General mechanisms of color lexicon acquisition: Insights from comparison of German and Japanese speaking children

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Abstract

This research investigated how German-speaking children learn color words, both in terms of centroid mappings and boundary delineation, and how they construct the color lexicon as a connected system. The results were compared to those of Japanese children to draw insights on general mechanisms that underlie the acquisition of words in the color lexicon. For both languages, *input frequency* and *category size* contributed to the ease of learning. In contrast, in both language groups, *naming (in)consistency* in adults predicted the adult-like boundary delineation.

Keywords: color word acquisition; lexical development; word learning; language-general mechanisms; role of input

Introduction

To use a word appropriately in diverse contexts, a speaker needs to understand its meaning in relation to other similar-meaning words (Saji et al., 2011). In other words, learning the adult-like meaning of a word must involve the understanding of which other words exist in the same lexical domain in the ambient language, and how this word is differentiated from the other words that surround it. The view that understanding of word meanings evolves developmentally as a connected system has been proposed in the literature (e.g., Saji et al., 2011; 2020; see also Ameel et al., 2008; Bowerman, 2005; Clark, 2006). Researchers of lexical development have described the process of semantic reorganization in some semantic domains, including spatial terms (e.g., Clark, 1972), container labels (Ameel et al., 2008), verbs for carrying actions (e.g., Saji et al., 2011) but the detailed developmental course and the underlying mechanism has not been sufficiently investigated.

The color lexicon is interesting as well as useful for understanding how children construct a lexical domain as a connected system. On one hand, we know that children perceive the color spectrum categorically, well before they start to show signs of understanding color words (Bornstein, 1985; Skelton et al, 2017), suggesting that infants have pre-segmented categories of colors. On the other hand, because languages differ widely in the way they divide the continuous visible spectrum of color by names (e.g., Berlin & Kay, 1969; Cook, Kay, & Regier, 2005; Roberson, Davies, & Davidoff, 2000), children have to discover how the continuous color spectrum is divided by a set of words by their language and where on the space different words should be mapped. For a full theory of color word acquisition, researchers have to offer an account not only for how children map words to the corresponding concepts but also for how children modify the initial universal perceptual categories to gain language-specific lexical categories (Saji et al., 2020).

Recent work by Forbes and Plunkett (2020) examined data from 11 languages from the Oxford Communicative Development Inventory and found that the order of color word acquisition is not uniform across these languages; they therefore concluded that culture plays an important role even at the beginning of the acquisition process. These authors further reported that, among age, gender, input frequency and phonological complexity, only the last two factors significantly contribute to the rate with which a given word is included in the early color vocabulary. Importantly, however, the authors also noted a general trend in acquisition order such that achromatic words are produced later than chromatic words and that *red* and *blue* are produced earlier than *yellow* and *green*. Yurovsky et al. (2015) also investigated the factors affecting the mapping of color words with English-learning children. They reported that perceptual saliency and category size contributes to the ease of word acquisition, and argue that general principles of category learning also apply to the mechanism of color word acquisition.

However, these works dealt only with the mapping of the category centroids, and did not consider how children acquire adult-like knowledge of boundaries. Saji et al. (2020) had Japanese-speaking children from 3- to 5-year-olds name 93 color swatches that systematically sampled a full range of colors to uncover children's knowledge of the meaning of basic color words, not only investigating how each word is mapped to category centroids but also how the boundary of each word is delineated. They found that different factors contribute the acquisition of the category centroid mapping and that of the boundary delineation: difficulty with category centroid mapping was explained by *input frequency* and *category size*, consistent with Yurofsky's results from English-speaking children; however, difficulty with boundary delineation was best explained by input (in)consistency, i.e., the degree of how consistently adults apply the given word to colors around the category boundary.

