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SHORT REPORT

Is it for real? Evaluating authenticity of musical pitch-space synesthesia

O. Linkovski · L. Akiva-Kabiri · L. Gertner · A. Henik

Abstract In spatial-sequence synesthesia, ordinal sequences are visualized in explicit spatial locations. We examined a recently documented subtype in which musical notes are represented in spatial configurations, to verify consistency and automaticity of musical pitch-space (M-S) synesthesia. An M-S synesthete performed a mapping pre-task (Exp. 1) used to indicate the locations of 7 auditory or visually presented notes, in 2 sessions a month apart. Results revealed strong correlations between sessions, suggesting the synesthete's musical forms were consistent over time. Experiment 2 assessed automaticity of M-S synesthesia. The same synesthete and matched controls preformed a spatial Stroop-like task. Participants were presented with an auditory or visual musical note and then had to reach for an asterisk (target) with a mouse cursor. The target appeared in a compatible or incompatible location (according to the synesthete's spatial representation). A compatibility effect was found for the synesthete but not for controls. The synesthete was significantly faster when the target appeared in compatible locations than in incompatible ones. Our findings show that for synesthetes, auditory and visually presented notes automatically trigger attention to specific spatial locations according to their specific M-S associations.

Keywords Synesthesia · Spatial attention · Spatial stroop · Pitch · SMARC · Music cognition

Introduction

Synesthesia, literally meaning "joined perception," is a phenomenon where stimuli from one modality (referred to as "inducer") induce an additional unusual perceptual experience (referred to as "concurrent") (Rich and Mattingley 2002). The inducer and concurrent can be in same modality (e.g., "7" induces perception of yellow) or bimodal (e.g., hearing the note B4 induces perception of blue). The associations between inducer and concurrent are automatic and consistent over time. There are several subdivisions of synesthesia; in *lower synesthesia,* a specific perceptual property of the inducer elicits the concurrent, whereas in *higher synesthesia,* the concurrent arises in response to conceptual processing of the inducer (Ramachandran and Hubbard 2001).

In 2006, Rusconi et al. introduced the spatial-musical association of response codes (SMARC) and theorized that musicians hold a vertical and a horizontal mental representation of pitch. Recently, Akiva-Kabiri et al. (2012) introduced a variation in spatial-sequence synesthesia, in which musical pitch tones constitute inducers that explicitly elicit particular spatial locations. Specifically, a diagonal cue detection task illustrated that a musical pitch-space (M-S) synesthete was unable to suppress spatial shifts in attention caused by auditorially presented musical notations.

The goals of the current research were to validate automaticity and consistency of M-S synesthesia and unveil which aspect of the inducers elicits this synesthesia.

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Fig. 1 Example of a musical note presented in the visual block

Experiment 1: pre-task mapping

Method

Participant

AB (23 years old) is a right-handed female synesthete with 12 years of formal musical training. She reports visualizing each musical tone of a given octave in a distinct spatial location, rising diagonally from lower left to upper right. She did not have absolute pitch (absolute pitch testing was adapted from Zatorre 2003).

Procedure

To corroborate the spatial arrangement of musical stimuli, AB performed an auditory and a visual mapping test. She completed both tests in two separate sessions, approximately 1 month apart. In these tests, AB either heard a musical pitch tone (auditory test) or saw a visual notation (visual test; see Fig. 1) and was asked to use a computer mouse to indicate the spatial position induced by the stimulus. Each of the 7 tones of the central C major scale was presented 10 times in each test, resulting in 140 experimental trials (70 in each modality), with X and Y coordinates of the spatial position constituting the dependent measures.

Results

The results of the spatial mappings of AB for musical notes and pitch tones can be seen in Fig. 2.

