Unique hue judgment in different languages: a comparison of Korean and English

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Abstract

Three experiments investigated unique hues (Hering, 1878) in native Korean and English speakers. Many recent studies have shown that color categories differ across languages and cultures, challenging the proposal that a particular set of color categories is universal and potentially innate. Unique hue judgments, and selection of the best examples of those categories have also been found to vary within an English-speaking population. Here we investigated unique hue judgments and possible discrepancies between unique hue and best example judgments in two languages. Experiment 1 found that the loci of unique hues were similar for English and Korean speakers. Experiment 2 replicated and extended this result, using both single and double hue scaling. Experiment 3 showed that, in both cultures, unique hue choices depended on the range, and organization of the array from which participants chose. The results of this study suggest that unique hue judgments vary according to the experimental task, in both languages.

Key words: UNIQUE HUES, COLOR CATEGORIES, RELATIVITY, CROSS-CULTURAL, FOCAL COLORS.

1. INTRODUCTION

According to Hering's (1878) opponent process theory of color perception, we cannot experience two components of opponent pairs of colors simultaneously under normal observation conditions. It is impossible to perceive a reddish green or a yellowish blue, because the opponent colors pairs red / green, and yellow/ blue are mutually exclusive. Since these opponent colors are pure hues that contain no tint of any other hue and cannot be further described by the use of the hue names other than their own (Wyszecki & Stiles, 1982), they are referred to as unique hues.

Neurophysiological evidence supports opponent processes (Svaetichin, 1956; De Valois, Smith, Karoly, & Kitai, 1958) and psychophysical studies have tried to establish the location of unique hues with monochromatic spectral lights. Sternheim and Boynton (1966) obtained hue scaling functions for all ranges of wavelength by multi-hue scaling, in which participants were required to scale the percentage of unique hues included in each stimulus using their names, i.e., red, yellow, green, and blue.

Given the recent evidence that color categories differ across languages and cultures both in the number of linguistic categories marked and in the placement of their boundaries (Berlin & Kay, 1969; Kay, Berlin, Maffi, & Merrifield, 1997), the present studies sought to compare unique hue judgments across languages. Malkoc, Kay, and Webster (2002) reported differences between unique hue judgments by English speakers as well as considerable individual variation in both unique hue judgments and the selection of the best examples of those categories, the so-called 'focal' colors in a hue-scaling task. A cross-cultural study by Webster et al. (2002) reported similar variations in both types of judgments in populations in the USA and India.

Kuehni (2001a, 2001b) reported divergence between judgments of some unique hues, such as red and green and focal color judgments among native English speakers. In a simultaneous comparison task using a set of paper Munsell color-chips (rather than monochromatic spectral lights), the most frequent choices of unique hues by native English speakers were Munsell hues 3.0R for red, 3.5Y for yellow, 2.5BG for green, and 2.75B for blue. Most frequently reported values for the foci of these categories are 5R for red, 2.5YR for yellow, 5G for green and 2.5PB for blue. A study by Oh, Kwon, Kim, Kim, and Lee (2003), found that native Korean speakers most frequently chose as unique hues Munsell hues 7.5R for red, 5Y for yellow, 2.5G for green, and 2.5PB for blue. It thus appears that the most frequent choices of unique hue for yellow and blue are similar across the two language groups, but those of red and green are quite different.

To examine the relationship between unique hues and focal colors in Korean, Pak and Lee (2005) assigned Korean participants to two experimental groups, and asked them to choose the most suitable color-chips to the definitions of either unique hue or focal color. A selection of Munsell color-chips was used, covering wide hue ranges for each color that included both potential candidates (English and Korean). Participants also identified unique hues using a multi-hue scaling method, with ranges that spanned more than one category. The change in methodology did not alter the unique hue judgments of Korean speakers for red and yellow, but resulted in a slight shift in judgments for green and blue to 5G and 5PB respectively. There was almost perfect coincidence between the color-chips chosen as unique hues and focal colors. Thus, native Korean speakers appeared to perceive some unique hues quite differently from native English speakers, and the difference between unique hues and focal colors reported for English speakers by Kuehni (2001a, 2001b) was not apparent in native Korean speakers.

The present study examined the discrepancy observed in previous research by collecting additional experimental data with similar tasks and using two comparative language groups. By comparing the results with previous findings, we hoped to establish whether there is a substantial difference between the unique hue perceptions of two language groups or whether differences between previous findings resulted from the use of different experimental tasks.

Experiment 1 set out to confirm the loci of unique hues in Munsell color space for Korean speakers and to compare them with those of focal colors in native English speakers. Experiment 2 used a familiar hue-scaling method to establish unique hues. A single-hue scaling is free from paint-bias and is a simpler technique than multi-hue scaling. In addition, a double hue scaling was used to seek confirmation for unique hues based on opponent processes. Hering (1878) suggested that intermediated colors are perceived by the combination of adjacent opponent colors. Thus, a specific hue can be most precisely described by the combined percentage of adjacent two opponent unique hues (e.g. yellow and blue). The results of Experiment 1 and 2 were compared with Pak & Lee' s (2005, 2006) data from Korean studies. Experiment 3 examined the unique hue selections of native Korean and English speakers by expanding Kuehni's (2001a) paradigm with more stimuli and different arrangements of stimuli.

2. Experiment 1

Experiment 1 compared the loci of unique hues and focal colors for native English speakers in Munsell color space. Participants were randomly assigned to two experimental groups to choose either unique hues or focal colors from the same color-chip stimuli set. The experimental conditions in each group were identical except for instructions. The results of Experiment 1 were compared with Pak and Lee's (2005) data obtained from native Korean speakers.

Method

Participants. Forty-four native English speakers from the University of Essex participated in the experiment for course credits or payment. They were randomly assigned either to designate unique hues or to designate focal colors. In the unique hue group, there were 10 males and 12 females (average age, 24.4); in the focal color group, there were 9 males and 13 females (average age, 26.4). All participants had normal color vision (Ishihara test, 1992 and City University test, Fletcher, 1980).

