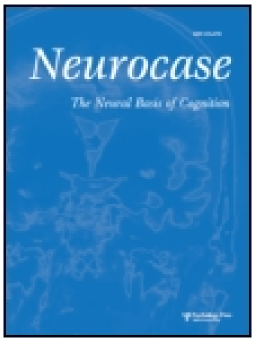

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The color of touch: A case of tactile–visual synaesthesia

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We report a single-case study, EB, who experiences synaesthetic sensations of color from tactile stimulation. Developmental synaesthesia is typically characterized by the consistency of synaesthetic pairings over time, in that stimuli tend to generate the same synaesthetic responses on different occasions. Here we demonstrate that EB's touch–color associations are significantly more consistent over time compared to a group of non-synaesthete controls, but that this comes in the face of surprisingly high consistency among non-synaesthetes themselves, for certain tactile stimuli. We show, too, that EB's touch–color correspondences are guided by an implicit rule system, and that this system is shared by non-synaesthetes. Both synaesthetes and non-synaesthetes are sensitive to tactile qualities such as smoothness and softness, and these qualities are systematically related to the luminance and chroma of associated colors.

Keywords: Synaesthesia; Cross-modality; Touch; Color; Neonatal synaesthesia hypothesis.

Synaesthesia is a condition with a genetic basis (Asher et al., 2009) which causes involuntary cross-modal experiences. Hence, for synaesthetes, input to one modality (e.g., visually reading a word) automatically and consistently triggers a vivid experience in a different modality (e.g., a taste). Synaesthesia affects at least 4.4% of the population (Simner et al., 2006) and 61 different manifestations of synaesthesia have been identified to date (Day, 2005, 2010). Each variant shares the characteristic of pairing a triggering stimulus, known as the *inducer*, with a resultant synaesthetic experience, known as the *concurrent* (e.g., Grossenbacher & Lovelace, 2001). Here we examine a variant triggered by tactile sensations against the skin, which gives rise to the synaesthetic concurrent of color.

The touch–color variant of synaesthesia is rare, even within the sphere of synaesthesia itself. There have been only a small number of touch-related synaesthesias reported in the literature. These include reports of two variants where touch is the concurrent, triggered either by sounds (Beauchamp & Ro, 2008; Ro et al., 2007) or by observing someone else being touched (known as 'mirror-touch' synaesthesia; Banissy, Kadosh, Maus, Walsh, & Ward, 2009; Blakemore, Bristow, Bird, Frith, & Ward, 2005). Additionally, Ramachandran and colleagues have reported two further cases where touch is the trigger, causing either experiences of movement and jumping (Armel & Ramachandran, 1999), or of powerful and consistent emotions (e.g., depression) which were verified by skin

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conductance responses (Ramachandran & Brang, 2009).

More relevant for the current study are reports of synaesthetes who respond to touch as an inducer, and who experience the synaesthetic sensation of color. This again is relatively rare; only 4% of the 572 synaesthete cases surveyed by Day (2005) experienced this type of synaesthesia, and there were no cases found in the largest random-sampling estimate of synaesthesia's prevalence to date (Simner et al., 2006) suggesting a prevalence of less than 0.2% in the population. As such, there are very few case-studies of touch–color synaesthesia in the peer-reviewed literature. One case, a blind synaesthete JF, reports colors when he touches Braille letters (Steven & Blakemore, 2004; Steven, Hansen, & Blakemore, 2006). However, since JF also experiences color when merely *thinking about* touching Braille, and since he does not see colors for other tactile sensations (e.g., touching objects), it is likely that his synaesthesia may be triggered by Braille-linked language processing, rather than by touch *per se*.

In the current study we report on synaesthete EB, a developmental case of touch–color synaesthesia. EB experiences colors in her mind's eye in response to tactile stimuli applied to the palms or fingers, or when she explores objects haptically. From our work with EB, it is clear that her experiences are complex. For example, when she held a palm-sized object made of plastic, wool and foam she said: 'There are many different textures here and there are colors for each texture. The smooth plastic outside part is a sort of blue-green silver grey color; it's metallic. The spongy bit is yellow, the wool is another color. For some reason, the inside of the plastic is white. That's quite clear'. The current study follows from an anecdotal description of EB in Ward, Banissy, and Jonas (2008), who described EB and one other case, TV. Although no data is reported in that study for these synaesthetes, Ward et al. provide an interesting description of their phenomenology. Both EB and TV report experiencing colors from touch, although EB is an 'associator' synaesthete (experiencing her colors in the mind's eye; Dixon, Smilek, & Merikle, 2004) while TV is a 'projector' synaesthete (experiencing his colors projected onto the touched body-part). Ward et al. also demonstrated that even non-synaesthete controls tend to show a type of cross-modal matching: in a forced choice task, they systematically paired darker colors with rougher and heavier stimuli (see later), and Ward et al. report that 'similar effects were noted in the two synaesthetic participants' (Ward et al., 2008, p. 264). In the current study we present a case-study of the touch–color synaesthete EB, and fully explore the nature of her experiences. We demonstrate the genuineness of EB's synaesthetic reports, as well as the underlying 'rules' that govern her touch–color associations. Below we briefly review the methodology for testing genuineness.

