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Absolute pitch is not necessary for pitch class-color synesthesia

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ABSTRACT

Sounds evoke color sensations in sound-color synesthesia. Recently, we showed that pitch classes (*do*, *re*, *mi*, etc.) have rainbow hues and that colors are linked to the names of pitch classes rather than to their sounds in 15 subjects who had "pitch class-color synesthesia." However, all synesthetes in our previous study had high levels of absolute pitch (AP); therefore the effects of AP on the condition remained unclear. The present study investigated 18 additional pitch class-color synesthetes who had no or lower levels of AP, and confirmed the generality of the above findings. Furthermore, behavioral experiments indicated a two-step process underlying color sensations: pitches are first associated with their pitch class names, and then the pitch class names evoke color sensations. Two separable brain functions underlie pitch-to-color conversion in pitch class-color synesthesia: a musical function of pitch class identification, and the synesthetic association between pitch class and color.

1. Introduction

Synesthesia has traditionally been viewed as a neurological condition in which one sensation is associated with another sensation at a low, pre-attentive level of sensory processing (Ramachandran & Hubbard, 2001). However, it has become evident that cognitive-level concepts or meanings can also trigger synesthetic sensations, which is sometimes referred to as ideasthesia (van Leeuwen, Singer, & Nikolić, 2015). For example, the same visual stimulus can evoke different color sensations depending on whether it is recognized as the letter "Z" or the number "2" (Myles, Dixon, Smilek, & Merikle, 2003). Recently, we described a novel type of ideasthesia in music, in which the cognitive-level concept of pitch class is associated with colors, termed "pitch class-color synesthesia" (Itoh, Sakata, Kwee, & Nakada, 2017). The present study was conducted to further investigate this underexplored condition.

According to the helical model of musical pitch perception, the perception of pitches in music consists of two components, pitch height and pitch class, (Drobisch, 1855; Shepard, 1964). Correspondingly, we hypothesized that synesthetic color sensations associated with musical pitches also comprise two components, pitch height-color synesthesia and pitch class-color synesthesia. Pitch height-color synesthesia is essentially the well-known crossmodal correspondence between pitch and lightness/brightness. Numerous studies have shown that high and low pitches are perceived as bright/light and dark colors, respectively, not only in synesthetes but also in those without synesthesia (Hubbard, 1996; Marks, 1974, 1975; Simpson, Quinn, & Ausubel, 1956; Ward, Huckstep, & Tsakanikos, 2006). The universality of this phenomenon suggests that the crossmodal association is processed at a low, sensory level. On the other hand, pitch class is a higher-order attribute of pitch that is acquired through music training (Allen, 1967; Platt, Racine, Stark, & Weiser, 1990). Little is known about the behavioral features of and the mechanisms underlying pitch class-color synesthesia.

In an effort to investigate this issue, we identified two main findings in our original study that examined 15 pitch class-color

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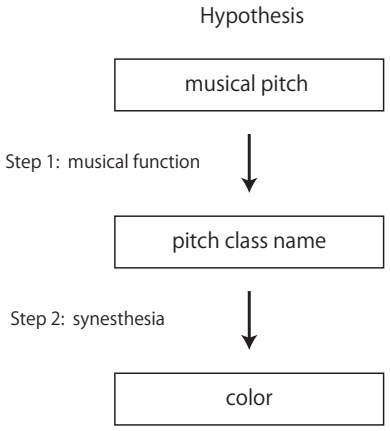

Fig. 1. A two-step hypothesis of how pitches evoke color sensations in pitch class-color synesthetes. Pitches are first identified with their pitch class names, and then the pitch class names are associated with their respective colors. The former is a general musical function, whereas the latter represents the defining feature of pitch class-color synesthesia.

synesthetes (Itoh et al., 2017). First, the color sensations were associated more strongly with the verbal labels of pitch classes (*do*, *re*, *mi*, etc.) than with the auditory sensations of pitches. Second, the seven pitch classes of the C major scale (*do*, *re*, *mi*, *fa*, *sol*, *la*, and *si*) had the hues of a rainbow. However, there was a critical limitation in our previous study: all subjects had absolute pitch (AP). AP is the ability to identify the pitch class of a musical sound without being given a reference pitch (Itoh, Suwazono, Arao, Miyazaki, & Nakada, 2005; Miyazaki, 1990; Takeuchi & Hulse, 1993). Accordingly, the present study investigated the generality of the above findings by expanding the subject group to include 18 additional pitch class-color synesthetes who had no or low levels of AP.

Another aim of this study was to clarify the mechanisms by which sounds evoke color sensations in pitch class-color synesthesia. In our previous experiment involving possessors of AP, the strong link between pitch class names and colors led to the hypothesis that a two-step process underlies color sensations evoked by pitches: first, pitches are converted to pitch class names, and then the converted pitch class name evokes color sensations (Fig. 1). The hypothesis decomposes pitch-color synesthesia into two distinct brain functions, with the first step representing general musical ability, and the second step representing the core defining feature of pitch class-color synesthesia. Here, it is important to note that pitch class identification in the first step can be accomplished not only by using AP, but also by using relative pitch, which is the musical ability to identify the pitch class of a note by identifying the interval between that note and a given reference note. In other words, the level of AP could determine the musical strategy for pitch class identification in the first step without affecting the second step of pitch class-color association. Subjects with low levels of AP provided an excellent condition for testing these predictions of the two-step hypothesis in behavioral experiments.

2. Materials and methods

2.1. Subjects

Thirty-three pitch class-color synesthetes participated in the study (18–24 years old, five males). Table 1 shows the profiles of all subjects. Fifteen participants with high levels of AP were examined in our previous study (Itoh et al., 2017), and are referred to here as the “high-AP group” ($n = 15$). These individuals were included here for the purpose of comparison. The new subjects with lower levels of AP are referred to as the “low-AP group” ($n = 18$). All participants reported that they had sensations of colors evoked by pitch classes, and the validity of their claim was confirmed by the consistency test described below. Twenty-one subjects reported having spontaneous color experiences when listening to music or musical sounds; that is, they had “colored hearing.” The other twelve had never experienced such sensations, despite their pitch class-color synesthesia. Many of our subjects experienced color sensations to other linguistic stimuli such as numbers, Japanese kana characters, alphabets, weekdays, or months (Table 1), although these were based on self-report and were not confirmed by objective tests. Possession of these forms of synesthesia did not affect the results.

All had received at least one year (though typically more) of formal music training outside of standard school education (Fig. 2). The average (± standard deviation, s.d.) number of years in training was 12.0 ± 4.0 years. All subjects were undergraduate or graduate students of the University of Niigata, Japan, and all were native speakers of Japanese.

The study was carried out in accordance with the human research guidelines of the Internal Review Board of the University of Niigata, and all subjects gave written informed consent before participating in the study.

2.2. Absolute pitch (AP) test

The AP ability of the participants was evaluated by an AP test (Itoh et al., 2005), in which the subjects named the pitch class of sixty chromatic scale notes in piano timbre covering five octaves, presented randomly in sequence with a stimulus onset asynchrony