Consistency analysis

X and Y coordinates of spatial locations were averaged for every pitch tone/musical note in a given session, resulting in 4 averages—two modalities, in two sessions. All averages were transformed into vectors (X and Y coordinates of a spatial position were squared and summed, and then, a square root was taken). A Pearson correlation coefficient was calculated on vector sizes between sessions for each modality separately. Correlations were significant in both modalities; adjusted R^2 of .98 for notes ($p < .001$) and 0.99

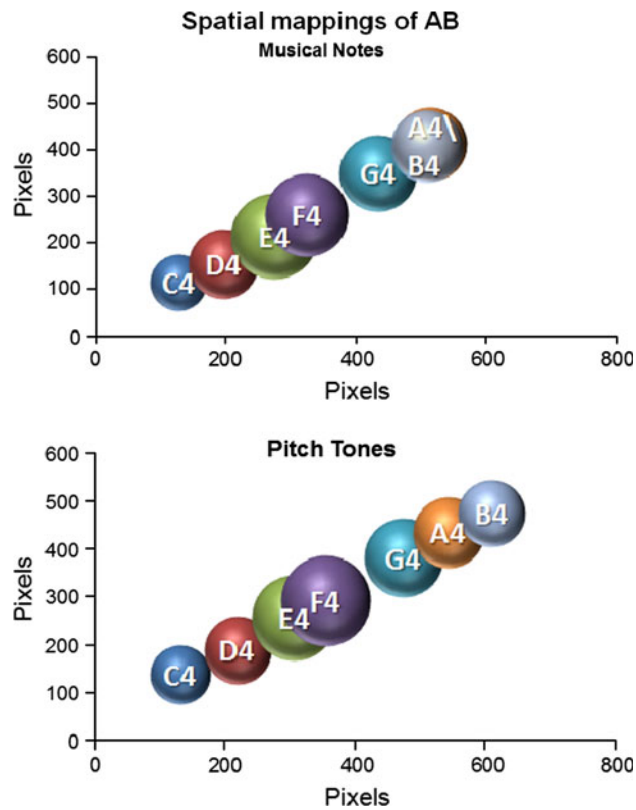

Fig. 2 AB's spatial mapping of seven musical notes and of the corresponding pitch tones. *Y* and *X axes* represent actual coordinates in pixels. *Bubble radius* was determined by averaging standard deviation of the *X* and *Y* coordinates for each note

for tones ($p < .001$). These findings indicated AB met the consistency criterion of synesthesia.

Experiment 2: automaticity

Automaticity is an important characteristic of synesthesia (Hochel and Milan 2008). Tzelgov (1997) suggested that for a process to be automatic, one must show it occurs even when not part of the task requirements. Adapting this principle to M-S synesthesia means examining whether musical pitch tones affect spatial judgments even when task irrelevant.

The current experiment was designed to address this by using a Stroop-like task. Participants were presented with auditory or visual musical stimuli that preceded or appeared simultaneously with an asterisk target. The asterisk location corresponded to the note position on the synesthetical tone form (i.e., compatible condition) or conflicted with it (i.e., incompatible condition). Varied stimulus onset asynchronies (SOAs) between stimulus onset and asterisk onset were used in order to suggest the level of the synesthetic connections: A compatibility effect at short SOAs (e.g., 300 ms or shorter; see Friesen and Kingstone 1998) would suggest synesthetic connections occurred at perceptual stages, while a compatibility effect only at long SOAs (e.g., longer than 300 ms) would suggest connections occurred at a post-perceptual stage.

We postulated the M-S synesthete would demonstrate a significant compatibility effect in both the auditory and visual tasks (i.e., slower reaction times (RT) in incompatible trials). Furthermore, we speculated this compatibility effect would be larger in the synesthete than in controls. As for the control group, the current research would enable a rigorous evaluation of the extent of the suggested (Akiva-Kabiri et al. in press) music–space connection: A significant compatibility effect would support a diagonal representation of musical notations since it would indicate that irrelevant musical stimuli affect spatial attention along a diagonal line. A null effect would imply the synesthete's tone form was different from the spatial-musical representation of non-synesthete musicians. Moreover, the current design would enable examining whether modality (auditory vs. visual) modulates music–space associations.

Method

Participants

Participants included AB, an M-S synesthete who participated in Experiment 1, and a control group of 4 undergraduate students from Ben-Gurion University of the Negev, who matched AB in musical training and age. None of the participants had absolute pitch (testing procedure was adapted from Zatorre 2003). All participants signed a consent form and received either a small monetary fee or course credits. The experiment was approved by the local ethics committee.

