Cross-modal association between colour, vowel and lexical tone in nonsynesthetic populations: Cantonese, Mandarin and English

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ABSTRACT

Previous studies suggested that the synesthesia-like coloured hearing could be found in nonsynesthetic population for both vowel quality and pitch. The vowel-colour and pitch-colour associations were investigated separately so it is unclear whether vowel quality or pitch has a stronger effect on cross-modal colour association, and how they may interact. No study has investigated this phenomenon in a tone language in which pitch differences are intrinsically coded with vowel qualities. The current study aims to examine whether there is non-random sound-colour mappings for Cantonese vowels in native and non-native (Mandarin and English) listeners. The results suggested that non-synesthetic subjects showed non-arbitrary vowel-colour associations of Cantonese vowels and pitch played a more fundamental role than vowel quality in coloured-hearing.

Keywords: cross-model perception, colour, tone, vowel, Cantonese

1. INTRODUCTION

Many studies have investigated various types of synesthesia – the mapping of sensation from one sensory domain to another. In coloured-hearing synesthesia, sounds are systematically associated with colours. Jakobson first [2] proposed that /a/ is associated with red, /i/ and /e/ with bright colours, and /o/ and /u/ with dark colours. He argued that compactness (articulatorily related to jaw opening) is related to chromaticity, and tonality (the front-back dimension of vowel, F2) is related to the light-dark dimension. Similarly, based on his meta-analysis on coloured-hearing synesthesia, Marks [3] found that vowel qualities contributed to coloured-hearing. The synesthetes he investigated associated the vowel /a/ with red or blue, /e/ and /i/ with white or yellow, /o/ with red and black, /u/ with blue, brown and black. He suggested the 'vowel pitch' (F2) and the F2/F1 ratio (compactness) of vowels have an influence on colour mappings. High-pitch sounds were associated with bright colours, while low-pitch sounds were mapped onto dark colours. The F2/F1 ratio was correlated to the greenness-redness dimension – as the F2/F1 ratio increases, the greenness increases, or vice versa.

Marks [4] suggested that the sound-colour associations are more regular and consistent across different individuals than other types of synesthetic perceptions in his review of colored-hearing synaesthesia. Moreover colored-hearing perception is also found in non-synesthetic population [1][5][6][7][8]. Ward et al. [5] compared sound-colour synesthetes with non-synesthetic controls. They found that both synesthetes and non-synesthetes showed a tendency to match high-pitch sounds with light colours, low-pitch sounds with dark colours, and used the same attentional mechanisms. Thus they suggested that cross-modal mechanisms of sound-colour synesthesia might be common to nonsynesthetes. For synesthetes, the cross-model mechanisms might be evoked automatically, while for non-synesthetes – strategically. They also suggested that the cross-model associations might be mediated by other factors such as linguistic labels.

Many studies on audio-visual cross-model perception in non-synesthetic population focus on the pitch-brightness and loudness-brightness associations, e.g. [1][3]. There are consistent findings that increasing pitch is mapped onto increasing brightness. The loudness-brightness association is less robust than the pitch-brightness association. The pitch difference was manipulated using pure tones or musical notes which differ greatly in frequency (e.g. 200 – 4000 Hz), and the colour contrast is limited to black/grey/white. It is unclear if linguistic pitch, which has a much smaller pitch range, is relevant for colour association.

Wrembel [6] [7] [8] investigated the vowel-colour mappings in non-synesthetic population focussing on vowel qualities. She found that native speakers of Polish have similar mapping patterns when hearing Polish vowels and English (their L2) vowels. In general, bright colours (yellow, green) are associated with high front vowel, while dark colours (brown, blue, black) are attributed to back vowels, and open vowels tend to be perceived as red, and central vowels are mapped onto grey.

It is clear in the literature that both pitch and vowel quality are associated with colour in cross-modal association. However, the two aspects were investigated separately, thus it is unclear which factor has a more robust effect on sound-colour association, and how they may interact. Moreover, most previous studies were based in English (for both listeners and materials), so whether there is any linguistic difference in cross-modal association awaits further investigation.

Tone languages give us a good opportunity to explore the above research questions, because linguistic pitch difference is intrinsically coded with vowel qualities. We can examine the influence of the two factors simultaneously. We have chosen Cantonese as the target language. In addition to being a tone language, Cantonese has two front-rounded vowels /y/ and /œ/ which allow us to separate the effects of F2 and vowel frontness on colour association. In order to investigate whether there is a cross-language difference in coloured-hearing, besides Cantonese listeners, Mandarin (tonal) and English (non-tonal) listeners were compared in this study.