Genuineness, consistency, and the continuity hypothesis of synaesthesia

Synaesthetic reports are typically characterized by their consistency over time, in that specific inducer stimuli tend to consistently generate the same synaesthetic concurrents throughout the synaesthete's lifetime. For example, if the letter *A* is red (for any given letter–color synaesthete), it tends to be reported as red in repeated testing on several occasions over considerable time intervals (e.g., Baron-Cohen, Wyke, & Binnie, 1987). This type of consistency has been shown across a range of developmental synaesthesias and is taken as the hallmark of genuineness (e.g., letter–color, number–color, word–taste, taste–shape, sound–taste, sequence–personality, sequence–space; e.g., Beeli, Esslen, & Jancke, 2005; Sagiv, Simner, Collins, Butterworth, & Ward, 2006; Simner & Holenstein, 2007; Simner et al., 2006; Smilek, Dixon, Cudahy, & Merikle, 2002; Ward, Simner & Auyeung, 2005).

In tests of consistency, synaesthetes typically score between 80 and 100% consistent over many months, or even years (e.g., Simner & Logie, 2007). In a typical task, the consistency scores of synaesthetes are compared to those of control participants, who are asked to generate analogous pairings by free association (e.g., A = red; B = blue) and then to recall these associations by memory alone. Synaesthetes typically out-perform controls by a significant margin (e.g., Ward & Simner, 2003), even where controls have been tested over far shorter time intervals (e.g., only 2 weeks). In the current study, we establish the consistency of synaesthetic mappings in our case of touch–color synaesthesia. We shall demonstrate an inherent methodological difficulty in showing consistency in this variant of synaesthesia, due to unusually high levels of consistency in touch–color pairings in the general population. To this end, we briefly review the growing body of work suggesting that non-synaesthetes, too, experience stable cross-modal associations between the senses.

Harrison and Baron-Cohen (1997) proposed that there may be a common mechanism accounting for cross-modal associations in both synaesthetes and non-synaesthetes, which is simply more pronounced and specific in synaesthetes. In this theory, which we refer to as the *Continuity Hypothesis*, both synaesthetes and non-synaesthetes may share systematic cross-modal associations, and differ only in the extent to which these cross-modal correspondences are available for conscious inspection: for synaesthetes they are. In other words, synaesthetes are *aware* of their cross-sensations (they *see* these colors in space or in the mind's eye) while non-synaesthetes are not (they do not see colors). Related to the Continuity Hypothesis is the *Neonatal Synaesthesia Hypothesis* of e.g., Maurer and Mondloch (2005) which proposes an explanation for this similarity between synaesthetes and non-synaesthetes. The neonatal account suggests that all humans may be born with explicit, synaesthetic cross-modal perception, but that this dies out in most people throughout childhood leaving only implicit associations in the average adult. In synaesthetes, however, some type of neuro-developmental difference may lead to enduring explicit cross-modal experiences which last into, and throughout, adulthood.

Together, the continuity account and the neonatal synaesthesia hypothesis propose a link between synaesthetes and non-synaesthetes, and an especially strong link between synaesthetes and the early childhood states in all people. Several arguments support these ideas. First, a growing body of evidence shows that even the general population experience systematic cross-modal associations, at least at an implicit, intuitive level. For example, non-synaesthetes consistently describe high pitch sounds as being brighter, smaller, and higher in space than low pitch sounds (Bernstein & Edelstein, 1971; Marks, Hammeal, & Bornstein, 1987). People are also able to systematically match across other dimensions (e.g., odors to colors; letters to colors; Gilbert, Martin, & Kemp, 1996; Simner et al., 2005). A second piece of evidence for the continuity hypothesis is that synaesthetes and non-synaesthetes appear to use similar 'rules' when matching cross-modally (e.g., Cohen Kadosh & Henik, 2007; Simner et al., 2005; Ward, Huckstep, & Tsakanikos, 2006; see Simner, 2009 for review). For example, Ward et al. (2006) showed that both synaesthetes and non-synaesthetes link lighter (more luminant) colors to higher pitched sounds. In other words, both synaesthetes and non-synaesthetes match sounds and colors in the same way, and this suggests that the same cross-modal matching mechanism might exist in all people (Ward et al., 2006).

Despite these similarities, synaesthetes and non-synaesthetes also differ in several ways. First, they differ in their reported phenomenology (synaesthetes report *conscious awareness* of their colors) and also in their consistency over time. They differ too in the specificity of their color experiences (synaesthetes are more specific in their reported color choices) and in their automaticity (synaesthetes' colors are evoked more automatically). In other words, while the underlying mechanisms linking the particular choice of colors to sounds in cross-modal matching seem to be shared across synaesthetes and non-synaesthetes, the phenomenology and consistency differ across groups. Below, we show that the general population also shows implicit associations between touch and color, and that these may reflect the experiences of synaesthetes.

Ludwig and Simner (2011) showed evidence of touch–color associations in non-synaesthetes (see also Martino & Marks, 2000; Morgan, Goodson, & Jones, 1975; Ward et al., 2008). They gave their participants a series of tactile stimuli, and asked them to select a color to match these tactile sensations, from an electronic palette. Non-synaesthetes responded systematically, such that smoothness, softness and roundness positively correlated with the luminance of colors chosen, while smoothness and softness also positively correlated with the chroma of colors chosen. Ludwig and Simner also assessed how these mappings were influenced by the age of participants, by testing a population ranging from 5 to 74 years. Three of these effects (smoothness–luminance, smoothness–chroma, and softness–luminance) were age-dependent, in that they either diminished with age (smoothness–chroma, smoothness–luminance) or grew over time (softness–luminance), and one effect in particular (smoothness–chroma) was found only in the childhood population, dying out completely with age. The present study extends this literature by comparing the touch–color cross-modal mappings of non-synaesthetes found in Ludwig and Simner (2011) with those shown by the adult touch–color synaesthete, EB.