To fully understand the mechanism of color lexicon acquisition, it is important to know whether the factors affecting the centroid mapping and boundary delineation in Japanese children are shared with other languages. In the current research, we examined German speaking 3- and 5-year-olds, using the same set of stimuli and method as Saji et al. In Experiment 1, we first examined the structure of the color lexicon of adult German speakers, and compared it to the properties found for adult Japanese speakers. In Experiment 2, we tested German-speaking 3- and 5-year-olds to trace the developmental trajectory towards the adult-like representation of the color lexicon. We compare the German results to the Japanese ones to draw insights onto the mechanisms for color word acquisition shared across languages, as well as to specify how cross-linguistic differences in the structure of the color lexicon affects the speed of learning the color lexical system as a whole and for individual color words.

We hypothesize that the mechanism underlying the acquisition of the color lexical system is shared across language, with a common set of factors affecting the acquisition both in light of centroid mapping and boundary delineation. Specifically, we expect that input frequency matters most for the centroid mapping, but input consistency on the category boundaries plays an important role for acquisition of adult-like boundaries. We also hypothesize, however, that the order of individual color words per se may be different across languages, as the way each language divides the color concepts is different. It is also possible that culture-specific conventional word usage (e.g., metaphorical use of a particular color word) may make learning of particular words difficult. In this light, it is interesting to see whether the early and later learned words for German children are different from those for Japanese children. Comparing the ease/difficulty of acquisition across German and Japanese children as well as extracting the common factors affecting the acquisition should give us important insights onto the process and mechanism of the acquisition of the color lexicon.

Experiment 1

In Experiment 1, Adult German speakers were tested on their naming of each of the 93 swatches used for Japanese adults in Saji et al. (2020) to obtain the basic characteristics of the color lexicon in German-speaking adults. The adult color lexicon was assessed in four respects: *identification of basic color words in German*, *category size*, *similarity structure of the color names* and *cross-individual naming (in)consistency*. These characteristics are compared to those for Japanese to examine how the structure of the color lexicon might interact with the acquisition of color words.

Method

Participants.

A total of 26 native German speaking adults, who were undergraduate and graduate students of a University in Germany, participated in the experiment.

Stimuli.

Stimuli were the same as those used by Saji et al. (2020), which were ninety-three color swatches selected from Practical Color Co-ordinate System (PCCS) developed by Japan Color Research Institute. PCCS consisted of 14 "tone" categories, each of which has 24 hues. Tone is a compound concept of lightness and metric chroma (Nayatani, 2003; see also Saji et al., 2020). We used colors from seven tones ("light", "bright", "soft", "vivid", "dull", "deep", and "dark") out of the 14 tones, which varied in lightness and chroma, so that the stimulus colors covered the entire color spectrum. Only half of the 24 hues (with every other even number) of each tone were used to reduce the number of stimuli. In addition to these 84 chromatic colors (7 tones x 12 hues) we included nine achromatic colors (black, white, and five different grays.

Procedure.

Participants were presented with the 93 color swatches one by one on a gray background in a random order, and were asked "*Welche* (what) *Farbe* (color) *hat* (has) *die* (the) *Karte* (patch)"? ("What color does the patch have?") by the experimenter under a standardized lighting condition that simulated natural daylight (D55) by using Solax XC-100AF (Seric Ltd.) on a gray background.

Results.

Basic color words and the category centroid in German.

We considered a word form to be a basic word if the word is applied most dominantly (i.e., most frequently) for at least one color swatch in our stimuli, following the criterion used in Saji et al. (2020). Compound color names such as *dunkelgrün* ('dark green') and *hautfarbe* (‘light orange') were considered as different word types from the basic color words such as *grün* and *orange*. Sixteen word types were identified in our list of “basic” words (see Table 1a). Interestingly, the number of basic words in German was the same as in Japanese (Table 1b). The swatch that received the highest agreement for each word was considered as the centroid of the word category.

German speakers’ representation of the color lexicon as compared to that of Japanese speakers

Figure 1A shows German speakers’ pattern of color naming on the Multi-Dimensional Scaling (MDS) solutions, following the algorithm proposed by Saji et al. (2020; see also Majid et al., 2008). In each matrix, there were 93 rows and 93 columns, each representing a swatch from the 93 stimulus colors. Each cell contained the number of times the given two color patches were named with the same word. The Japanese speakers’ MDS solutions in Saji et al. (2020) are shown in Figure 1B for comparison.