2. METHOD

2.1. Subjects

Three groups of participants were recruited in this study: 59 native speakers of Cantonese (21 males, 38 females, mean age 20.88±2.24 years), 31 native speakers of Mandarin (8 males, 23 females, mean age 22.68±1.66 years) and 19 native speakers of English (13 males, 6 females, mean age 19.95±0.85 years). None of the subjects reported hearing or neurological problems. They participated either for course credits or payment.

2.2. Materials

238 different sound stimuli were used. 14 of these stimuli are vowel-only syllables, seven Cantonese vowels (/i y ɛ œ a ɔ u/) with two tones – Tone 1 (T1, a high-level tone [55]) and Tone 4 (T4, a low-falling tone [21]) in Cantonese. The other 224 stimuli are CV syllables, combining the seven vowels on two tones with 16 different Cantonese initial onset consonants. The CV data is not reported for page limit. All the stimuli were natural speech sounds produced by a female Cantonese native speaker.

2.2. Procedure

The experiment is a sound-colour matching task. Following Wremble [5], we used 11 basic colours in our study (black, blue, brown, green, grey, orange, pink, purple, red, and yellow). 11 colour squares would appear on the screen with a sound stimulus. Participants were asked to choose one from the 11 colour squares and then press the corresponding button on the keyboard. For each trial, participants would have 7 seconds to respond. The single vowel stimuli were repeated for five times and each CV syllable appeared only once. The order of the sound stimuli and colour squares was pseudorandomized. There are 294 trials in total.

The brightness/darkness of the chosen colours was rated by participants in a post-experiment online survey. The survey contained a seven-point Likert scale. Participants were asked to rate how light or how dark a colour is by giving the colour a mark from one (extremely light) to seven (extremely dark). 57 of 59 Cantonese speakers, 26 of 31 Mandarin speakers and 19 English speakers completed the survey.

3. RESULTS

3.1. Vowel-colour mappings

To examine whether there is a non-random association between Cantonese vowels and the 11 basic colours, a series of chi-square tests were conducted using total observations on the results from the single-vowel condition. The chi-square tests indicate that there is a significant sound-colour association for all 14 sounds for Cantonese listeners, for 11 of the 14 sounds for Mandarin listeners, and for 10 of the 14 sounds for English listeners. Table 1 shows the detailed association (only the significant association with the highest percentage is given).

Table 1: Most significant vowel-colour association in a) Cantonese b) Mandarin c) English listeners. (Numbers in brackets indicate specific percentages of sound-colour association)

(a)	/a/	/ɛ/	/i/	/ɔ/	/œ/	/u/	/y/
Tone 1	Red(33)	White(21)	White(33)	Orange(20)	Yellow (14)	Brown(16)	Yellow(13)
Tone 4	White(28)	Grey(18)	White(17)	White(18)	Brown (20)	Brown(19)	Brown(12)
(b)	/a/	/ɛ/	/i/	/ɔ/	/œ/	/u/	/y/
Tone 1	Red(19)	Red, Yellow(17)	Yellow(23)	White(20)	Yellow(19)	-	Orange(15)
Tone 4	Black(21)	-	-	Black(14)	Brown(17)	Brown(22)	Grey(16)
(c)	/a/	/ɛ/	/i/	/ɔ/	/œ/	/u/	/y/
Tone 1	-	-	Yellow(25)	Orange(27)	Orange(16)	Blue(28)	Blue(33)
Tone 4	-	Brown(16)	-	Orange(28)	Brown(15)	Blue(31)	Blue(32)

Table 2: Most significant association between colour and vowel categories.
(Numbers in brackets indicate specific percentages of sound-colour association)

	Front Unrounded		Front Rounded		Back Rounded	
	Tone 1	Tone 4	Tone 1	Tone 4	Tone 1	Tone 4
Cantonese	White(27)	White, Grey, Brown(14)	Yellow(13)	Brown(16)	Orange(14)	Brown(17)
Mandarin	Yellow(20)	Grey(13)	Yellow(15)	Grey(15)	White(15)	Brown(17)
English	Yellow(20)	-	Blue(22)	Blue(20)	Blue(21)	Blue(19)
	High		Mid		Low	
	Tone 1	Tone 4	Tone 1	Tone 4	Tone 1	Tone 4
Cantonese	White(17)	Brown, Blue(14)	White(16)	Brown(17)	Red(33)	White(28)
Mandarin	Yellow(20)	Grey (13)	Yellow(14)	Brown, Grey(14)	Red(19)	Black(21)
English	Blue(22)	Blue(23)	Orange(18)	Orange, Grey(14)	-	-