Stimuli and Apparatus. Experimental stimuli were 91 Munsell color-chips used in Experiment 1 of Pak & Lee (2005), distributed over red (R), yellow (Y), green (G), and blue (B) areas of Munsell color space with hue ranges 7.5RP~2.5YR for red, 10YR~10Y for yellow, 7.5GY~7.5BG for green, and 7.5B~7.5PB for blue. Across different paradigms, the loci of unique hues and focal colors had been identified at slightly different levels of Munsell Value (brightness) and Chroma (saturation) as well as Hue (Kuehni, 2001a; Oh et al., 2003; Pak & Lee, 2006). To include the full range of samples from previous experiments, Munsell stimuli with Chroma values between 6 and 16 in two levels of Value (3 and 4 in red, green, blue; 8 and 8.5 in yellow) were included. The total number of color-chips stimuli presented was 25 for red, 23 for yellow, 21 for green, and 22 for blue (a full list of stimuli is presented in Appendix I).

All color-chips were displayed on a neutral grey background (Munsell N5; 13×10 cm), that also partitioned the testing cubicle, and observed under natural lighting conditions (GretagMcbeth Exemolite D65 daylight). Order of presentation of the different color sets and of the color-chips within each set was randomized.

Procedure. All participants were tested individually and adapted to the experimental lighting conditions while carrying out the color vision tests. Red, yellow, green, and blue sets of color-chips were presented to participants one at a time, in random order. In the unique hue condition, participants were instructed to "*choose a uniquely (red/green/blue/yellow) chip that is unique and pure in color and does not contain a tint of any other color*". Participants in the focal color condition were instructed to "*choose a color chip that is the most typical and representative of the color category described by the name (red/green/blue/yellow)*". Other procedures were identical in the two conditions.

Results and Discussion.

Table 1 shows the most frequent choices of unique hue and focal color for each of red, blue, green and yellow, compared to the result of native Korean speakers (Pak & Lee, 2005). There was considerable variability in the lightness (Value) and saturation (Chroma) of individual choices, but less variation in hue. Figure 1 shows the frequency of hue choices, summed across Value and Chroma.

(Table 1 about here)

The most frequent loci of unique hues were 7.5R for red, 5Y for yellow, 2.5G for green, and 2.5PB for blue and those of focal colors were at the same Munsell coordinates.

That result was unexpected, given the loci of unique red and green reported by Kuehni (2001a) for English speakers, (2.5R and 2.5BG) and that focal red for native English speakers is usually reported as 2.5R (ISCC-NBS, 1976; WCS, 1997). Furthermore, the unique hues and focal color selections of native English speakers were almost identical to those of native Korean speakers (Pak & Lee, 2005), suggesting that there is no substantial difference in selection on either criterion between the two different languages, even though a previous cross-cultural comparison between American and Indian observers (Webster et al., 2002) found considerable variation between as well as within populations.

(Figure 1 about here)

3. EXPERIMENT 2

Experiment 2 identified the loci of unique hues in Munsell color space using hue-scaling. In this paradigm, observers are asked to rate what percentage of hue corresponding to the given color-name is present in a specific color stimulus. If one stimulus is judged to contain 0% of any other hues except its own, then it must be rated to contain 100% of one hue (e.g. green) and would meet the criterion for a unique hue. Miller and Wooten (1992) adopted a single-hue scaling paradigm in which only one color-name was used to scale the unique hue corresponding to the name, so participants rated only the perceived percentage of one color name at a time for each stimulus. Experiment 2, uses both single-hue scaling, and an adapted double-hue scaling, consistent with the concept of opponent processes.

METHOD

Participants. Twenty native English speakers (9 males and 11 females with an average age of 24 years) participated in the single hue-scaling condition and 19 in the double hue-scaling condition (9 males and 10 females with average age of 25.5 years) for course credits or payment at the University of Essex. All had normal color vision (Ishihara test, 1992 and City University test, Fletcher, 1980).

Stimuli and Apparatus. For the single hue-scaling condition, the same sets of Munsell color-chips were used as in Experiment 1. The four sets were given to each participant in randomized order, along with a response sheet which has a blank column corresponding to each color-chip under the unique hue name. For the double hue-scaling condition, 40 color-chips were taken from Experiment 2 of Pak & Lee (2006). The hue ranges in each unique hue set were 10P ~ 5YR (11 color-chips) for red, 7.5YR ~ 5GY (8 color-chips) for yellow, 7.5GY ~ 2.5B (11 color-chips) for green and 5B ~ 7.5P for blue (10 color-chips). Various levels of Value and Chroma were used, because the structural characteristics of Munsell space differ for the different hues tested (see Appendix for a full list).

Procedure. In the single hue-scaling condition, participants used a prepared response sheet to rate the percentage of a specific unique hue in each color-chip. (e.g. 'red' in the red set of chips). They completed the four sets in random order and the order of stimuli within each set was randomized for each participant. In the double hue-scaling condition, if the stimulus looked like a unique hue, they could use a single unique hue name to rate it. Otherwise they were required to rate the percentages of two unique hue names in the stimulus. Participants were not permitted to compare the stimuli each other or to refer to other stimuli during the rating.

RESULTS AND DISCUSSION.

The percentages of hue scaling for the stimuli of each unique hue set in the single hue-scaling are shown in Figure 2. Hue scaling for color-chips with the same Value level and the highest Chroma levels were then compared. This resulted in the comparison of 7 in red stimuli, 5 yellow stimuli, 9 green stimuli, and 5 blue stimuli[1].

(Figure 2 about here)

Figure 2 shows that the highest points of the scaling fall around 7.5R for red, 5Y for yellow, 2.5G for green, and 2.5PB for blue. Again, the results of native English speakers are very similar to those of native Korean speakers in the single hue experiment of Pak & Lee (2006). In particular, the highest hue scaling of unique red and yellow were found at the same hue level, 7.5 and 5Y, for both language groups. However, those of unique green and blue in the comparison were slightly different, i.e., 2.5G vs. 5G and 2.5PB and 5PB respectively. The variation of participants' scaling gradually reduced as their judgments approached their perceived unique hues.

