Feature-based analysis of word pairs in Experiment 2

	Maximum Difference (SS)						Maximum Difference (Less SS)				
	k	e	ts	i	#		C	i	t	e	tʃ
	#	u	b	o	m		N	u	dʒ	o	z
Consonant Features											
Place	1		1		1		1		1		1
Manner	1		1		1		1		1		1
Voice	1		1		1		1		1		1
Vowel Features											
Height		1		1							
Backness		1		1				1		1	
Rounding		1		1				1		1	
Crossmodal Associations¹											
Word 1	*	*	~	*			~	*	*	*	~

Word 2		O	O	O	O		~	O	~	O	~
Total Difference					19						15

1. Congruence Pattern is indicated as * ‘kiki-type’ and O ‘bouba-type’, and ~ ‘intermediate’ according to canonical patterns previously established for Serbian (Ilic, Kovic & Jankovic, 2012).

Results and discussion

Descriptive results for accuracy (percentage of correct responses) are presented in the following table and figure (for each phase and within phase blocks):

Table 4

Accuracy of responses in Experiment 2

Label condition	Training				Test		
	N	M (%)	SD	95% CI	M (%)	SD	95% CI
Maximally Different no sound symbolism	20	80.49	10.62	[75.57, 85.09]	85.42	7.81	[82.20, 88.96]
Maximally Diff. sound symbolism congruent	19	81.25	5.27	[78.81, 83.76]	85.91	5.92	[83.26, 88.54]

Figure 5: Percentage of correct responses (with 1 standard error within the respective block) over phases and blocks in Experiment 2

A two-way mixed-design ANOVA was conducted with Label condition as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test).

There was a significant main effect of Phase ($F(1,37) = 19.676$, $p < .001$, $\eta^2 = .347$), with no further effects or interactions (Label: $F(1,37) = 0.079$, $p = .780$, $\eta^2 = .002$; Label x Phase: $F(1,37) = 0.016$, $p = .901$, $\eta^2 < .0005$). Post-hoc power analysis was conducted with $\beta = .998$ (Faul et. al, 2007).

This finding suggests that learning occurred over the course of the training blocks, and people were able to generalize their learning to novel exemplars of the learned category, but when the label pair contains a large number of phonological differences, sound symbolic congruence between the labels and the visual categories did not add a boost to the learning

outcomes. Hence, we can conclude that in our experiment, there were no discernable effects of sound symbolism on category learning.

In the reaction times analysis, data were transformed (inversed transformation) and trimmed for two standard deviations. A two-way mixed-design ANOVA was conducted with Group as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test). Results showed that there was no significant main effect of Group ($F(1,37) = 0.036$, $p = .850$, $\eta^2 = .001$). However, there was a significant main effect of Phase ($F(1,37) = 6.841$, $p = .013$, $\eta^2 = .156$). Additionally, there was no significant Phase x Group interaction ($F(1,37) = 1.349$, $p = .253$, $\eta^2 = .035$). These results showed that participants did not differ between groups in the selection speed. However, participants responded faster in the test phase compared to the training phase (as in previous experiment), since they already knew most of the stimuli in the test condition and took them less time to make a selection.

COMPARISON OF RESULTS IN STUDY 1 AND STUDY 2

In the second experiment, we found no added benefit for a sound symbolic match between labels and shapes, over and above the learning benefit of having highly discriminable labels. To put these results in context, we conducted a supplementary analysis to bring together the results from both experiments focussing on the three maximally different conditions (Maximally Different with congruent sound symbolism, Maximally Different with incongruent sound symbolism, Maximally Different without sound symbolism), and the Minimally different condition. Figure 6 shows the combined results where it is clear that the three Maximally

Different conditions pattern very closely together throughout the training phase, and in the test phase.