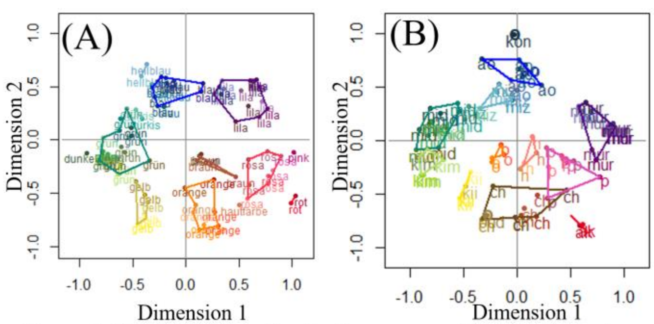

Figure 1: MDS solutions for A: German-speaking adults and B: Japanese-speaking adults

In both language groups, the identified basic words were used contrastively with little overlapping along the boundaries. At a glance, relative topological relations between words seem to be comparable across the two languages with some local differences. For example, both German and Japanese have terms that correspond to English *orange* and *brown*, but the ranges the two terms cover are different: while *orange* is applied more broadly than *braun* in German, in Japanese, *cha* (brown) is applied much more widely than *orenji* (orange). Also, both German and Japanese adult speakers used two terms to name the range of colors to which English speakers would apply the word *pink*; namely *rosa* and *pink* in German and *pinku* and *hada-iro* in Japanese. However, the category centroids and the range covered by the two terms are substantially different across the two languages.

Category size. We quantified the *category size* of a given word by counting the number of swatches which were labeled by that word most dominantly (i.e., by the largest number of participants), following the method used by Yurovsky et al. (2015). For example, since two swatches (out of 93) were dominantly labeled as *rot* (‘red’), the value for *category size* was 2. Figures 2AB show the c

ategory size value for each basic word in German and Japanese, respectively. There were similarities between the two languages. For example, *rot* and *aka* and *gelb* and *ki* cover narrow ranges, while the sizes of *blau* and *grün* and *ao* and *midori* are fairly broad. As noted earlier, the size of *orange* is much larger than *braun* in German, but in Japanese, *cha* is much broader than *orenji-iro.*

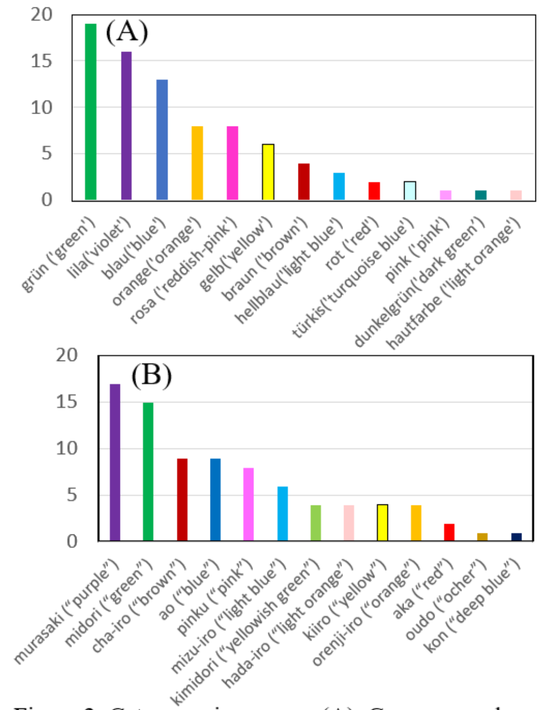

Figure 2: Category size scores. (A) German speakers; (B) Japanese speakers

***Cross-individual naming inconsistency*.** The size of the clusters on the MDS plane reflects the degree of individual inconsistencies in color word naming, in that the distance between two points on the MDS plane indicates the degree of disagreement in naming. For each word cluster, we averaged the Euclidian distance between the centroid and each swatch in the cluster. This score was used as the index of *naming inconsistency* (see Saji et al. 2020 for detailed information about the algorithm). A higher *naming inconsistency* score indicates that the swatches around the category boundary tend to receive multiple names.

