Consciousness and Cognition 53 (2017) 122–135

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Multilevel analysis of individual differences in regularities of grapheme–color associations in synesthesia

Daisuke Hamada*, Hiroki Yamamoto, Jun Saiki

Graduate School of Human and Environmental Studies, Kyoto University, Japan

ARTICLE INFO

Keywords:
Grapheme–color synesthesia
Individual difference
Regularity of grapheme–color association
Second-order relation
Synesthetic experience
Multilevel analysis

ABSTRACT

Grapheme–color synesthesia is a neurological phenomenon where visual perception of letters and numbers stimulates perception of a specific color. Grapheme–color correspondences have been shown to be systematically associated with grapheme properties, including visual shape difference, ordinality, and frequency. However, the contributions of grapheme factors differ across individuals. In this study, we applied multilevel analysis to test whether individual differences in regularities of grapheme–color associations could be explained by individual styles of processing grapheme properties. These processing styles are reflected by the type of synesthetic experience. Specifically, we hypothesized that processing focusing on shape differences would be associated with projector synesthetes, while processing focusing on ordinality or familiarity would be associated with associator synesthetes. The analysis revealed that ordinality and familiarity factors were expressed more strongly among associators than among projectors. This finding suggests that grapheme–color associations are partly determined by the type of synesthetic experience.

1. Introduction

Grapheme–color synesthesia is a neurological phenomenon in which visual perception of letters or numbers (graphemes) induces simultaneous perception of a given color (e.g., the letter "F" may be perceived as being green and the number "2" as red) (Cytowic & Eagleman, 2009). There are two important characteristics of this synesthetic experience: grapheme–color associations are surprisingly strong and consistent in individuals, with almost no change after childhood (Rich, Bradshaw, & Mattingley, 2005), and the color sensation is heterogeneous and idiosyncratic among individuals (Laeng, Svartdal, & Oelmann, 2004; Ward, Li, Salih, & Sagiv, 2007). For example, when shown the letter "B," one individual may report blue, another green, and others yellow. Even synesthetic monozygotic twins report different colors stimulated by the same letter (Rich et al., 2005).

What determines the associations between a grapheme and a color? There is some evidence of commonality among individuals in grapheme–color associations. English-speaking synesthetes often associate synesthetic colors with the initial letter of common color name words, such as "R" being red and "G" being green (Rich et al., 2005; Simner et al., 2005), and with phonological information, such as "I" [aɪ] being white [waɪt] (Rich et al., 2005). These aspects of synesthetic associations suggest that direct correspondences between a grapheme and its color (a first-order relation) are too elusive to guide the investigation of possible associative mechanisms. However, recent studies have begun to explore correspondences between the second-order relation of relations among graphemes and those among colors (Watson, Akins, & Enns, 2012). Brang, Rouw, Ramachandran, and Coulson (2011) showed that similarity between synesthetic colors depends on visual shape similarity in the shape of alphabetical letters. Eagleman (2010) suggested that letters early in their respective alphabets (e.g., A, B, C, D) tend to be associated with colors that are more distinct from each other,

* Corresponding author at: Graduate School of Human and Environmental Studies, Kyoto University, Yoshida, Nihonmatsu-cho, Sakyo-ku, Kyoto 606-8501, Japan.
E-mail address: hamada@cv.jinkan.kyoto-u.ac.jp (D. Hamada).

http://dx.doi.org/10.1016/j.concog.2017.05.007
Received 30 September 2016; Received in revised form 29 March 2017; Accepted 27 May 2017
Available online 27 June 2017
1053-8100/

whereas letters that come later (e.g., V, W, X, Y) tend to be associated with colors that were quite similar to each other. A similar ordinality has also been found in Japanese hiragana characters for Japanese synesthetes (Asano & Yokosawa, 2013). Beeli, Esslen, and Jäncke (2007) showed that graphemes that appear more frequently in print tend to be associated with more luminous colors. Grapheme frequency is closely related to grapheme familiarity, but these two factors differ in that familiarity is subjective whereas frequency is determined by a corpus of publications, such as newspapers. Asano and Yokosawa (2013) used subjective familiarity instead of frequency to more validly reflect the mental processing efficiencies of young Japanese children, who have not yet been exposed to published literature. Thus, in terms of the second-order relation, recent studies have shown some regularities in grapheme–color associations.