Aims of the present study

In this study we show that touch–color synaesthete, EB, shares similar types of underlying cross-modal mechanisms as non-synaesthete controls, but that she differs to controls in her phenomenological experience of those colors, and in their consistency over time. In Experiment 1 we presented synaesthete EB and a group of control participants with tactile stimuli that varied along the dimensions of smoothness (rough to smooth), softness (hard to soft), and roundness (pointed to round). Participants were required to select a color for each tactile stimulus: EB indicated her synaesthetic color, and controls generated colors by free association. We first assessed whether synaesthete EB showed the behavioral hallmark of synaesthesia in being significantly more consistent than controls in her touch–color associations over time. Next we examined whether EB showed any systematicity in her touch–color mappings. We saw above that non-synaesthetes map tactile dimensions of roughness, hardness and roundness with the visual dimensions of saturation and chroma (e.g., Ludwig & Simner, 2011) and we investigated whether EB was also sensitive to these same types of associations.

In Experiment 2 we revisit the question of consistency over time. We shall see that the choice of materials of Experiment 1 (which systematically varied tactile stimuli along three dimensions) afforded a surprisingly high degree of consistency in the touch–color mappings of *non*-synaesthetes. We shall also see that this high ceiling effectively prevents our synaesthete from performing at a significantly higher level of consistency than controls. For this reason, in Experiment 2, we again assess the consistency of our synaesthete against controls, but with a different set of materials. These materials were selected to specifically lower the ceiling of controls. With these materials we now demonstrate a significantly higher consistency in our synaesthete's touch–color associations, compared to controls, and this serves as the test of genuineness for touch–color synaesthesia. In both Experiments 1 and 2 we also assess the phenomenology of our synaesthete's color experiences, with measures of how certain, automatic and precise her colors feel. Hence the present investigation has two main goals: to show *differences* between synaesthetes and non-synaesthetes in the consistency and phenomenology of their reports, and to show *similarities* between synaesthetes and controls in the 'rules' that come to pair tactile sensations with colors.

EXPERIMENTAL INVESTIGATION

Case description

EB is a 50-year-old female who experiences touch–color synaesthesia, as well as a range of other variants (e.g., lexical–gustatory synaesthesia and sequence–space synaesthesia; see Ward & Simner, 2003 and Simner 2009 for overviews of these varieties). In EB's touch–color synaesthesia, colors are perceived in response to haptic touch via (inter alia) the fingertips, and these colors are perceived internally in the mind's eye. EB reports a family history of synaesthesia, including a sister with apparent grapheme–color synaesthesia. Her experiences date back as far as she remembers, and she first became aware that these sensations were not shared by others around the age of 6 years. EB has been described anecdotally in Ward et al. (2008), where these authors, too, suggested that EB's touch–color associations might show similarities to the touch–color associations of non-synaesthetes. However, it is not clear from that study exactly how EB's associations might reflect those of non-synaesthetes, and so the current study serves as an empirical and statistical investigation of this possibility.

Experiment 1

In this study we had three aims: (a) to show that the self-reported phenomenology of touch–color correspondences for synaesthete EB differs to controls in their automaticity, specificity, preciseness, consistency, and certainty, (b) to test whether her self-reported consistency can be captured by a standard test-of-genuineness, comparing the consistency of EB's touch–color associations to those of matched controls, and (c) to assess whether there are any underlying systematic 'rules' that dictate the particular pattern of touch–color correspondences shown by EB, and whether these mirror those found in non-synaesthetes (taken from Ludwig & Simner, 2011).

Methods

Participants. Touch–color synaesthete EB was paid £12 for participating in each of two testing sessions. EB's performance was compared to a group of non-synaesthete controls ($n = 210$, 116 female, mean age 17.29 years, $SD = 14.76$, span 5–74 years) whose touch–color data have been described previously elsewhere (Ludwig & Simner, 2011) and whose touch–color associations were elicited in a single test session. The current study will additionally analyze the phenomenological reports provided by the adults within this sample ($\geq$19 years, $n = 55$, 35 female, mean age 38.56, $SD = 14.13$, span 21–74). Ten of these adult controls were also selected to be retested in a second test session for the purposes of the current study, in order to assess the consistency of their touch–color associations over time. These 10 controls were age-matched to EB (mean age = 46.00 years, *SD* = 5.03, span 39–54, 7 female). These 10 participants received £12 for their retest session. All 210 control participants verbally confirmed they did not experience touch–color synaesthesia after being provided with written information about this condition. They were recruited and tested at the Edinburgh Science Festival, or from existing databases in the Department of Psychology. Ethical approval was obtained locally prior to testing.