We were unable to calculate *naming inconsistency* for *dunkelgrau*(‘dark gray’), *dunkelgrun* (‘dark green’), *hautfarbe* (‘light orange’), and *pink*, because only one swatch was dominantly named by each of these words. Thus, these words were excluded from further analyses, but this did not affect the analysis of Experiment 2, as these color words were rarely produced by children. The distribution of the *naming inconsistency* scores for the German group was shown in Fig. 3A, with those for the Japanese group shown in Figure 3B for comparison.

Experiment 2

Experiment 2 examined 3- and 5-year-old German-speaking children to see how their pattern of color word acquisition compares to that of the Japanese-speaking children reported by Saji et al. (2020), and to see (1) how properties of the adult lexicon affect it and (2) whether general mechanism underlying acquisition of the color lexicon shared across languages can be identified.

Method

Participants.

A total of 52 German speaking children (26 3-year-olds and 26 5-year-olds) participated, with parental consent.

Stimuli and procedure.

The stimuli and the procedure were the same as those in Experiment 1 with one exception: children received warm-up trials before the main test. Children were presented with six pictures of three different cats, two different dogs and one rabbit, and were asked to name each picture to make sure that they understood that they could say the same name more than once across different trials.

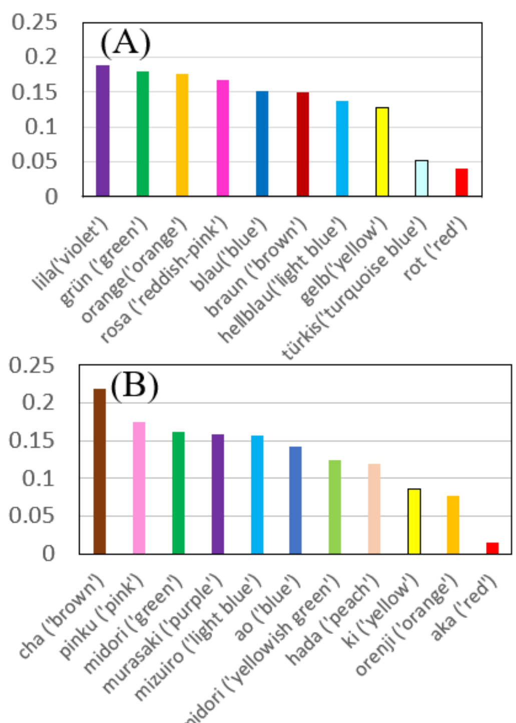

Figure 3: Naming inconsistency scores: (A) German speakers: B) Japanese speakers.

Results

Naming accuracy for the category centroids

We examined in what degree children could apply the basic color words for the category centroids identified in Experiment 1. Table 1A shows the proportion of German 3-year-olds who produced the appropriate basic color words to the correct referents. For comparison, the results from the Japanese 3-year-olds are presented in Table 1B.

Tables 1AB show clear commonality between German and Japanese children in the pattern of successfully and poorly labeled words. In both languages, among the 16 "basic" words the adults dominantly produced, those that were successfully mapped to the centroids by 3 are the equivalents of the basic words Berlin and Kay (1969) identified for English; the words German and Japanese 3-year-olds failed to name were those that are specific to German or Japanese. Among the early-learned words, those corresponding to the English words *white*, *black*, *red*, *yellow*, *blue* and *green* were named better than those corresponding to *orange*, *pink*, *brown* and *purple* in both languages. *Grau* and *hai-iro*, which correspond to English word *gray*, were not successfully labeled in both languages.

Overall, German-speaking 3-year-olds labeled the centroids more accurately (Mean=72.6%) than Japanese age-peers (Mean=62.0%) on the words shared by the two languages.