However, there are individual differences in such regularities. Watson et al. (2012) examined three second-order mappings (shape difference on hue distance, ordinality difference on hue distance, and frequency difference on luminance distance) and showed that 30% of synesthetes had positive correlations for all three mappings, 48% for two mappings, and the remaining 22% for only one mapping. Individual differences in regularities in the second-order relation relate to which grapheme properties the individual is likely to process. Which grapheme properties a synesthete processes may be reflected by the type of subjective experiences the synesthete perceives. A minority of synesthetes (11 of 100), called "projectors," perceive associated colors visually in external space, characterizing them as existing "out there on the page." In contrast, the majority of synesthetes, called "associators," perceived colors in internal space, characterizing them as existing "in my mind's eye" or "in my head" (Dixon, Smilek, & Merikle, 2004). Brang et al. (2011) showed a positive correlation between tendency toward projector characteristics and associations between shape similarity and synesthetic colors. This result was predicted based on a model for projectors in which cross-activation between graphemes and color processing areas is involved in the feature-component level of graphemes (lines, curves, etc.). This model suggests that graphemes sharing similar component features should activate more similar synesthetic colors (Brang et al., 2011).

However, this explanation does not consider associator synesthetes, who seem to rely less on low-level visual features, and more on conceptual processing of graphemes (Ramachandran & Hubbard, 2001). Differences in processing graphemes for perceiving synesthetic colors between projectors and associators depend on whether connections between graphemes and colors processing are a top–down or bottom–up pathway. Projectors subjectively experience synesthetic colors as perceptual qualia through a bottom–up process, while associators experience synesthetic colors as memory recall through a top–down process. Indeed, brain-imaging studies of projector and associator subjects have provided evidence consistent with subjective experiences of perceiving synesthetic colors. Specifically, connections between graphemes and colors in projectors involve gray matter volumes in the sensory systems (visual, auditory, and motor cortex) and the letter shape area in the fusiform gyrus. In contrast, connections between graphemes and colors in associators involve gray matter volumes in the hippocampus and the superior parietal lobe (Rouw & Scholte, 2010; Van Leeuwen, den Ouden, & Hagoort, 2011). This suggests that projectors tend to process perceptual properties of graphemes through bottom–up pathways, while associators tend to process conceptual properties of graphemes through top–down pathways. Note that differences in projector–associator status were considered as a continuum, not categorical (Rouw & Scholte, 2010; Skelton, Ludwig, & Mohr, 2009; Van Leeuwen et al., 2011). Van Leeuwen et al. (2011) showed that projector–associator difference on the questionnaire correlated with the balance in the top-down versus bottom-up changes in connectivity for synesthesia experience. Thus, individual differences in regularity of grapheme–color association could be affected by the continuous difference in graphemes processing on the axis of synesthetic experience.

In line with prior research, this study aimed at obtaining evidence for the following hypotheses: Because shape differences reflect a lower-level perceptual property of graphemes, projectors tend to show strong effects of shape difference on synesthetic colors, consistent with previous studies. In contrast, because ordinality and familiarity reflect conceptual higher-level properties of graphemes, associators tend to show strong effects of ordinality and familiarity on synesthetic colors.

To test these hypotheses, we used techniques of multilevel analyses, also known as hierarchical linear modeling or random coefficient modeling. Multilevel modeling facilitates the analysis of hierarchical data where observations may be nested within higher levels of classification (Hox, 2002; Leyland & Goldstein, 2001). The most common kind of multilevel data structure has two levels, with lower-level (level 1) data nested within higher-level (level 2) data. Level 1 scores are within-person data, and analyses of these scores provide estimates of within-person relations. Level 2 scores are between-person data, and analyses of these scores provide estimates of between-person relations (Silvia, 2007). Within-person relations vary among individuals. For example, some synesthetes are affected by ordinality, but others are not. Multilevel modeling elucidates individual differences in between-person relations by other predictors as individual characteristics. Note that multilevel analysis simultaneously estimates the effects of level 2 and level 1 variables.

Simultaneous estimation in multilevel analyses can resolve a statistical issue related to handling nested data in ordinary studies of individual differences. Ordinary regression analysis often calculates means per participant, then those means are regressed on predictors. This two-step procedure leads to information loss at the within-participant level and lowers the power of statistical tests. For example, assume an analysis of second-order relations in a sample size of 325 English alphabet letter pairs within each participant. Previous studies using multiple regressions obtained dependent variables for each letter pair by averaging across participants, which loses information regarding individual differences. This information loss leads to estimates with a large standard error, lowering estimation accuracy. This statistical issue is not resolved by the methods of previous studies. Multilevel analysis, in contrast, retains both within-participant information and the power of statistical analyses without aggregating data. Researchers can thus evaluate to what extent variance exists at the between-participant level through interclass correlation (ICC), which is often used in preliminary analyses before multilevel modeling. The ICC indicates the proportion of total variance that can be attributed to between-person differences. If the ICC shows systematic variation between participants, researchers must investigate not effects in the averaged data, but effects at the between-participant level using multilevel analysis. However, no previous studies have systematically evaluated