Materials. Our materials comprised 18 objects, varying along three tactile scales (rough-to-smooth; hard-to-soft; pointed-to-round) with six items in each scale. These materials have been described in Ludwig and Simner (2011) and a brief description is repeated here. The materials for our *Rough–smooth gradient* were six flat surfaces (23 × 28 cm; see Figure 1, top left panel) ranging from rough to smooth. The roughness of the first five surfaces gradually decreased, as quantified by ISO grit value (P60, P120, P240, P600, P1200), and the sixth surface was entirely smooth. These ISO values denote the number of grains bonded to each inch of the surface, where a low value corresponds to a rougher surface (i.e., fewer, but bigger, grains) and a high value corresponds to a smoother surface (i.e., more, but smaller, grains). The exponential increase of ISO in our materials yields perceptually equidistant degrees of rough → smoothness (revealed by piloted studies, see Ludwig & Simner, 2011). Our *Hard–soft gradient* comprised six cubes of foam (150 × 100 × 75 cm), ranging from hard to soft, covered in black material (see Figure 1, top right panel). Estimated hardness values (provided by the supplier) in Newton for the foam stimuli were *270* (hardest; possible range: 240–300), *215* (range: 200–230), *175* (range: 155–195), *132.5* (range: 115–150), *85* (range: 70–100), and *40* (softest; range 30–50). Finally, our *Pointed–round gradient* comprised six wooden polygons (10 cm high) ranging from pointed to round (see Figure 1, bottom), which were manufactured following mathematical formulae that incrementally altered the shape from pointed to round (see Ludwig & Simner, 2011).

Procedure.

Session 1. Participants were tested individually and each felt 18 objects hidden behind a screen one by one. Participants were required to ‘choose a colour that seems to fit the way each object feels’ (see Figure 2). They were told not to guess the real color of the objects, but to pay attention to how the objects felt against the hand, and EB was told to rely on her synaesthetic colors. Instructions were given verbally by the experimenter, and repeated on screen. Participants made choices by operating a mouse with their right hand while simultaneously feeling the stimulus with their left hand (with the exception of synaesthete EB, who preferred to handle the mouse with her left hand). Participants chose colors from a color wheel shown on black background, and indicated its light- or darkness on a separate bar. A preview of the chosen color was shown on the left of the screen.

Participants began by first feeling the six extremes of each scale behind the screen (i.e., pointed, round; hard, soft; rough, smooth) so that participants could judge the relative degrees of the tactile stimuli. Objects were presented in one of 40 pseudo-randomized orders. Pseudo-randomization ensured that no more than two objects of the same type (e.g.,

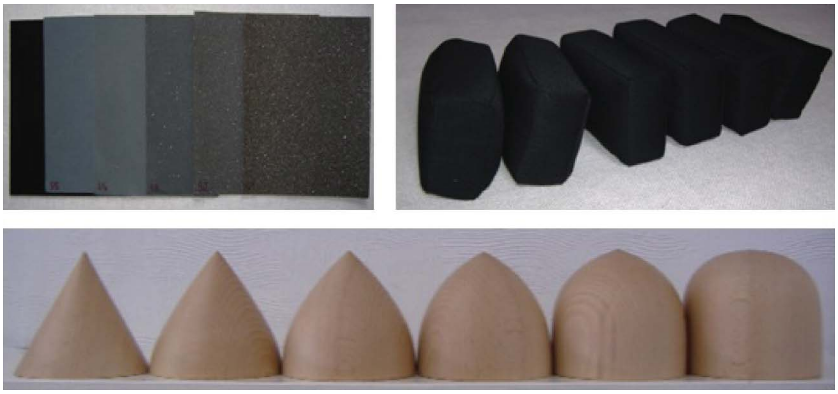

Figure 1. Stimuli used for the rough–smooth gradient (top left), for the hard–soft gradient (top right), and for the pointed–round gradient (bottom) in Experiment 1.

Figure 2. Experimental set up.

foam) were presented in succession. At the beginning of each trial the preview color switched to grey, and a 'get ready' prompt appeared for a few seconds on the screen. The experiment took 5–10 minutes to complete.

Participants were also given two forms of questioning about the phenomenology of their experiences. First, after confirming each color choice by a button press, the question 'How sure were you?' appeared for adult participants who then indicated their confidence using a slider on a continuous scale from 'very unsure' to 'very sure'. Next, after the experiment, adult participants also filled in the following on-screen questionnaire (adapted from Simner et al., 2006).

1. During the experiment, I felt I KNEW FOR CERTAIN what the color should be.
2. During the experiment, I felt I was GUESSING what the color should be.
3. Whenever I touch objects, I AUTOMATICALLY associate the touch with a particular color.
4. Whenever I touch objects, I NEVER automatically associate the touch with a particular color.
5. Touch sensations always evoke VERY PRECISE colors for me.
6. I always associate the SAME colors with certain touch sensations and they never seem to change.

Response options were 'strongly disagree', 'moderately disagree', 'mildly disagree', 'mildly agree', 'moderately agree', and 'strongly agree', and selection was made by clicking on a corresponding button.