The scaling using two color names for each unique hue are shown in Figure 3. The highest hue scaling points of unique hues are placed roughly around 7.5R for red, 5Y or 7.5Y for yellow, 5G for green, and 2.5PB or 5PB for blue respectively. The results obtained from the double hue-scaling are very similar to those obtained with single hue scaling and, again, the results from native English speakers are in line with those from native Korean speakers (Pak & Lee, 2006). The ease with which participants completed the double-hue scaling task may reflect the opponent characteristics of unique hues.

(Figure 3 about here)

[1] Some categories (such as yellow have a more restricted range of exemplars than others, so the range of possible choices of unique hue is also smaller.

4. EXPERIMENT 3

The results of both hue scaling tasks supported the findings of Experiment 1 that the loci of unique hues do not differ from the loci of focal colors, at least when making a selection from a restricted set of Munsell stimuli. Unique hues and focal colors appear to be judged on the same criteria. This is at odds with the findings of Kuehni (2001a) who found different loci of unique hues and focal color. In that experiment, the Munsell hue of unique green was 2.5BG, a considerable distance from the location of focal green (2.5G). The difference between 2.5BG and 2.5G corresponds to one tenth of whole range of hues, from red to purple in the Munsell hue circle.

More recently, however, Miyahara (2003) found that the selection of unique hues and focal colors did not differ for all four color-names. Experiment 3 therefore set out to replicate Kuehni's experimental conditions with both native English speakers and native Korean speakers. In addition to replicating Kuehni's experimental condition we also introduced two other conditions, using an additional expanded hue range and an additional viewing condition, to assess whether previously conflicting results arose through the use of limited hue ranges and sequentially ordered stimulus presentation.

METHOD

Participants. One-hundred and fifty native Korean speakers from Korea University and Yeungnam University in South Korea (66 males and 84 females, average age = 21.9 years) and 117 native English speakers from the University of Essex (21 males and 96 females, average age = 21.6 years) were assigned to four experimental conditions (2 hue ranges, i.e., partial or expanded condition × 2 stimulus presentation methods, sequentially ordered or randomly ordered stimuli) in each language group. Thus, there were 40, 30, 40, and 40 participants in native Korean group and 30, 20, 20, and 39 participants in native English group for partial sequential, partial randomized, expanded sequential, and expanded randomized condition respectively. All participants had normal color vision (Ishihara test and City University test).

Stimuli and Apparatus. Two experimental stimulus ranges were used. One condition replicated Kuehni's (2001a) experiment, with 9 stimuli in the red set, 7 in yellow, 9 in green, and 7 in blue. The hue ranges were 10P to 10R for red, 5YRP to 10Y for yellow, 2.5G to 2.5B for green, and 5B to 10PB for blue. In the expanded range condition, the hue ranges of each set included 40 hues. The hue ranges were 10P to 5YR for red, 7.5YR to 5GY for yellow, 7.5GY to 2.5B for green, and 5B to 7.5P for blue. Table 2 illustrates the two conditions.

(Table 2 about here)

Selected color-chips for each unique hue set were arranged with an interval of 0.5cm between them on grey boards (Munsell N5; size 20×30cm). Half the participants in the partial and half the participants in the expanded condition saw the color-chips displayed on the boards sequentially ordered by hue, while the remaining participants in both conditions saw the stimuli presented in randomized hue order. The order in which the sets were given to participants was also randomized and all sets were observed under natural lighting conditions (GretagMcbeth's Exemolite D65, daylight). Each participant was provided with a response sheet for each of the four stimulus color boards on which to write down the number of color-chip chosen as unique hue.

Procedure. Participants were tested individually in a quiet experimental booth. After testing their color vision the experimenter explained the task. The response sheet also contained a reminder that *'A unique hue is a pure color that does not contain a tint of any* *other color. For example, unique yellow is yellow that is neither greenish nor reddish'* in either English or Korean.

RESULTS AND DISCUSSION

Responses across the four conditions in both language groups were compared by chi-square, based on the difference between expected and observed. For the partial hue range, the difference between Korean and English speakers was significant for participants in the ordered array condition for red: $X^2(4, N=78)=12.85$, p<.01, yellow: $X^2(4, N=78)=10.49$, p<.03, green: $X^2(5, N=78)=22.96$, p<.01 and blue: $X^2(4, N=78)=10.90$, p<.03, but for participants who saw the randomized array, there was no significant difference between Korean and English speakers for red, yellow or green, however it was also significant for blue in the randomized condition, $X^2(3, N=50)=12.28$, p<.01.

For Korean speakers, the difference between ordered and randomized conditions was significant for red: $X^2(3, N=70)=10.63$, p<.01, yellow: $X^2(5, N=70)=12.49$, p<.03, green: $X^2(5, N=70)=18.99$, p<.01, and blue: $X^2(4, N=70)=17.06$, p<.01. However, none of these differences were significant for English speakers.

With the expanded hue range, the difference between Korean and English speakers in the ordered display condition was significant for red: $X^2(4, N=78)=12.85$, p<.01, yellow: $X^2(4, N=78)=10.49$, p<.03, green: $X^2(5, N=78)=22.96$, p<.05 and blue: $X^2(4, N=78)=10.90$, p<.03. Again, with a randomized order, it was significant for unique blue choices: $X^2(3, N=50)=12.28$, p<.01, but not for red, yellow, or green. The difference between ordered and randomized conditions in Korean speakers was significant for red, $X^2(3, N=70)=10.63$, p<.01, yellow: $X^2(5, N=70)=12.49$, p<.03, green: $X^2(5, N=70)=18.99$, p<.01, and blue: $X^2(4, N=70)=17.06$, p<.01, but none of those differences were significant in English.