Table 1: Proportion of correct naming for the centroid color for each basic color in German 3-yr-olds and Japanese 3-yr-olds.

A: German 3-year-old		B: Japanese 3-year-old	
color name	ratio	color name	ratio
weiß('white')	0.94	aka ('red')	0.85
gelb('yellow')	0.94	kuro ('black')	0.8
blau('blue')	0.92	shiro ("white")	0.8
grün ('green')	0.91	kiiro ("yellow")	0.75
rot ('red')	0.85	ao ("blue")	0.7
schwarz ('black')	0.8	midori ("green")	0.68
orange('orange')	0.72	pinku ("pink")	0.65
braun ('brown')	0.7	orenji-iro("orange")	0.58
lila('violet')	0.68	murasaki ("purple")	0.52
rosa ('reddish-pink')	0.35	cha-iro ("brown")	0.5
pink ('pink')	0.28	mizu-iro ("light blue")	0.25
grau ('gray')	0.18	kimidori ("yellowish green")	0.05
hautfarbe ('light orange')	0.09	hada-iro ("light orange")	0.05
dunkelgrün ('dark green')	0.08	hai-iro ("gray")	0
hellblau ('light blue')	0.08	oudo ("ocher")	0
türkis ('turquoise blue')	0.08	kon ("deep blue")	0

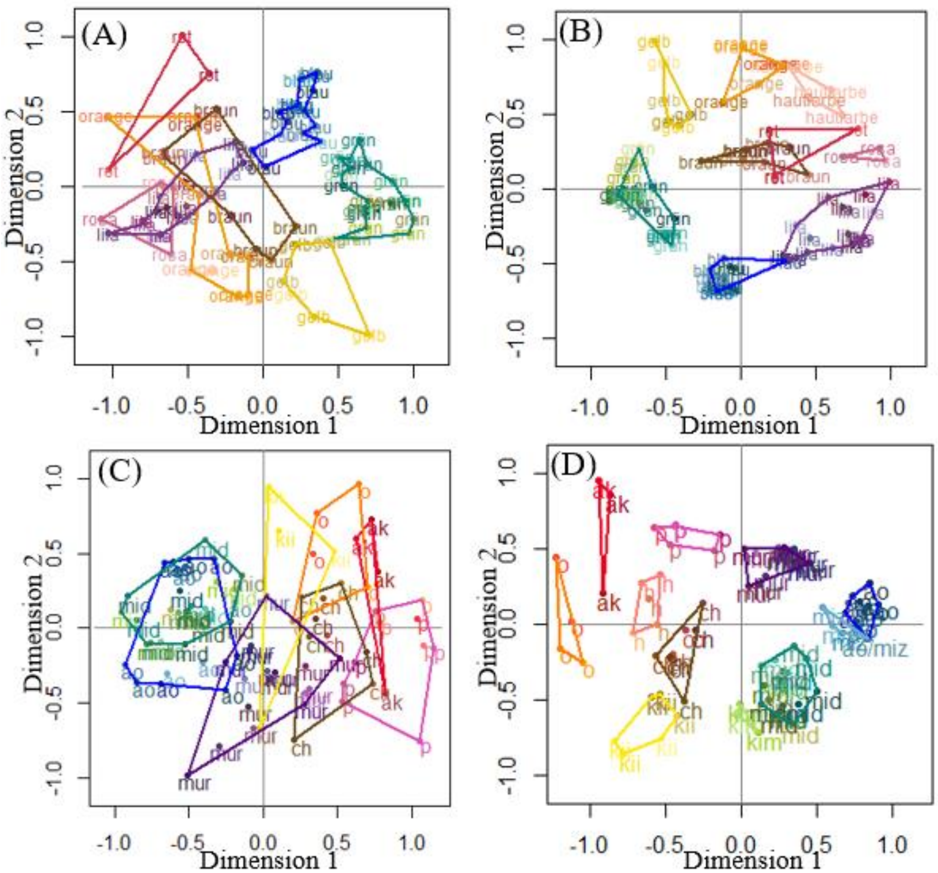

Figure 4. Multi-Dimensional Scaling solutions for German and Japanese children.
A) German 3-year-olds; B) German 5-year-olds; C) Japanese 3-year-olds;
D) Japanese 5-year-olds. The Japanese results were borrowed from Saji et al. (2020).