Session 2: Consistency Test. Eleven of our participants performed a surprise retest in a second testing session, some time later. Ten non-synaesthete controls were retested after 2 weeks only ($M = 15.30$ days, $SD = 4.11$), while synaesthete EB was tested after approximately 2 months (64 days). The longer interval for synaesthete EB was chosen to test her more conservatively, and this type of conservative approach is common in synaesthetic tests of consistency (e.g., Simner et al., 2005)

Results

Phenomenology. After each color choice, participants had been asked to rate the level of their certainty in responding. Synaesthete EB reported being relatively certain about her color choices (average for all stimuli 827.56 on a scale from 0 to 1000) and this was numerically higher than the mean of non-synaesthete controls (507.00, $SD = 218.89$, $n = 55$), but this missed significance, $Z = 1.46$, $p = .14$ (two-tailed). There were 5 (out of 55) controls who reported being more confident about their choices than EB.

At the end of the test, participants also completed a questionnaire. In this questionnaire, prior research (Simner et al., 2006) shows that synaesthetes are expected to moderately or strongly agree to question 1 (i.e., feeling that they *knew for certain* what the colors should be), question 3 (i.e., *automatically* associating touch with color), question 5 (i.e., associating *precise* colors with touch sensations), and question 6 (i.e., associating always the *same* colors with certain touch sensation). Also, they were expected to moderately or strongly *dis*agree to question 2 (i.e., feeling as if they were *guessing* the color) and question 4 (i.e., never associating touch with a color). None of the non-synaesthete controls showed this pattern of responses whereas synaesthete EB did. A questionnaire score was calculated following Simner et al. (2006) in which answers on the questionnaire were coded 0–5, with the highest score corresponding to the answers typical for synaesthetes (i.e., strongly agree for questions 1, 3, 5, and 6, and strongly disagree for questions 2 and 4). The questionnaire score for synaesthete EB was 29 whereas the average score for the non-synaesthetes was only 11.94 (*SD* = 5.69, $n = 54$).[1] This difference was significant, $Z = 3.00$, $p < .01$ (two-tailed). In summary, synaesthete EB responded significantly differently to non-synaesthetes in her self-reported phenomenology of touch–color sensations, although she was not significantly more certain about her choices.

Colour choices.

Data preparation. Colour responses were initially recorded in RGB (red, green, blue) color space, and then converted into CIE L*a*b* space (a perceptually real color space in which the Euclidian distance between two points reflects their visual difference as perceived by a human observer; Tkalcic & Tasic, 2003). These locations were then coded as CIE L*C*h°, which are coordinates within the same space, where L* describes the lightness value (our first dependent variable) and C* describes the chroma of a color (our second dependent variable). Because hue (h°) is a cylindrical coordinate, it resists a meaningful comparison of means, and so was not analyzed in our study (following previous research, e.g., Ward et al., 2006). Hence our dependent variables were luminance (i.e., lightness) and chroma (i.e., saturation).

Consistency analysis. Euclidian distances between the colors chosen on the first testing occasion and the colors chosen on the second occasion for the same stimulus were calculated, and were then averaged across items (following Tkalcic & Tasic, 2003). The average test–retest color distance for EB was 50.93. The non-synaesthete control group ($n = 10$) performed worse with a mean of 59.94 (*SD* = 16.96). EB was hence 0.53 *SD*s more consistent than the average control, but this was not significant $Z = –0.53$, $p > .50$ (two-tailed). Moreover, there were two control participants who were more consistent than EB.

One possible explanation for high performing controls is that they might be selecting from a smaller set of colors than EB (by picking broadly the same color for all wooden stimuli, for example). This would make it easier for controls to recall colors in their re-test, and consequently, to perform well in the consistency test. To address this, we calculated a variability score for each participant, reflecting the average distance between color choices within each stimulus category in the first testing session.[2] The two participants who outperformed EB in consistency showed an exceptionally low variability score (38.18 and 45.34) compared to the average control ($M = 69.82$, $SD = 21.31$, $n = 10$). EB's variability score was higher (65.15). However, the lack of significance when comparing EB's consistency with controls' was not statistically driven by this: even when these two controls are excluded, EB still performs equivalently to the eight remaining controls ($Z = –0.40$, $p > .50$, two-tailed). Moreover, the variability scores of EB and the ten controls were not significantly different, $Z = –0.22$, $p > .80$, two-tailed. Hence, for these stimuli, controls were indeed equally consistent over time in their color choices, when compared to synaesthete EB. We return to this in Experiment 2.

Tactile–color mappings analysis: synaesthete EB and controls. We first ask whether synaesthete EB experienced similar touch–color associations to non-synaesthetes. Ludwig and Simner (2011) have shown that this same group of non-synaesthetes show systematic relationships across tactile and visual dimensions, in this cross-modal matching task; specifically, smoothness, softness, and roundness positively correlated with the luminance of the color associated with it, and also, smoothness and softness positively correlated with its chroma. Ludwig and Simner's data is based on a large group of ($n = 210$) non-synaesthetes, including all controls used in the current study. Given these characteristics of non-synaesthetic touch–color mapping, we now ask whether a similar type of rule-based system dictates the touch–color correspondences of synaesthete EB. Below we present six analyses of EB's touch–color associations, to mirror those found in non-synaesthetes: smoothness–luminance, softness–luminance, roundness–luminance, smoothness–chroma, softness–chroma, and roundness–chroma (the latter is not found in non-synaesthetes, but is analyzed here for completeness).

We first examined associations with the *luminance (lightness)* of colors. Recall that for non-synaesthetes, softness strongly correlated with lightness, and here we found the same pattern in the

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[1] The questionnaire data for one adult was missing due to a failure of the computer program.