(Figure 4 & 5 about here)

Figure 4 and Figure 5 show the percentage of unique hue choices from red to blue in all conditions in the ordered or randomized presentation conditions for partial or expanded hue range by native Korean or English speakers. Overall, the patterns of unique hue choices in each condition were very similar to those found in Experiments 1 and 2. The unique hues chosen most frequently in both presentation methods and language groups for the partial hue range was 7.5R for red, 5Y for yellow, 2.5G for green, and 10B or 2.5PB for blue. Both language groups selected unique hues similar to those chosen in other paradigms in Experiments 1 and 2 - 7.5R for red, 5Y or 7.5Y for yellow, 10GY or 2.5G for green, and 10B or 2.5PB for blue. Unlike the previous experiments however, there were some significant differences between the choices of native Korean and English speakers but, with the exception of unique blue, these only emerged for those participants viewing the ordered arrays.

English speakers made very similar selections regardless of the arrangement of the stimulus array. Korean participants, however, made very different choices with the randomized array, although their choices with the ordered array were generally similar to those of English speakers (except for blue). Extending the range from which participants could choose impacted on Korean choices of unique green in particular, with more choices towards the yellow end of the range.

Choice patterns in unique blue also differed with experimental condition. In the partial range condition, only native Korean speakers in the randomized condition choose 10B as unique blue whereas in the ordered array they selected a more purplish hue (2.5PB). Native English speakers selected 2.5PB as unique blue in both viewing conditions. With an expanded range native English speakers in both viewing conditions chose 10B, as did some native Korean speakers in the randomized condition. A similar shift is apparent in both languages for yellow, with an expanded range available to choose from. These different response tendencies suggest that unique hues vary according to the experimental task, at least for Korean speakers.

Despite the variation in choices of unique hues found using different hue ranges, and orders of presentation, the results of the ordered array condition support those observed in Experiment 1 and 2 that unique hue choices closely resemble choices of focal color, in both language groups. It is possible that a randomized array promotes closer attention to comparisons of neighboring stimuli, and that this has the effect of biasing choices in a particular direction, compared with hue rating paradigms in which participants are asked to rate the percentage of one or more unique hues in one stimulus at a time.

In simultaneous color-chip comparison, choices appear to be more volatile and easily affected by viewing conditions and available range of alternatives. When the experimental stimuli are presented in an ordered array, participants may tend to avoid the extremes of the stimulus range and to prefer stimuli near the mid point of the range. In Experiment 3, when color-chips were presented in an ordered array, unique hue choices, particularly in green, were located closer to the middle of the hue range. In those circumstances, population choices may appear more homogenous, because they regress to the mean. This effect might also occur with monochromatic lights, giving the impression of less individual variation than would be found with other methods. When the order of stimuli was randomized, choices of unique hue were seen to move away from the centre of the range.

5. General Discussion

The present study sought to unify previous results with either native English or native

Korean speakers. Oh et al. (2003) found that the unique hues of red and green, identified by native Korean speakers were both closer to yellow than those found in studies of English speaking observers (e.g. Kuehni, 2001a). Korean speakers unique hue choices seemed to reflect the location of Korean's focal colors more than English speakers (Kim, 1998; Kim, Pak & Lee, 2001; Lee & Kim, 1997; Lee et al., 2002).

In Experiment 1 native English speakers identified either unique hues or focal colors, and, like native Korean speakers, their choices in the two conditions coincided. Experiment 2 used a hue scaling method to identify unique hues. Both single-hue scaling and double-hue scaling showed similar results and supported the findings of Experiment 1 and the results of previous Korean studies. In Experiment 3, using the same stimuli and condition as Kuehni's experiment as well as an additional condition with an expanded hue range the results were quite different from those reported by Kuehni. The results of Experiment 3 showed that previous results might have been affected by response bias because participants tended to select exemplars at the centre of the stimulus array.

The selection of unique red, predicted to be 2.5R, at least for English speakers, shifted to 7.5R which is the same hue selected as focal red in both languages, regardless of the experimental task used. Choices of unique yellow and green differed between the two language groups, particularly in the randomized order of presentation and the expanded hue range of Experiment 3, even though they were almost identical in the hue-scaling paradigm in Experiment 2. With the modified experimental conditions of Experiment 3, the unique green choices of both Korean and English native speakers differed widely from the unique green location (2.5BG) reported by Kuehni (2001a, 2001b) using limited hue ranges. This suggests that unique hues do not always differ from focal color judgments, but vary according to the experimental task, in both languages.

Previous neurophysiological and psychophysical studies, have shown that the opponent processes in the visual receptors i.e., the neural activities of L-M and S-(L+M) channels do not match the unique hues that individuals select (e.g., De Valois, De Valois, Switkes, & Mahon, 1997; Jameson & D'Andrade, 1997; Valberg, 2001). The large individual variability in unique hue judgments combined with the discrepancy in some psychophysical experiments indicates that a unified perception of unique hues may not exist (Kuehni, 2003; Malkoc, 2003; Malkoc et al, 2002). Recent results from Korean similarity rating experiments suggested that recognition of unique hues was not faster than other hues (Oh, Kim, Jung, & Lee, 2006). So, unique hues may not have a direct relationship to opponent processes or any special perceptual saliency in color perception.