Procedure

The experiment consisted of two tasks using C4, E4, G4, and B4 of the C major scale as inducers. They were selected because they are relatively equally spaced across the scale. The auditory task employed pitch tones while the visual task employed musical notations (Fig. 1).

As in Experiment 1, both tasks began with 4 orienting chords of the C major scale (C-F-G-C), in order to permit the participants to recognize the subsequently presented pitch tones. A trial began with a fixation circle appearing in the lower right corner of the screen. Once a participant moved the mouse cursor to the fixation circle, a musical stimulus was presented. For the auditory task, an auditory pitch tone was presented for 150 ms, and for the visual task, a musical staff with one of the four notes (Fig. 1) was presented in the lower right corner of the screen for 150 ms. Presentation of the musical stimulus was accompanied with four empty squares (Fig. 3). The squares' locations represented the four different tone locations of the synesthete and were adjusted according to her mapping in Experiment 1. After a varied SOA (0, 250, 500, and 750 ms), a target asterisk appeared inside one of the squares.

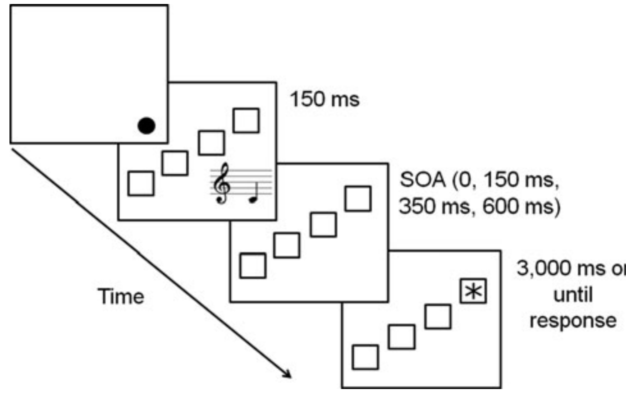

Fig. 3 Illustration of a visual trial

The asterisk could appear in a compatible location (e.g., lower-left-hand square for C4) or an incompatible location (e.g., upper-right-hand square for C4). Participants were instructed to ignore the musical tone and target the asterisk by pressing any of the mouse cursor buttons at the target location. RT was defined as the time from the target asterisk onset until the participant clicked a mouse button. A response was considered accurate only if the participant hit the target asterisk.

Each note appeared 3 times in the compatible location and 3 times in the incompatible locations for each of the four SOAs, resulting in 96 trials for each task (4 notes $\times$ 3 repetitions $\times$ 2 compatibility $\times$ 4 SOAs). Both tasks began with 12 training trials. Thus, the entire experiment had 216 trials (192 experimental + 24 training).

Results

The average error rate of the synesthete was .07 and for control group, ranged from .02 to .26. More importantly, analysis of RTs of accurate trials was conducted separately for every participant as follows: A separate mixed three-way analysis of variance (ANOVA) ($2 \times 2 \times 4$ experimental design) was applied to each of the tasks (auditory, visual) with group (synesthete, non-synesthetes) as a between-subjects variable and compatibility (compatible, incompatible) and SOA (0, 250, 500, and 750 ms) as within-subject variables. In order to compare one synesthete to several controls in a factorial design, AB completed two sessions about a month apart.

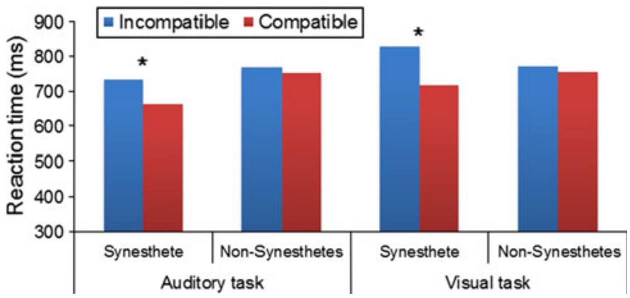

Fig. 4 Reaction times as a function of task, group, and compatibility. *Indicates a significant difference, $p < .05$

In the auditory task, a significant compatibility effect of 43 ms was found, $F(1, 4) = 12.15$, $p = .02$, meaning that participants were slower on incompatible trials compared with compatible trials. Planned comparisons of the compatibility effect in each of the groups yielded a significant effect of 70 ms for AB, $F(1, 4) = 12.05$, $p = .02$, but not for non-synesthetes, $F(1, 4) = 1.27$, *ns* (Fig. 4). A significant main effect for SOA was evident, $F(3, 12) = 16.63$, $p < .001$. No other interactions or main effects were found.