[2] These scores were determined by calculating the Euclidian distances between all color choices for the rough–smooth, hard–soft, and the pointed–round stimuli on the first testing session, and averaging the outcome.

data of EB. For each increase in softness, EB's color choices increased on average by 7.96 points on the CIE Lightness scale (i.e., the value for the slope of the fitted line), and this fit accounted for 66% of the variance in these data ($p < .05$; see Figure 3, middle left). Recall also that for non-synaesthetes,

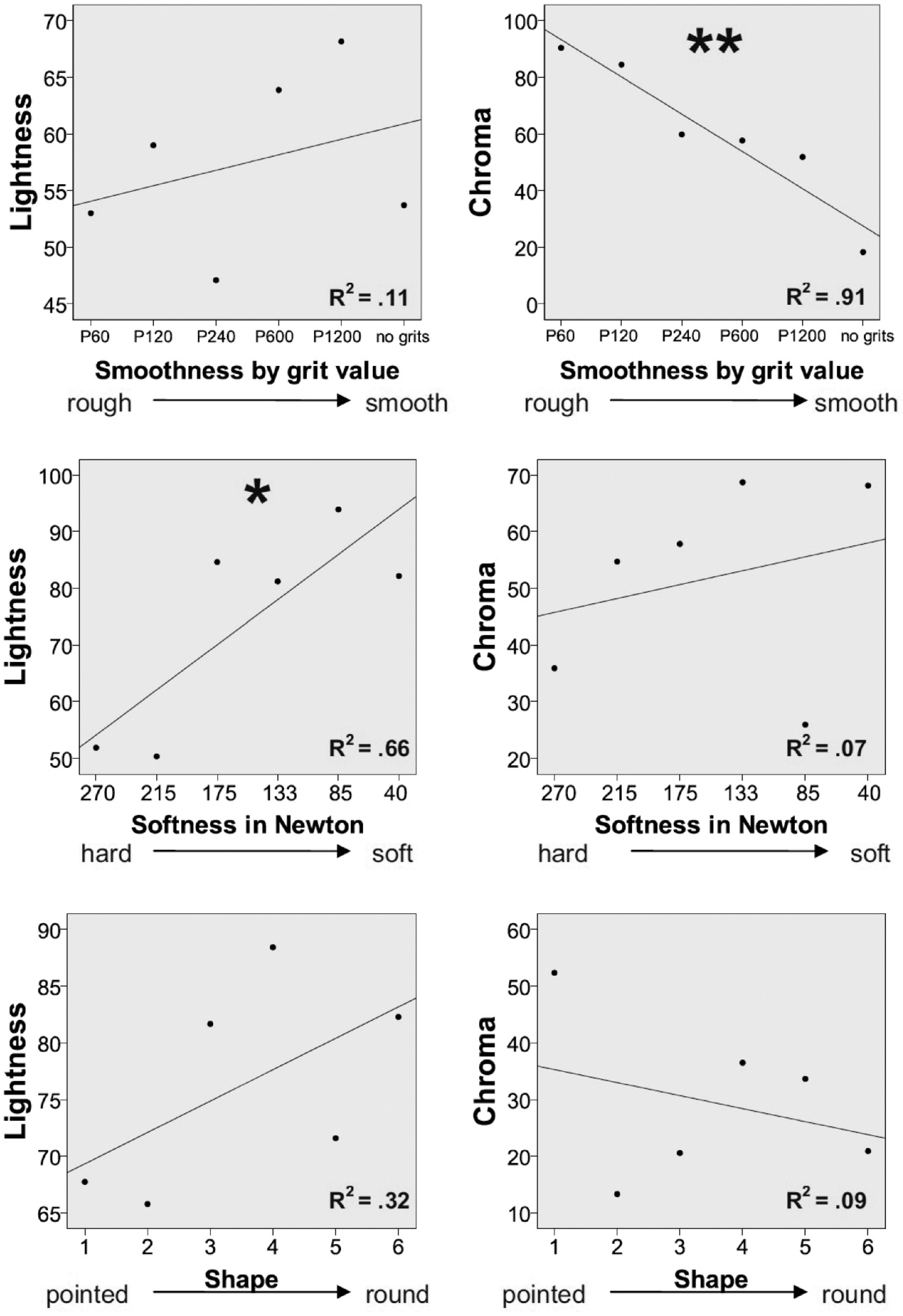

Figure 3. (Experiment 1) Effects of smoothness (top), softness (middle), and roundness (bottom) on CIE lightness (left) and CIE chroma (right) of EB's choices in Experiment 1. Each dot represents the lightness/chroma value of EB's colour choice for one particular stimulus on the first testing occasion. In the analysis, tactile scales (e.g., 270 Newton, 215 Newton) were coded with values from 1–6. To compare, in non-synaesthetes, softness, smoothness, and roundness positively correlated with luminance, and softness and smoothness also correlated with chroma (Ludwig & Simner, 2010). *$p < .05$; **$p < .01$ (two-tailed).

smoothness was correlated with lightness, but here, EB showed no significant effect (Figure 3, top left, $p > .50$). Recall finally that non-synaesthetes also chose lighter colors for rounder stimuli, and a trend in this direction was also seen for EB with a relatively high $R^2 = .32$ (Figure 3, bottom left) but this was not significant, $p = .24$.