Unique hues may lack perceptual salience because they are seldom experienced in daily life. As noted by van Brakel and Saunders (1997), unique hues may be created with the monochromatic spectrum or color-chips used in a laboratory, but it is difficult to experience them outside the lab, even though they might have a distinct perceptual quality. Given the present results that unique hue judgments can be influenced by context, it may be necessary to reconsider the conceptual definition of unique hues. [2]

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Appendix Ⅰ. Munsell chips used in Experiment 1 and 2-1

Red	Munsell Code	Yellow	Munsell Code	Green	Munsell Code	Blue	Munsell Code
R1	10RP 4/12	Y1	10Y 8/10	G1	5G 3/8	B1	2.5PB 3/10
R2	2.5R 4/14	Y2	5Y 8.5/14	G2	2.5BG 4/8	B2	10B 3/8
R3	10R 4/10	Y3	2.5Y 8/16	G3	5G 4/10	B3	7.5PB 3/10
R4	7.5RP 4/10	Y4	5Y 8/10	G4	10G 3/8	B4	5PB 4/8
R5	10RP 3/10	Y5	10Y 8.5/12	G5	2.5G 3/8	B5	10B 4/10
R6	7.5R 3/12	Y6	5Y 8.5/10	G6	5BG 4/8	B6	7.5PB 4/8
R7	5R 4/12	Y7	7.5Y 8/12	G7	10G 4/10	B7	5PB 4/12
R8	7.5R 4/16	Y8	10YR 8/14	G8	7.5GY 4/8	B8	7.5B 3/8
R9	7.5R 4/12	Y9	7.5Y 8.5/10	G9	7.5G 3/8	B9	5PB 3/10
R10	2.5R 3/10	Y10	2.5Y 8/12	G10	2.5G 3/10	B10	2.5PB 4/8
R11	5R 4/14	Y11	2.5Y 8.5/10	G11	7.5G 4/10	B11	10B 4/8
R12	7.5RP 3/10	Y12	10Y 8/12	G12	7.5BG 3/8	B12	7.5PB 4/12
R13	5R 3/10	Y13	5Y 8/12	G13	2.5G 4/10	B13	7.5PB 3/8
R14	2.5R 4/10	Y14	10YR 8/10	G14	2.5BG 3/8	B14	5PB 3/8
R15	10R 4/12	Y15	2.5Y 8.5/12	G15	7.5G 4/8	B15	7.5B 4/10
R16	7.5R 4/14	Y16	5Y 8.5/12	G16	10G 4/8	B16	2.5PB 3/8
R17	10RP 4/14	Y17	10Y 8.5/10	G17	7.5BG 4/8	B17	7.5PB 4/10
R18	7.5R 3/10	Y18	2.5Y 8/10	G18	10GY 4/8	B18	5PB 4/10
R19	7.5RP 4/12	Y19	7.5Y 8/10	G19	5G 4/8	B19	7.5B 4/8
R20	2.5YR 4/10	Y20	10YR 8/12	G20	5BG 3/8	B20	2.5PB 4/10
R21	10RP 4/10	Y21	2.5Y 8/14	G21	2.5G 4/8	B21	7.5PB 3/12
R22	10R 3/10	Y22	7.5Y 8.5/12			B22	10B 3/10
R23	2.5R 4/12	Y23	5Y 8/14				
R24	7.5R 4/10						
R25	5R 4/10						

AppendixⅡ. Munsell chips used in Experiment 2-2 and 3

Red	Munsell Code	Yellow	Munsell Code	Green	Munsell Code	Blue	Munsell Code
R1	10P 4/12	Y1	7.5YR 7/14	G1	7.5GY 5/10	B1	5B 4/10
R2	2.5RP 4/12	Y2	10YR 8/14	G2	10GY 5/10	B2	7.5B 4/10
R3	5RP 4/12	Y3	2.5Y 8/14	G3	2.5G 5/10	B3	10B 4/10
R4	7.5RP 4/12	Y4	5Y 8/14	G4	5G 5/10	B4	2.5PB 4/10
R5	10RP 4/12	Y5	7.5Y 8/12	G5	7.5G 5/10	B5	5PB 4/10
R6	2.5R 4/12	Y6	10Y 8/12	G6	10G 5/10	B6	7.5PB 4/10
R7	5R 4/12	Y7	2.5GY 8/12	G7	2.5BG 5/10	B7	10PB 4/10
R8	7.5R 4/12	Y8	5GY 7/12	G8	5BG 5/10	B8	2.5P 4/10
R9	10R 4/12			G9	7.5BG 5/10	B9	5P 4/10
R10	2.5YR 5/12			G10	10BG 5/10	B10	7.5P 4/10
R11	5YR 5/12			G11	2.5B 5/10		

Table 1. Location of unique hues (UH) and focal colors (FC) identified by native English speakers compared with native Korean speakers (Pak & Lee, 2005)

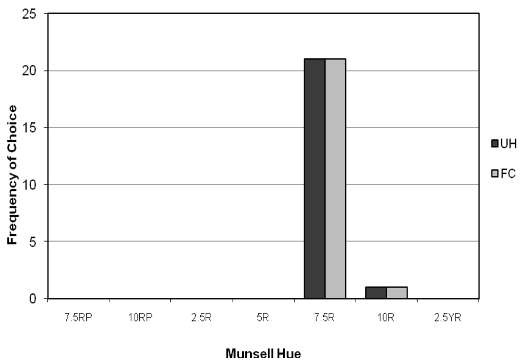
	Red		Yellow		Green		Blue	
	UH	FC	UH	FC	UH	FC	UH	FC
English	7.5R 4/16 (40.9%)*	7.5R 4/16 (63.6%)	5Y 8.5/14 (22.7%)	5Y 8/14 (31.8%)	2.5G 3/10 (27.3%)	2.5G 3/10 (36.4%)	2.5PB 3/10 (40.9%)	2.5PB 3/10 (27.3%)
Korean	7.5R 4/16 (53.3%)	7.5R 3/12 (46.7%)	5Y 8.5/14 (30%)	5Y 8.5/14 (40%)	5G 4/10 (33.3%)	5G 4/10 (36.7%)	2.5PB 3/10 (43.3%)	5PB 3/10 (36.7%)

* (   ) is the percentage of choice response.