Figure 6: Percentage of correct responses (with 1 standard error within the respective block) over phases and blocks

To check whether the conditions differed systematically, we conducted a two-way mixed-design ANOVA with Group as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test), followed by planned comparisons for between-group differences, with Bonferroni correction for multiple comparisons providing a corrected α -level of 0.0083 (adjusted for 6 comparisons). We observed significant main effects of Phase and Group (Phase: $F(1,74) = 46.921$, $p < .001$, $\eta^2 = .388$; Group: $F(3,74) = 5.595$, $p = .005$, $\eta^2 = .157$), with no significant interaction ($F(3,74) = 1.697$, $p = .175$, $\eta^2 = .064$). This indicates that people

learned in the task, and that task performance (overall) differed between groups. The planned comparisons revealed there was a significant difference between Minimal Difference condition and all other conditions (Maximum difference with congruent sound symbolism: mean-difference = -8.059, $p = .003$; Maximal difference with incongruent sound symbolism: mean-difference = -8.464, $p = .002$; Maximum Difference without sound symbolism: mean-difference = -7.431, $p = .006$), but no significant differences between the three Maximum Difference Conditions.

Regarding the reaction times, data were transformed (inversed transformation) and trimmed for two standard deviations. A two-way mixed-design ANOVA was conducted with Group as a between-subjects factor and Phase as a within-subjects factor with two levels (training and test). As in the analysis of the previous two experiments, no significant main effect of Group was observed ($F(3,74) = 1.302$, $p = .280$, $\eta^2 = .050$), suggesting that participants did not differ between groups in the selection speed. However, there was a significant main effect of Phase ($F(1,37) = 6.841$, $p = .013$, $\eta^2 = .156$). Additionally, there was no significant Phase x Group interaction ($F(1,37) = 1.349$, $p = .253$, $\eta^2 = .035$). As in previous experiments, participants responded faster in the test phase, since they already knew most of the stimuli in the test condition and took them less time to make a selection.

From these results, we can conclude that there is a unique effect of phonological difference on category learning which is independent from the internal coherence of a label based on the sound symbolic associations of its segments (e.g., all 'round sounding' versus all 'spiky sounding'), and independent from whether the sound symbolic associations of a label are aligned with the visual characteristics of the items in a to-be-learned category. This finding

differs from the results obtained in Lupyan & Casasanto (2015). The most likely reason for the difference between our finding and the previously reported Sound Symbolic effect is a ceiling effect: participants' performance was around 90% on average in all maximally different conditions. It is therefore possible that sound symbolic congruence between labels and items may emerge for pairs of labels that have less phonetic difference, which may benefit more from the bootstrapping sound symbolism to the learning process (Imai, Kita, Nagumo & Okada, 2008). The fact that we had nine training plus four testing blocks (thirteen in total) in comparison to Lupyan's experiment, where they had sixteen training blocks (the significance level was $p = .04$) is one of the possible explanations why we did not reach statistical significance of sound symbolic congruency effect.

GENERAL DISCUSSION

Results obtained in *experiment 1* show that participants *learned* categories that were labelled with phonologically maximally different labels significantly *better* compared to categories labelled with minimally different labels and without labels (silent condition). Between these extremes, the phonologically moderately different condition shows that phonological differences fall on a graded spectrum, and the degree of phonological difference has a systematic effect on the learnability of label-category pairings.

As far as *generalization* is concerned (generalization in Lupyan's terms from Lupyan et al., 2007, phase II), there is a similar pattern to the learning results, except that level of generalization in the silent condition was different compared to the pattern in the learning condition (interaction).

In *experiment 2*, we observed that an effect of maximal phonological difference on category learning which is independent from sound symbolism. Although this result differs from previous reports of sound symbolism enhancing learning (Lupyan & Casasanto, 2014; Nygaard, Cook & Namy, 2009; Kantartzis, Imai & Kita, 2011; Lockwood, Dingemanse & Hagoort, 2016, Kovic, Plunkett & Westermann, 2010), the current paradigm may lack the sensitivity to detect subtle sound symbolic differences. Firstly, the Maximally Different word pairs turned out to be highly learnable, regardless of the congruence of their pairings with visual categories. Individual performance was around 90% on average in all of the maximally different conditions, resulting in a ceiling effect, where a sound symbolic boost was not detectable. Secondly, although Lupyan et al.'s the rating study (Lupyan et al., 2007) shows that people do classify the items in the different categories as more or less spiky, the differences are rather subtle, and a sound symbolic boost may be more evident in paradigms where the sensory congruence (or incongruence) is easier to detect.