Next we examined associations with the ***chroma (saturation)*** of colors. Recall that for non-synaesthetes, both smoothness and softness corresponded to higher chroma (Ludwig & Simner, 2011). EB too showed a significant effect in the rough–smooth scale, but it was in the opposite direction to non-synaesthetes. That is, EB chose colors with significantly *lower* chroma as smoothness increased (slope of the fitted line: –13.15, $R^2 = .91$, $p < .01$, Figure 3 top right). For the hard–soft scale and for the pointed–round scale, EB showed no trends for an association with chroma (see Figure 3, middle right, and bottom right, both p's $> .50$).

Discussion

Our touch–color synaesthete EB responded differently to controls in questions exploring the phenomenology of touch–color associations. She scored higher on a synaesthesia questionnaire in which high scores indicate more synaesthetic-like phenomenology, and in this respect, EB's self-report suggests she is experiencing the colors with more automaticity, precision, consistency and specificity than non-synaesthete controls. However, although EB also reported being fairly certain about the specific color choices in this study, she did not differ significantly from non-synaesthete controls in this measure. Moreover, in our test of consistency, EB was no more consistent than non-synaesthetes over time, although she was among the highest performing participants.

In our analyses exploring the types of colors selected for each tactile scale, EB showed sensitivity to the same types of tactile and visual qualities as our non-synaesthete controls. Both EB and controls had non-random pairings, and both generated touch–color associations that were mediated by systematic mappings between smoothness and chroma on the one hand, and softness and luminance on the other. In particular, we found, first, that EB's associations positively correlate softness and luminance (i.e., she pairs softer objects with lighter colors), and exactly this effect has been found also in non-synaesthetes (Ludwig & Simner, 2011).

We also found that EB's associations negatively correlate smoothness and chroma (i.e., she pairs more saturated colors with rougher stimuli) and there are two important observations to make about how this mirrors the patterns found in non-synaesthetes. First, a pairing between smoothness and chroma is also found in the general population, although it is particularly interesting that this one effect in non-synaesthetes is found only in children (i.e., it dies out in non-synaesthete adults; Ludwig & Simner, 2011). The fact that EB appears to mirror *earlier states* of normal cross-modal development in non-synaesthetes provides intriguing support for a continuity account of synaesthesia, and for the related neonatal synaesthesia account. Second, we point out that the *direction* of EB's cross-modal effects is also of particular interest. EB's smoothness–chroma effect was the mirror-image of the effect found in controls: EB chose colors with *higher* chroma as roughness increased. We return to this fact in the general discussion.

Experiment 2

In other variants of synaesthesia, standard tests of consistency have shown that synaesthetes are significantly more consistent in their synaesthetic inducer–concurrent pairings when tested over time, compared to non-synaesthete controls. In Experiment 1, we were unable to demonstrate this type of consistency to a significant degree for EB. Although EB was relatively consistent, and one of the most consistent participants tested, our control group of non-synaesthetes also showed a surprisingly high level of consistency themselves. This raised ceiling effectively prevented EB from performing significantly higher. We believe there were three specific causes for the high consistency in our control data: first, the relatively small number of stimuli (18 stimuli, in just three categories) might have allowed participants to more easily recall their color associations from the first testing session, when performing the re-test 2 weeks later. Second, a *post-hoc* analysis revealed that participants had sometimes chosen real-world color associations (e.g., shades of brown for our 6 stimuli made out of wood). Even though controls' color responses were equally variable to those of EB (see Experiment 1), in some cases, such real-world association might have led to high consistency over time for controls. Third, we know from Ludwig and Simner (2011) that non-synaesthetes themselves make relatively consistent touch–color associations based on rules linking hardness, softness, and roundness with the visual dimensions of chroma and saturation. Given these considerations, our synaesthete may have been unable to clearly distinguish herself from controls *with the stimuli of Experiment 1*, because they are precisely the type of stimuli to trigger relatively consistent touch–color associations, even in non-synaesthetes.

Since we consider it a necessary requirement to show that our synaesthete EB is indeed a synaesthete by some objective measure, we return to this issue of consistency in Experiment 2. Here, we aim to address the problems that arose in study 1 by eliciting EB's synaesthetic colors to a new set of stimuli. These new items were designed to be more perceptually complex in their tactile properties, and so they no longer varied consistently along a small number of dimensions. Furthermore, these novel stimuli had no obvious real-world color associations. With these revised materials we anticipate that the test–retest consistency of our controls will be comparatively low, but that the consistency of our synaesthete will remain high.

Methods

Participants. We tested touch–color synaesthete EB, and 30 new non-synaesthete participants (20 females) recruited from the University of Edinburgh community, aged between 18 and 26 ($M = 20.60$, $SD = 1.54$). The participants were tested individually and all control participants first confirmed that they were not touch–color synaesthetes after reading an informative page about synaesthesia. Participants were paid £12 for participation in each of two testing sessions.