Results of the visual task were quite different. A significant three-way interaction between group, SOA, and compatibility was found, $F\ (3, 12) = 18.10$, $p = .01$ (see effect sizes in Fig. 5). In addition, 3 two-way interactions of compatibility X group, compatibility X SOA, and SOA X group were significant: $F\ (1, 4) = 10.90$, $p = .02$; $F\ (3, 12) = 11.08$, $p = .02$; and $F\ (3, 12) = 18.8$, $p = .007$, respectively. Planned comparisons revealed significant compatibility effects (160 ms and 264 ms) only for the synesthete at long SOAs (500 ms, 750 ms), $F\ (1, 4) = 8.74$, $p = .04$, and $F\ (1, 4) = 44.76$, $p = .002$, respectively.

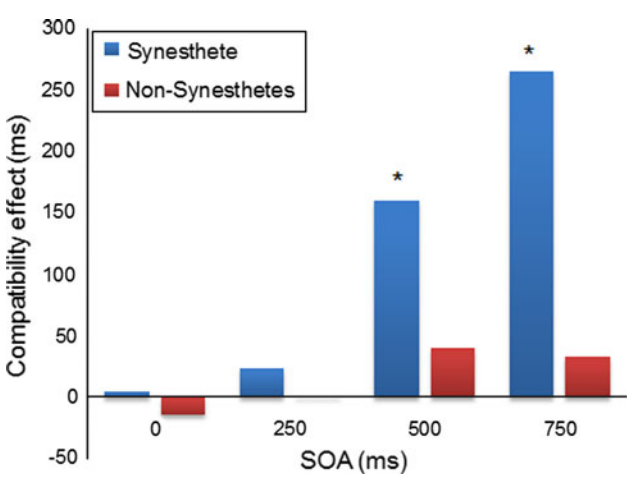

Fig. 5 Size of the compatibility effects in the visual task. *Indicates a significant difference, $p < .05$

Due to the proportion of errors, accuracy rate analysis was carried out in an identical experimental design (i.e., separate three-way ANOVAs for each task, with group and compatibility as between-subject variables and SOA as a within-subject variable). No significant differences were found in the auditory and visual tasks, indicating that differences in error rates could not account for differences in RT.

Discussion

Results validated the existence of M-S synesthesia. Incompatibility between visual or auditory tones and spatial locations increased RT in the synesthete but not in the control participants. This compatibility effect appeared at long (500 ms, 750 ms) SOAs in the visual modality and was not modulated by SOA in the auditory modality.

This pattern of results, in which similar spatial concurrents were elicited by conceptually identical inducers in different modalities, indicated the synesthete reacted to an abstract concept of the musical notation (i.e., the identity of the notation), characterizing *higher* synesthesia. Hubbard and Ramachandran (2005) theorized that synesthetic connections of such synesthetes occur at a late stage of perception. The fact that in the visual task AB exhibited compatibility effects only at long SOAs (Fig. 5) supports this aspect of *higher* synesthesia, since spatial concurrents did not influence her spatial attention when the target appeared simultaneously or shortly after musical stimuli. Further corroboration was provided by a recent study demonstrating electrophysiological differences between time–space synesthetes and a control group at post-perceptual stages (Teuscher et al. 2010).

The null effect of the non-synesthetes replicates findings of Akiva-Kabiri et al. (2012). It might be that synesthetes and non-synesthetes visualize the spatial-musical space differently, (e.g., non-synesthetes might have a vertical alignment and not a diagonal one). However, given the novelty of our automaticity task, it seems expeditious to make such a claim.

Future research should replicate current findings using larger samples and attempt to employ vertical and horizontal alignments in the automaticity task to check for the existence of SMARC-like effects. Imaging studies of M-S synesthetes are another promising line of future research since it could shed light on the involvement of areas such as the intra-parietal sulcus in spatial aspects of musical perception (see discussion in Jarick et al. 2009).

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