Technical Report on Attention and Cognition (2016) No.5

Exploratory analysis of synesthetic colors distribution in the color space（共感覚色分布の探索的解析）

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This study investigated distribution of synesthetic colors in the color space to understand perceptual properties of synesthetic colors. This analysis requires a large amount of data for a single synesthete. We therefore collected large samples of data from five synesthetes. We obtained over 1000 synesthetic colors associated with Japanese kanji characters for each of two synesthetes, and over 100 synesthetic colors for each of the other synesthetes. We then analyzed the distribution pattern of synesthetic colors in the color space by using techniques of spatial statistics. The spatial statistical analysis revealed that synesthetic colors are concentrated in multiple regions in the color space, that is, they form "synesthetic color clusters". The synesthetic color clusters indicate that synesthetic colors are not randomly decided, but specific colors preferentially become synesthetic colors for each synesthete.

Keywords: grapheme–color synesthesia, Japanese kanji characters, synesthetic colors, distribution of synesthetic colors

Introduction

Synesthesia is a neurological phenomenon in which ordinary stimuli elicit vivid individual perceptions in unrelated pathways, without a corresponding physical stimulus. For example, grapheme-color synesthetes, the most common form of synesthesia, experience subjective colors upon viewing black characters. Grapheme-color pairs are consistent in individuals, with almost no change since childhood. While grapheme-color pairs are idiosyncratic between individuals. For example, when shown the letter "B", one individual may report blue, another green, and others yellow.

Previous studies have explored the several grapheme properties that affect synesthetic grapheme-color correspondence: visual shape similarity (Watson et al., 2012), ordinality (positions in a grapheme sequence) (Watson et al., 2012) and sound (Asano and Yokosawa, 2011, 2012). However, a fundamental issue has overlooked in the literature: Can any color be a synesthetic color for a synesthete? More explicitly, are synesthetic colors distributed randomly in the color space? Notably, this question cannot be answered without collecting a large amount of data for a single synesthete. Therefore, we collected a large number of synesthetic colors for Japanese kanji, hiragana, katakana, Latin letters, and Arabic numerals from each of five synesthetes. And, we explored the pattern of distribution of synesthetic colors in the color space.

Experiment

Participants

Five Japanese synesthete (three females: SH, AH and MH; two males: SO and HS; age range = 18–21 years) participated in two experiments.

Color selection experiment

Visual stimuli and Procedure

The test stimuli comprised individual black graphemes printed centrally on a white card, called the "character card" (127 mm × 89 mm). Character cards included 482 kanji, 46 hiragana (あ-ん), 46 katakana (ア-ン), 26 Latin letters (A-Z), and 10 Arabic numerals (0-9). The participant was asked to view a character card and select the color(s) that best matched their perceived synesthetic color using color chips from the *Munsell Book of Color, Matte Finish Collection*.

Color matching experiment using a CRT monitor

Visual stimuli and Procedure

For the 26 Latin letters and 10 Arabic numerals, the color coordinates (CIE L*a*b*) of each synesthetic colors were determined by a color-matching task using a CRT monitor. The participant was asked to adjust the color of the displayed reference patch so that it best matched their perceived synesthetic color of the test character.

Analysis

The distribution of synesthetic colors was investigated using spatial statistics analysis. Distribution patterns fall into three general categories: random, clustered, and uniform. We considered the distribution and the density of synesthetic colors in an a*b* chromaticity plane to be a 2D point pattern, and then explored which distribution patterns the synesthetic colors exhibited. The type of the synesthetic color's point pattern was judged by the L-function, computed from Ripley's K-function, which is defined as

$$K(r) = E(r)/\lambda. \quad (1)$$

In the K-function, which is a function of search radius r, $E(r)$ is the expected number of points within radius r of an arbitrary point. λ is the density of points (synesthetic colors per unit region), estimated by $\lambda = n/a$, with n points (synesthetic colors) in a given region a. If a point pattern is random, the K-function becomes

$$K(r) = \pi r^2. \quad (2)$$

The L-function can be computed from the K-function as

$$L(r) = \sqrt{K(r)/\pi} - r. \quad (3)$$

Using this L-function, we could classify the synesthetic color's point pattern as being one of the three types: random when $L(r) = 0$, clustered when $L(r) > 0$, or uniform when $L(r) < 0$.