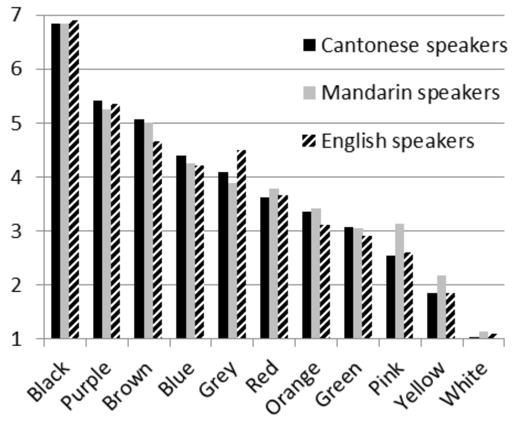
It is clear that Cantonese and Mandarin listeners share more similarities than English listeners. Cantonese and Mandarin listeners are likely to map /a/ (Tone 1), /œ/, and /u/ onto the same colours, while English listeners tend to associate one colour (e.g. orange and blue, see Table 1c) with multiple sounds.

Further, the vowels are grouped into six categories in terms of vowel qualities: front unrounded (/i ɛ/), front rounded (/y œ/), back rounded (/ɔ u/), high (/i y u/), mid (/ɛ œ ɔ/) and low (/a/) vowels. As the detailed association in Table 2 shows, both Cantonese and Mandarin listeners show a tendency to assign light colours to Tone 1 (high tone) and dark colours to Tone 4 (low tone). It is interesting to note that Cantonese listeners tend to associate Tone 1 with white and yellow, Tone 4 with brown for front, back, high and mid vowels. Similar, Mandarin listeners tend to associate yellow with Tone 1, grey with Tone 4 for front, high and mid vowels. This suggests tones are important cues for colour selection to Cantonese and Mandarin listeners. English speakers show a different pattern. They map three types of vowels (front rounded, back, high) to blue, regardless of tones.

3.2. Sound-brightness associations

Results of the rating task suggest that the three groups of subjects have similar brightness ratings for the 11 colours (see Fig. 1). The ratings of the chosen colours for each sound (averaged across five trials for single vowels) were entered into a series of mix factorial ANOVAs to examine the association between vowels, tones and brightness of colours. Results from single vowel condition show that there is a main effect of vowel ($F = 9.644$, $p < 0.001$). Bonferroni-adjusted post-hoc t-tests suggest that /u/ is the darkest vowel and /i/ is the brightest vowel. /u/ shows significant difference with /a ɛ i ɔ/ ($p < 0.009$). In addition, /œ/ is significantly darker than /ɛ/ ($p = 0.018$), /i/ ($p < 0.001$) and /ɔ/ ($p = 0.039$). /y/ is significantly darker than /i/ ($p = 0.001$). There is also a significant main effect of tone ($F = 19.186$, $p < 0.001$). Tone 4 is significantly darker than Tone 1. The difference between groups is not significant. All the interactions do not reach the significant level. In addition, the interaction between vowel and group is significant ($F = 2.617$, $p = 0.002$). Simple effect analyses reveal that the effect of vowels is significant in the Cantonese ($F = 7.82$, $p < 0.001$) and English ($F = 4.47$, $p < 0.001$) groups, but not in Mandarin group. This suggests for Mandarin listeners, the association between vowel and brightness is not so robust.

Figure 1: Brightness ratings of selected colours.



Further, to examine the effect of different vowel qualities, front unrounded vowels /i ɛ/ are compared with front rounded vowels /y œ/ (for roundedness), front rounded vowels /y œ/ with back rounded vowels /ɔ u/ (for frontness), high vowels /i y u/ and mid vowels /ɛ œ ɔ/ (height) in a series of mix factorial ANOVAs. A main effect of roundedness was found in both single vowel condition ($F = 27.244$, $p < 0.001$), with rounded vowel darker than unrounded vowels. No main effect of frontness or vowel height was found.

3.2. Vowel qualities and colour dimensions

As chi-square results show that Cantonese and Mandarin listeners are more sensitive to tones than English listeners are, multiple regression analyses using Forced entry were conducted to examine the possible contribution of spectral measurements (F0, F1, and F2) to vowel-colour association in tone language speakers (Cantonese and Mandarin). The spectral measurements were taken from the sound stimuli. In four analyses, averaged R, G, B values and Lightness ratings (L) of the 11 basic colours constituted the dependent variable, respectively.