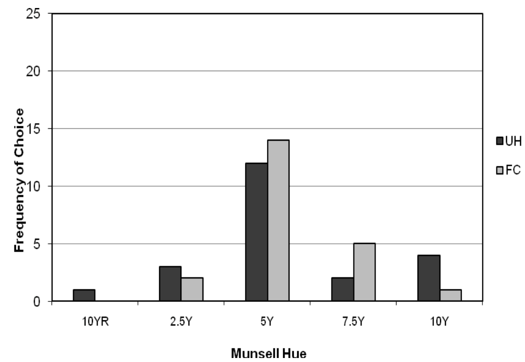
Table 2. The hue ranges of Munsell in partial and expanded condition

<table>
<tr><th colspan="4">R</th><th colspan="4">YR</th><th colspan="4">Y</th><th colspan="4">GY</th><th colspan="4">G</th><th colspan="4">BG</th><th colspan="4">B</th><th colspan="4">PB</th><th colspan="4">P</th><th colspan="4">RP</th></tr>
<tr><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td><td>2.5</td><td>5</td><td>7.5</td><td>10</td></tr>
<tr><td colspan="4">Red</td><td></td><td colspan="7">Yellow</td><td colspan="4"></td><td colspan="9">Green</td><td colspan="7">Blue</td><td colspan="3"></td><td colspan="5">Red</td></tr>
<tr><td colspan="6">Red</td><td colspan="8">Yellow</td><td colspan="11">Green</td><td colspan="10">Blue</td><td colspan="5">Red</td></tr>
</table>

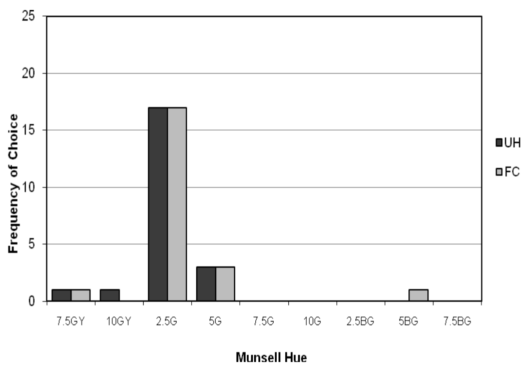
(a) red



(b) yellow



(c) green



(d) blue

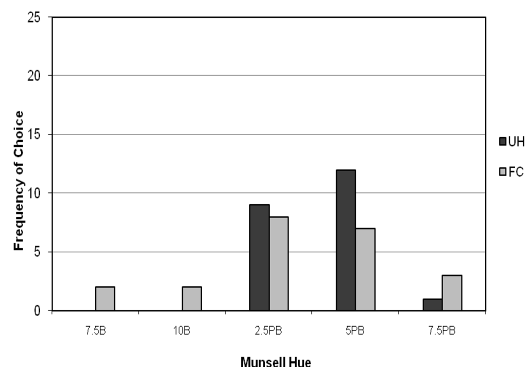


Figure 1. Frequency of UH and FC choices by Hue (summed over Value and Chroma) for (a) red, (b) yellow, (c) green, (d) blue.

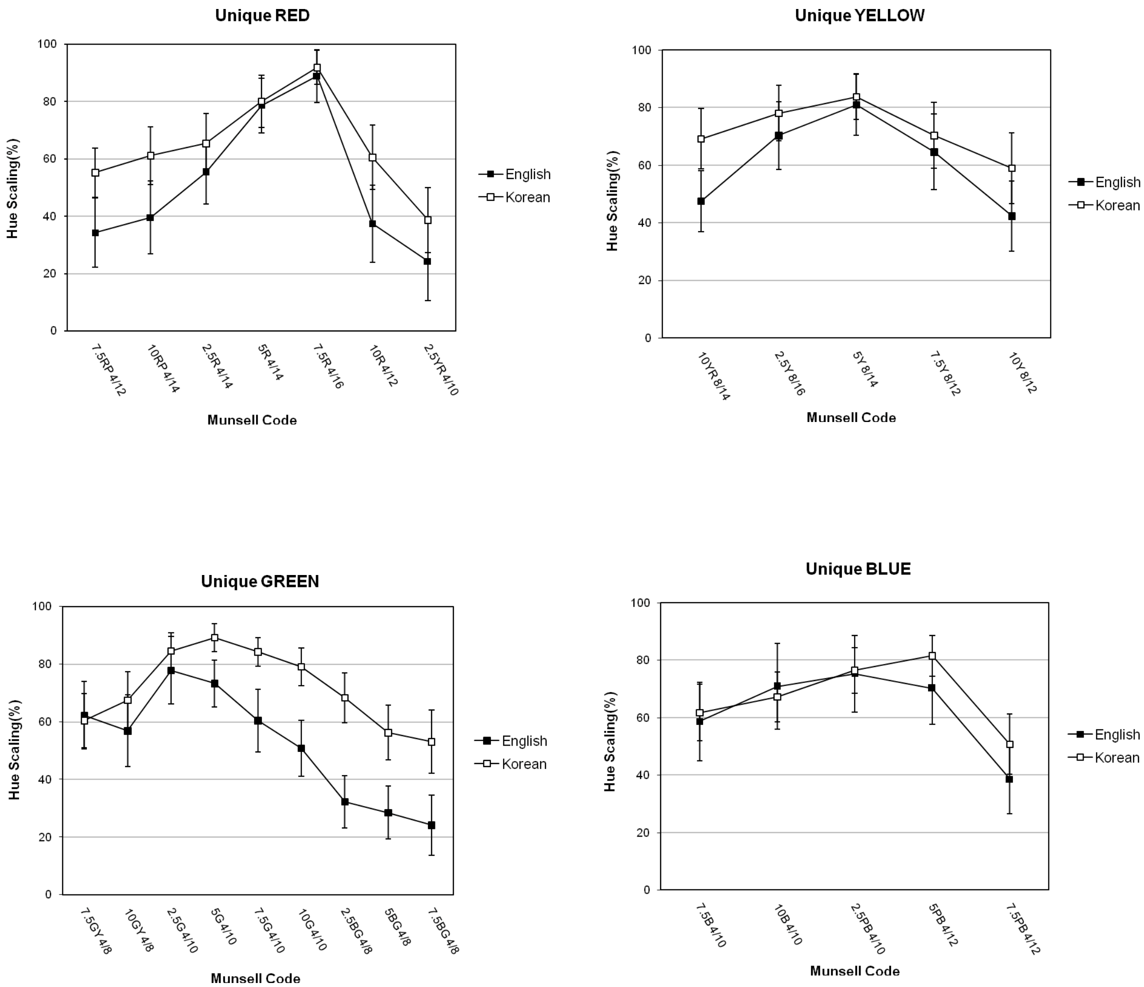


Figure 2. Unique hues of native English and Korean (Pak & Lee, 2006) speakers in single-hue scaling experiment.