Results and Discussion

We collected a total of 1229 (SH), 2349 (AH), 429 (SO), 325 (MH) and 191 (HS) synesthetic colors collected, respectively. We projected the colors to the a*b* chromaticity plane, visualizing the point pattern of synesthetic colors (Fig. 1a, c). Second, we estimated the density of the point pattern by Kernel estimation. For two synesthetes, SH and AH, over 1000 synesthetic colors were concentrated in multiple regions in the a*b* chromaticity plane (Fig. 1b, d). For the other three synesthetes, SO, MH, and HS, over 100 synesthetic colors were concentrated in original point.

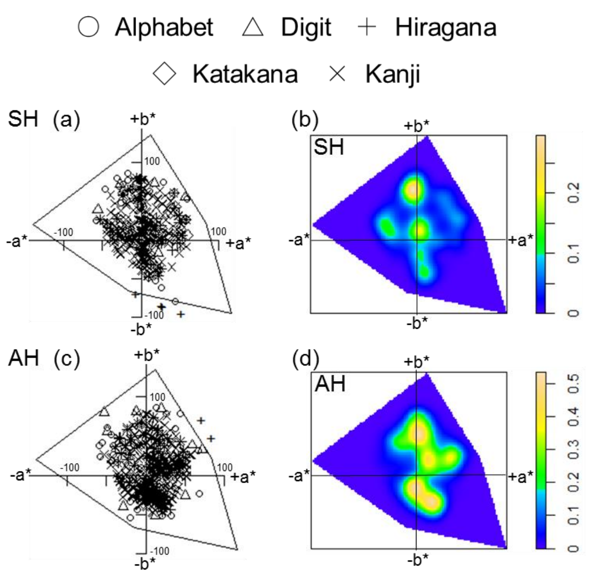

Figure 1. (a, c) The point patterns of synesthetic colors in the a*b* chromaticity plane for SH and AH. (b, d) The density plot of synesthetic colors as estimated by Kernel estimation for SH and AH. Achromatic synesthetic colors were excluded. Color bars denote density λ of the points within a specified search distance (σ = 8.46) of each point.

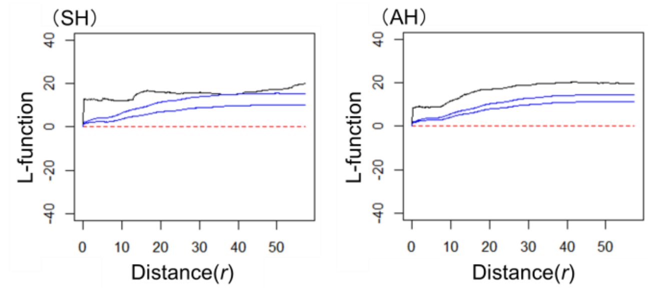

Figure 2. L-function of the point pattern for the chromatic synesthetic colors at distance r of a given point for SH and AH. The solid black line indicates the computed L-function. The interval between the two blue lines indicates the 95% confidence intervals. Specifically, many spatial point patterns (1000) randomly selected from the Munsell renotation data can be generated under CSR and Ripley's K-function estimated for each one.

Finally, to confirm these synesthetic color clusters, we analyzed the type of point pattern using the L-function. As shown in Fig. 2, the L-function returned positive values greater than the confidence intervals for SH and AH. For the other three synesthetes, similar results were obtained. This suggests that the synesthetic color distribution was neither random nor uniform. Instead, synesthetic colors formed multiple clusters in the color space, that is, they form "synesthetic color clusters". This result corroborates a previous similar finding (Yamamoto, 2009) in hiragana, Latin letters, and Arabic numerals.

The synesthetic color clusters indicate that synesthetic colors are not selected randomly from the color space, but specific colors regularly become synesthetic colors for each synesthete.

Conclusion

We obtained over 1000 or 100 synesthetic colors associated with Japanese characters for each of five synesthetes. The spatial statistical analysis revealed that synesthetic colors are concentrated in multiple regions in the color space (synesthetic color clusters). The clusters indicate that synesthetic colors are regularly decided. Therefore, clusters are important clue to investigate regularities of grapheme-color associations.

Reference

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