Taken together, these results reveal that when categories are labelled with phonologically maximally different labels, they are learned better compared to items labelled with minimally different labels, or no labels at all. Furthermore, the recall of labelled categories is better compared to the non-labelled condition, which goes in line with the hypothesis that labelled concepts are generalized better (Lupyan et al., 2007, Lupyan, 2012). In our study this effect is attributable solely to the degree of phonological difference between the word pairs, rather than to sound symbolism, which may have been masked by ceiling effects.

Interpretation of these results could be taken from two different points: why categories labelled with phonologically more different labels are *learned* better compared to the ones

labelled with phonologically more similar labels? Furthermore, why categories labelled with phonologically more different labels are *recalled* better than those labelled with minimally different labels? And finally, as a part of the previous question, why generalization of labelled conditions was better than non-labelled condition?

The first question is related to learning, which could be interpreted through external properties of the categories (but could also include some internal elements). The second question is related to generalization, which could be interpreted through internal conceptual representation.

Learning results could be interpreted with James' hypothesis: effect of labels on category learning is obtained since labels are more different than categories. Maximally different names, adhered to two categories compose entities which are more easily discriminated than the categories solely. Once minimally different labels are adhered to the categories, those entities will not be easily discriminated as those with maximally different labels. Likewise, the former will be learned faster compared to the latter (which was obtained in the experiment), since more different objects are easier discriminated than more similar ones (James, 1890).

Further explanation of results could be obtained from Lupyan's language augmented thought hypothesis. Lupyan claims that linguistic labels are strongly connected with typical features of the concepts. Once the exemplar of the category is encountered, it activates the label, which in return activates these typical features on-line. In the process of learning categories and labels, this effect becomes more and more evident in the learning process. This feedback loop may explain why labelled categories are learned faster, but also generalized better than non-labelled ones. However, Lupyan's theory does not explain how the degree of phonological

difference between label pairs makes a difference to the general learning effect of simply having labels versus none.

Related to the *generalization* problem and phonological difference of labels, we could again interpret results based on James' hypothesis: once concepts are created and labels learned, they are stored in the long term memory, but somehow interconnected (via association between the representation of the concept and the representation of the label). Activation of one leads to the activation of the other and vice versa. This activation increases discriminability between concepts, because they do not consist solely on visual representation, but also on the name as an additional feature.

This means that label differences are also mapped on representational level. These representations are associated with concept visual features at the conceptual level. Activation of the visual concept activates label representation as well. If these labels are more phonologically different, they will lead to the higher difference of associated concept-label composite entity. Hence, phonologically more different labels would lead to better generalization on representational level.

In order to quantify previous interpretations, we can use logic from Sloutsky's model of Similarity Induction Naming Categorisation in young children – SINC (Sloutsky & Fisher, 2004; Sloutsky & Fisher, 2012). According to this model, when learning about what features differ between objects belonging to different categories, visual features of physical objects and acoustic features of auditory cues/labels can be combined into a representation of the category structure. Importantly, this model includes quantification of label phonological differences. Although the

model was originally developed to describe the categorization behaviour of infants, it can be used here since it uses multiplicative rule for exemplar differences with which object differences can be quantified (Medin, 1975; Medin & Schaffer, 1978). And finally, even if adults in Sloutsky's experiments do rely almost solely on labels in category classification task (for example Sloutsky, Lo & Fisher, 2001), in our experiments this strategy is not possible since labels are presented after the participant's response. In a strict empirical sense, this label can be considered as another feature (available for learning) which adheres to the conceptual representation and which does not help in solving individual experimental trials.