The results are shown in the following equations (coefficients are standardized).

(1) $L = -.49\ F0 - .05\ F1 - .01\ F2$ ($R^2 = 0.24$)

(2) $R = .55\ F0 + .29\ F1 + .12\ F2$ ($R^2 = 0.341$)

(3) $G = .51\ F0 - .06\ F1 + .11\ F2$ ($R^2 = 0.278$)

(4) $B = -.02\ F0 - .22\ F1 + .09\ F2$ ($R^2 = 0.062$)

F0 is significantly associates with brightness ($p < 0.001$). F0 ($p < 0.001$), F1 ($p < 0.001$) and F2 ($p = 0.034$) all significantly contribute to the association between vowel and Red, F0 is significantly associates with Green ($p < 0.001$). F1 is the only variable that significantly associates with Blue ($p < 0.001$), however the relative small R square value suggest that the equation can only predict only 6.2% of the association with Blue. To summarise, in terms of the association with brightness, redness and greenness, F0 is the most important cue for Cantonese and Mandarin listeners.

4. DISCUSSION

The results of the current study indicate that the mappings between Cantonese vowels and basic colours are not random in all three groups of listeners: Cantonese, Mandarin, and English. This is consistent with previous findings in Polish and English vowels [6] [7] [8], suggesting that there are non-arbitrary associations between vowel sounds and colours even in non-synesthetic population. Moreover, non-native listeners, including speakers of a tone language (Mandarin) and a non-tone language (English) showed non-random associations for Cantonese vowels, although native speakers showed a stronger vowel-colour correlation than non-native speakers. This support the proposal by Ward et al. [5] that cross-modal mechanisms of sound-colour mapping might be common to all population.

In terms of sound-colour mapping patterns, most of our results are in line with previous findings: /a/ is associated with red, /i/ with white and yellow, /ɔ/ with orange, /u/ with brown and blue. We also found unconventional mapping patterns for other vowels: /ɛ/ elicited white and grey in Cantonese listeners, red in Mandarin listeners and brown in English listeners; /ɔ/ elicited white in Cantonese listeners, white and black in Mandarin listeners. For front rounded vowels /œ/ and /y/ that were not tested in previous studies, Cantonese listeners associated them with yellow and brown. Mandarin speakers associated yellow and purple with /œ/, orange and grey with /y/, while English listeners associated orange and brown with /œ/, and blue with /y/.

Although in our studies the specific colours that are associated with six vowel categories are different with Wrembel's findings [7], the chi-square results suggest a tendency that front vowels are brighter than back vowels, high vowels are brighter than mid vowels, which is consistent with previous studies [3]. The ANOVA results suggested that only roundedness, but not frontness and height, had an influence on the association with brightness. Previous studies only compared front unrounded vowels with back rounded vowels, so they have confounded frontness and roundedness. Our results can separate their effects.

The effect of pitch is more robust than that of vowel qualities. The chi-square results show that Cantonese and Mandarin listeners have the tendency to map the light colours to the high tone and dark colours to the low tone across vowels. Specifically, they tend to choose one light colour for most high tone sounds, and one dark colour for most low tone sounds, regardless of vowel categories. The ANOVA results suggest that all the three groups have the pitch-brightness association. There is a significant difference, however, in the vowel-colour mappings between the three groups. Moreover, as the regression analyses also reveal that F0 played the most important role in the association with the brightness, redness and greenness among Cantonese and Mandarin listeners.

Ward et al.'s hypothesis [5] that synesthetes and nonsynesthetes use the same mechanisms for cross-model perception can partially account for the results of the current study. They also suggested that there might be some high-level cognitive processing mediating the cross-model associations, such as linguistic labels, which could account for the difference we found between Cantonese, Mandarin and English speakers. Further analysis of the data of the CV conditions will allow us to examine the effects of consonants on vowel-colour mappings later. More studies are needed to investigate what may influence cross-language differences.

To conclude, in the current study we found non-random vowel-colour associations for Cantonese vowels in both native and non-native listeners. Lexical tones are found to be significantly correlated with brightness. High tone tends to be associated with lighter colour and low tone with darker colour. Further investigation on linguistic mediation is needed to gain a better understanding of colored-hearing in different language speakers.

5. REFERECES

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