The structure of the color lexicon on the MDS analyses. German children's patterns of naming for the 93 swatches were submitted to the MDS analyses, separately for 3-year-olds and 5-year-olds (see Figures 4AB, respectively). The MDS by Japanese 3- and 5-year-olds reported by Saji et al. (2020) were shown in Figures 4CD for comparison.) In both cases, two dimensional solutions were employed because the stress values were sufficiently low (s<0.2). In both language groups, clear developmental changes towards adult-like representation were observed: word boundaries were more overlapping in 3-year-olds than 5-year-olds, and for 5-year-olds, the boundaries were mostly separated from one another. Visual inspection indicates that the degree of overlapping was greater in Japanese 3-year-olds than German 3-year-olds, suggesting that boundary delineation is slower in Japanese than in German children. The most striking difference between German and Japanese 3-year-olds was observed in the differentiation of *blue* and *green.* While Japanese 3-year-olds greatly confused *ao* and *midori*, German children already showed a clear differentiation in their use of *blau* and *grün* at the age of 3.

Correlation between the child groups and the adult groups.
To examine how German children's pattern of color term naming matches that of German adults, the correlation between the adult group and each of the two child groups were calculated, following the algorithms proposed by Saji et. al. (2020). The correlation values were .71 and .81 for 3- and 5-year-olds, respectively, which are much higher than the corresponding correlation values of .32 and .57 in Japanese age peers.

Degree of the appropriate extension for each word.
To quantify the degree to which children had achieved an adult-like boundary delineation for each color word, the *f-measure* was calculated for each word. The F-measure index represents the degree to which each child correctly assigned a given color term to the swatches, without over- or under-extending the word meaning. The *f-measure* value is represented as the harmonic mean of the *precision* and *recall* scores. The *precision* score is obtained as the fraction of the retrieved instances that are relevant, while the *recall* score is obtained as the fraction of the relevant instances that are retrieved. Since there is an inverse relationship between *precision* and *recall*, the *f-measure* score is

commonly used to evaluate the measure of proper retrieval considering both over- and under-extension (Powers, 2011).

For example, suppose that 8 swatches from the 93 swatches were dominantly named bl*au* ("blue") by adults, and that a child labeled 5 swatches with this name. Suppose further that, of the 5 swatches named *blau* ("blue") by the child, only 3 matched the swatches so named by adults (true positives), while adults did not use the word for the remaining two (false positives). In this case, the *precision* score is 3/5 while *recall* is 3/8, which yields the *f-measure* value of .46, taking the harmonic mean of the two scores. The f-measure scores for each word was used as indexes for the degree of boundary delineation.

Factors which best explain the ease of learning color words (Models).

The MDS and f-measure analyses reported so far indicate that some color names are learned more readily than others, in terms of both centroid mapping and boundary delineation. To identify factors affecting color word acquisition in the two respects, we examined the role of the following six factors: (a) *hue uniqueness*, (b) *input frequency*, (c) *category size*, (d) *naming inconsistency*, (e) *age*, and (f) *interactions between age and other factors*, following Saji et al.'s model analyses (Saji et al., 2020). Input frequency values for each word were obtained from the Sketch Engine German corpus.

Of particular interest was whether the ease and order of color word learning is explained by different sets of factors, depending on the indexes of word acquisition, i.e., the centroid mapping and boundary delineation, as was the case with Japanese children. Saji et al. reported that *input frequency* and *category size*, but not *naming inconsistency*, contributed to the centroid mapping, while only *naming inconsistency* was included in the final model for predicting the difficulty of boundary delineation in Japanese children. If the same set of factors are found for each of the two indexes of acquisition in German children, despite differences in the order of acquisition of individual colors terms between German and Japanese, those factors would likely underlie acquisition of the color lexicon across different languages of the world.