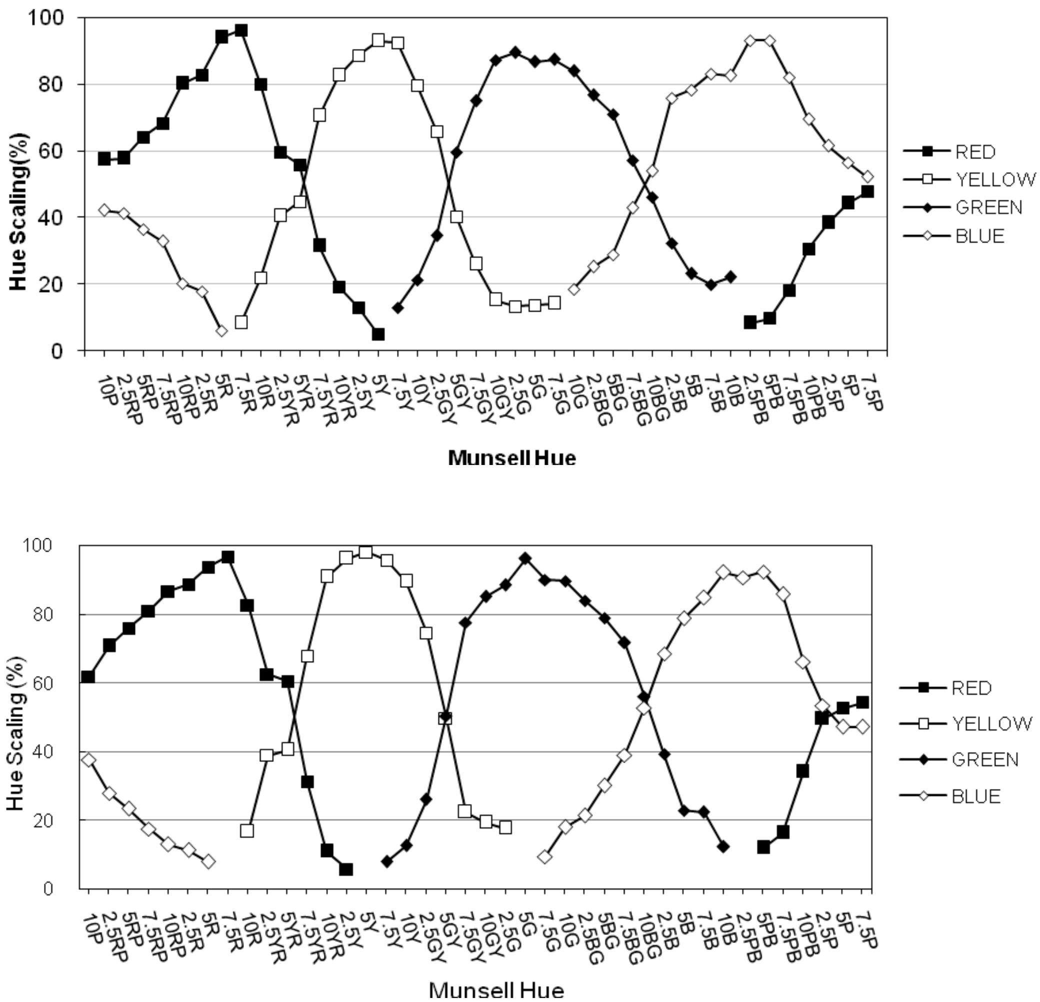


Figure 3. The double-hue scaling ratings of native English speakers and native Korean speakers (Pak & Lee, 2006).