Another framework that could be used in the description of differences between category exemplars is the Context Model (Medin, 1975), and its more recent incarnations, the Generalized Context Model, proposed by Nosofski (Nosofsky 1992; Nosofsky & Palmeri 1997) and amended by Ashby and Maddox (Ashby & Maddox, 1993). Both Sloutsky's SINC Model and the Generalized Context Model - GCM are designed to illustrate a comparison of exemplar to either another exemplar (Sloutsky) or group of exemplars (GCM). Based on the logic of these previous models, we propose a new model *Category learning based on the degree of difference*. Each category consists of several dimensions – D^7 . Let us assume that these dimensions are values from 0 (no difference) to 1 (maximum difference). In that case, the difference between two categories in one dimension we can express with the following equation:

$$diff(I, J)_i = S_i \times D_i$$

⁷ Detailed description of between categories difference for each dimension D_i will be presented in a different paper specifically related to this problem.

where I and J are two categories, i is a dimension, S is the attentional weight of the dimension i (0 – no attention, 1 – maximum attention) and D_i is the difference between categories on the dimension i .

We can further specify overall difference of the categories, using multiplicative rule

$$diff(I, J) = \prod_{i=1}^m S_i \times D_i$$

where $\prod$ represents product from $i=1$ to m (number of relevant dimensions). This value will be between 0 (no difference) to 1 (maximum difference).

If we assume that the difference between two categories will be learned easier once the overall difference is higher (Nosofsky 1992), once this difference level is calculated, the probability (meaning ease) that these two categories will be differentiated (learned) in a given time can be expressed with the following equation

$$P(I, J) = diff(I, J) = \prod_{i=1}^m S_i \times D_i$$

where $P(I, J)$ represents probability that categories I and J will be discriminated (learned).

Since all previous discussions were related to visual features. We can conduct a similar calculation for the label difference ($diff_L$):

$$diff_L(I_L, J_L) = \prod_{i=1}^3 S_i \times D_i$$

where I_L and J_L are labels of the categories I and J , S_i and D_i are attentional weights and level of differences on dimension i .

Likewise, the total difference of labelled categories can be specified as follows.

$$diff(I, J)_r = diff(I, J) \times diff(I_L, J_L)$$

Hence, taking together the differences in the visual characteristics of the exemplars making up a category, and the phonological differences between the labels applied to the categories, the probability of learning a labelled category is as follows.

$$P(I, J) = diff(I, J)_r = diff(I, J) \times diff(I_L, J_L)$$

At this point, we still cannot claim whether the space of verbal label difference is only tridimensional and/or is it orthogonal or not. Further, this model does not specify whether the influence of labels on concept similarity is different than the influence of visual attributes, meaning whether words have special status compared to visual features.

This quantification model was designed for the learning process. As far as generalization is concerned, we can assume that a similar representative process is involved: mental representations of individual category exemplars and names are stored and more easily discriminated if they are more different. This would explain why recall was better for a maximal

different condition compared to a minimal different condition: the representations of the former were more different than the representations of the latter.

This model of category learning we can name as *category learning based on the degree of difference (CLODD)*. Finally, it is necessary to note that this is a kind of speculative quantifying (how things could work). For further confirmation, additional empirical testing with a different research objective would be necessary.

As a final constraint, we can specify that these results are predicated on the assumption that participants do not have any previous knowledge about the categories and labels to be learned. In the current study, we can be certain of this due to our use of novel stimuli and labels. In other real life learning scenarios, there are many situations in which prior knowledge can be brought to bear on interferes about novel categories and their labels (Murphy & Medin, 1985). It remains to be seen how the phonological sensitivity of the CLODD model interacts with prior knowledge in more ecologically valid learning scenarios.

CONTEXT PARAGRAPH

Our research shows that category learning is influenced by not just labelling, but phonology. In a study that varied the degree of difference between labels (presented incidentally during visual category learning), we found that more phonologically different labels lead to faster category learning. We further showed that effect can be assigned to phonological difference solely and is independent from sound symbolism.

Finally, we present a mathematical model of Category Learning based On the Degree of Difference (CLODD), which proposes that the probability of category learning in a given time

depends on the level of difference between categories, but also on level of label phonological difference.

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Author Contributions

B. Lalic developed the study concept and design, under the supervision of V. Kovic. Verbal stimuli were designed by SJ Styles. B. Lalic developed experiments and conducted data collection by assistance of A. Savic. B. Lalic conducted data analysis and interpretation under the supervision of V.Kovic and SJ Styles. B. Lalic drafted the manuscript, and SJ Styles, A. Savic and V. Kovic provided critical revisions. All authors approved the final version of the manuscript for submission.