Factors affecting naming accuracy for the category centroids. We employed a logistic mixed-effects model. A series of models were conducted with all possible pairs of the aforementioned six fixed effects. The best model (i.e., the best combination of the fixed and random effects) was determined by the BIC (Bayesian information criterion; Bhat & Kumar, 2010). The best model (see Table 2) included *Input frequency, category size* and *age* as fixed effects, suggesting that the words children hear frequently and which cover a relatively broad range of the color space were mapped to their typical referents more readily than others.

Factors affecting the degree of appropriate boundaries (F-measure). Table 3 presents the best model according to the BIC criterion for the German children. The best model for the German children included *naming inconsistency* as in the case with Japanese children. In addition, *category size* was included, suggesting that the boundaries of words that have broader coverage and higher inconsistency in adults' naming were poorly delineated. Importantly, on this measure, as was the case with the Japanese children, *input frequency* was not included in the final model.

Table 2 The best model for predicting naming accuracy for the category centroids in German children.

Fixed effects	Estimate	Standard error	*z* value
Intercept	-15.6	1.63	-9.6
Age	.92	.31	3.0
Input frequency	.25	.04	7.0
Category size	2.74	.29	9.4

Table 3 The final (best) model predicting the proper boundary delineation for German children.

Fixed effects	Estimate	Standard error	*t* value
Intercept	.74	.03	25.23
Category size	.02	.00	7.9
Naming inconsistency	-1.70	.27	-6.4

General Discussion

As expected, German children's pattern of color word acquisition was similar to that found for Japanese children with common factors affecting the order of acquisition. In both language groups, input frequency influences the centroid mapping most strongly, while naming (in)consistency played a prominent role in the acquisition of adult-like category boundaries. Despite this similarity, there were interesting cross-cultural differences in the order of individual word acquisition. For example, while *pinku* ('pink') was learned easily by Japanese children, German children showed much lower accuracy for the corresponding word *pink*. This was probably due to a presence of the word *rosa*. *Rosa* is used to refer to orangish pink, while *pink*, loaned from English, is used to refer to pale pink. The language-specific *rosa*-*pink* distinction is likely difficult to find.

Also of interest was the difference between *midori* and *grün*, both roughly refer to colors what English speakers would name *green*. Berlin and Kay's universal color word hierarchy theory would predict that *green* should be one of the earliest learned word. German children indeed showed high accuracy (over 90%) at 3, but Japanese children showed substantially lower accuracy for *midori*. This could be due to the conventional word use for *ao* ('blue') in

Japanese. Due to historical reasons, the word *ao* is used for typical green color, such as the color of traffic light and green vegetables. This could be confusing because Japanese children consistently hear *ao* and *midori* for centroid green colors in different contexts. These observations suggest that language-specific convention of word use might affect the ease of learning.

Despite such local differences, however, it is striking that a common set of factors differentially predict the rate of learning in both languages, i.e., *input frequency* and *category size* for the centroid mapping, and consistent application of names by adults for boundary delineation.

Also noted was that, in general, the acquisition of color lexicon terms seems to be faster for German- than for Japanese-speaking children. This could be due to the heavy use of loan words in Japanese, which means that that children hear both Japanese native words (*ao*, *hai-iro*, *midori*) and loan words *buru* ('blue'), *gurei* ('gray'), *guriin* ('green') simultaneously for the same color. In other words, Japanese children may be exposed to more inconsistent word use beyond basic color words. Further research is necessary to investigate this possibility.

Lastly, we should note that the input frequency of color words in this paper was calculated using an internet corpus on Sketch Engine. However, care takers may use color words differently when talking to young children than to adults. Future research should investigate color word use to young children using CHILDES corpus to conduct model analyses to examine whether the same results as the results in this paper are obtained.

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