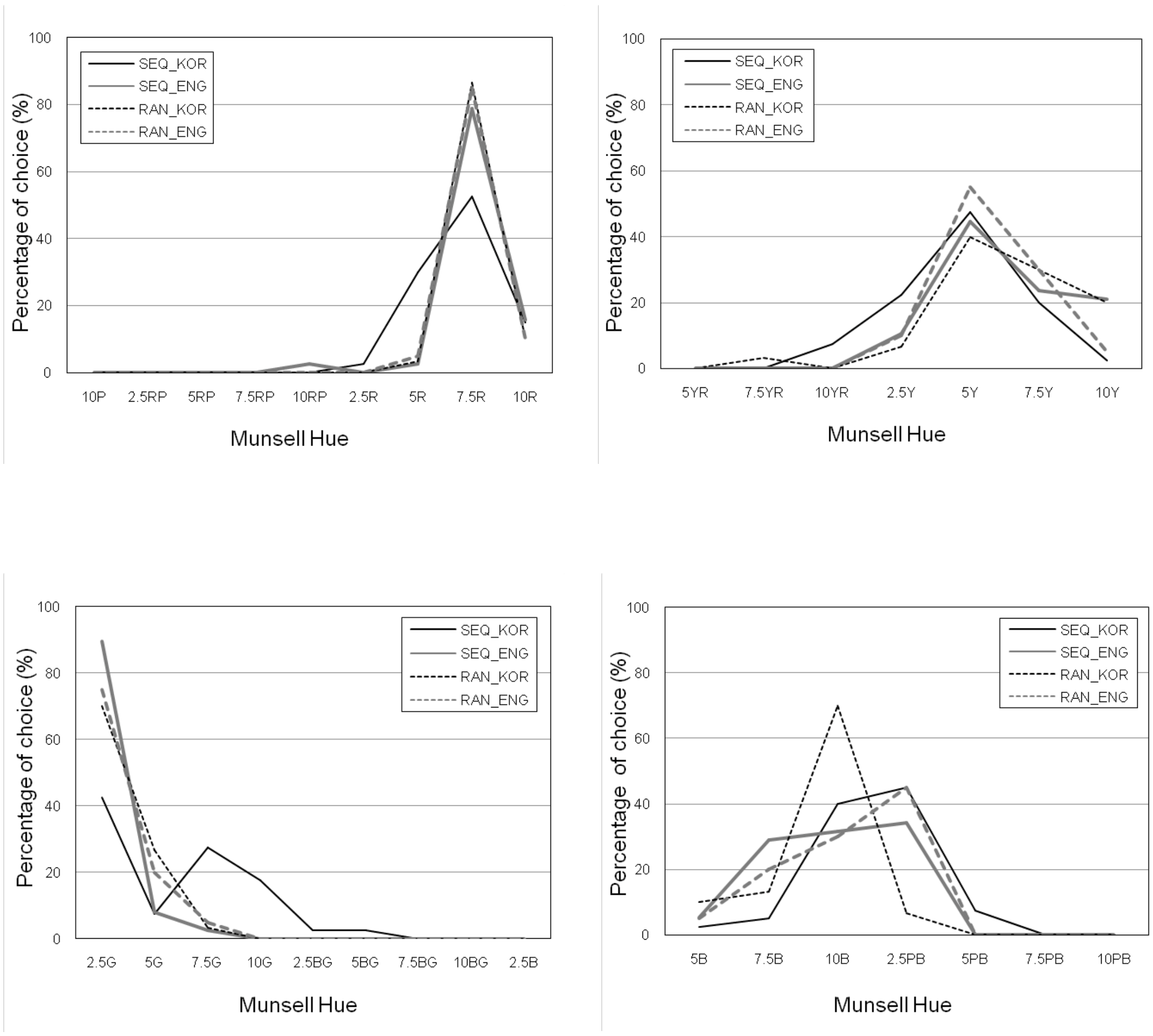


Figure 4. Unique hue choices of native Korean speakers and native Korean speakers in partial hue range condition.

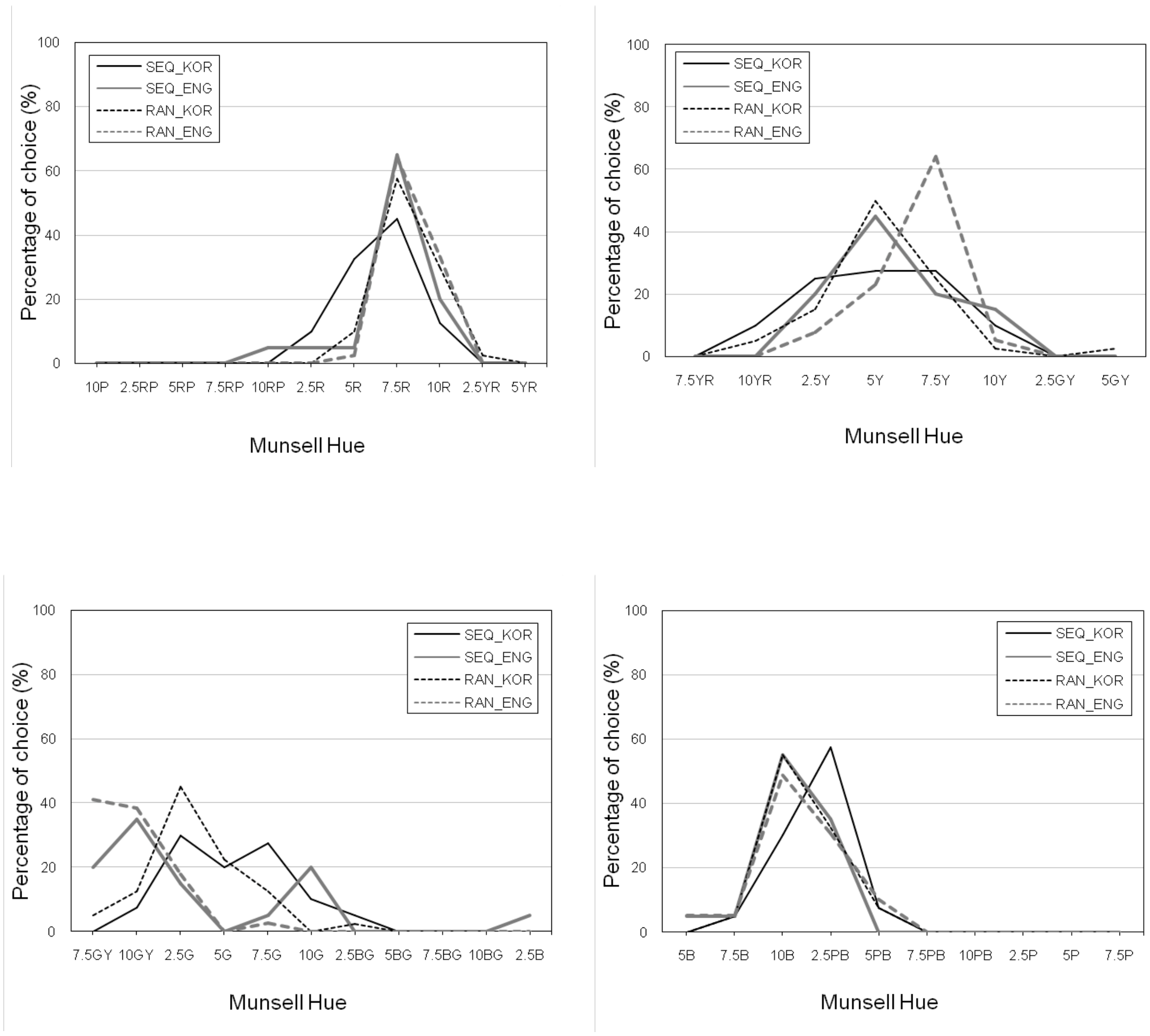


Figure 5. Unique hue choices of native Korean speakers and native English speakers in the extended hue range condition.