Materials. Our materials comprised 30 palm-sized objects made from a mixture of plastics, wood, thread, metal and stone. These 30 items had been selected from an original cohort of $n = 90$, via a norming procedure. During norming, a group of non-synaesthete research assistants ($n = 7$; aged 20–22 years) haptically explored each object one by one, out of sight behind a small screen, and then rated each object on a scale from 1 to 10 for how strongly it was associated with a real world color, and for how confidently they could identify it. We selected the 30 most suitable objects as those with the lowest real-world color association, and lowest likelihood of being identified. Seventeen of these objects were of an abstract design with no real-world context or use (for example, a cardboard tube encircled by elasticated bands; see Figure 4, left). The remaining 13 objects were household items of different shapes, sizes (approximately 1–30 cm) and textures (for example, a soft rubber children's toy, see Figure 4, right).

Figure 4. Example stimuli (out of 30) selected after norming for use in Experiment 2.

Procedure. The procedure was identical to that of Experiment 1, with the following exceptions. Participants now gave color associations for 30 items, and there was no questionnaire component (i.e., they were not required to describe the phenomenology of their color experiences in self-report) although participants again gave certainty ratings for each color choice. Participants were then given a surprise retest of their colors after 16 days for non-synaesthetes ($M = 16.44$, $SD = 1.80$) and approximately 4 months (110 days) for EB. In the retest, the same items were presented but were randomized per subject.

Results

Phenomenology. After each color choice, participants rated the level of their certainty in responding, and synaesthete EB reported being more certain about her color choices (893.80 on a scale from 0 to 1000) compared to the non-synaesthete controls (402.40, $SD = 52.84$, $n = 30$), and this difference was highly significant, $Z = 9.3$, $p < .001$ (two-tailed).

Colour choices. Data were again prepared for a consistency analysis as described in Experiment 1 by calculating Euclidian distances between the colors chosen on the first testing occasion and the colors chosen on the second occasion. The data for three stimuli (3, 20, and 21) were excluded for all participants due to technical problems during the procedure. The average test–retest color distance for EB was 60.86. The control group ($n = 30$) performed worse with a mean of 77.43 ($SD = 6.34$) and this difference was significant ($Z = -2.61$, $p < .01$, two-tailed).

Discussion

In this study we aimed to show that EB was significantly more consistent in her touch–color associations than a group of non-synaesthete controls, by providing materials that were more difficult for non-synaesthetes to systematically color in free associations. These materials were difficult to identify and had no obvious real-world colors (unlike the materials of Experiment 1). With our revised approach, we were now able to show that the consistency score of EB remained high, while those of non-synaesthetes were significantly lower. Furthermore, we again elicited self-report scores of how certain participants were about their color selection, now that stimuli were perceptually more complex and had no obvious real-world colors. Synaesthete EB's scores were even higher than those from Experiment 1. In contrast, the certainty ratings from controls fell dramatically and were significantly lower than those of EB. We discuss the interpretation of these findings below.

GENERAL DISCUSSION

We have introduced a detailed case study of a rare form of tactile–visual synaesthesia. For our participant, EB, tactile stimulation triggers the sensation of colors, and we assessed both the nature of these experiences and their underlying roots. We examined the phenomenology in self-report, as well as the consistency of colors over time, and of how specific colors come to be associated with specific tactile sensations.

In self-reported phenomenology in Experiment 1, we found that the reports of our synaesthete, EB, differed from non-synaesthete controls in our synaesthesia questionnaire (adapted from Simner et al., 2006). EB reported that her touch–color associations felt more certain, more automatic, were more specific in their detail, and felt more consistent over time than the touch–color associations generated by non-synaesthetes. We next sought to empirically validate the consistency of EB's touch–color associations. Research on synaesthesia typically reveals that synaesthetes are highly consistent over time, and this is often taken as a confirmation of the genuineness of the case (e.g., Rich, Bradshaw, & Mattingley, 2005; Simner et al., 2006; Simner & Logie, 2008). We elicited the synaesthetic colors from EB on two occasions, and compared their consistency to a group of non-synaesthete controls, who were required to make color associations to the same stimuli, based on intuition alone. We found that although EB was relatively consistent, she was not significantly more consistent than controls. We speculated three reasons, and subsequently tested this in a second study. We saw that our controls had themselves been relatively consistent in their touch–color associations for Experiment 1 items, which represented systematic changes along tactile dimensions (smoothness, softness, roundness) and which were made with relatively easily identified materials (e.g., wood). Since controls are themselves known to make systematic associations of color to this type of stimuli (Ludwig & Simner, 2011) we speculated that this may have given rise to a relatively high ceiling in control consistency against which to compare our synaesthete. Moreover, a *post-hoc* assessment of our controls' responses showed that they had made real-world associations between the fabric of our materials in some cases (e.g., wood-brown) and that this had further facilitated their consistent responding over time. In Experiment 2, we created materials that were more perceptually complex, were not easily identifiable, and which had no obvious real-world colors. We found that the consistency of touch–color associations of our controls fell in this study (by 17.5 points on our distance scale) but that our synaesthete was less affected (falling only 9.9 points), and she was now significantly more consistent than controls. Moreover, the confidence of controls in their touch–color pairings fell in Experiment 2 when stimuli were difficult to identify and had no obvious real-world colors (falling by 132 points on our confidence scale compared to Experiment 1), while the confidence of our synaesthete actually increased (by 66 points). Together, our data demonstrate that this variant of synaesthesia can be shown to be consistent over time, but that certain methodological considerations are required in conducting this type of research. We offer this methodological finding for any researcher who has failed to find a consistency difference between their own synaesthete case and non-synaesthete controls. Our findings suggest that differences may indeed be there, but that careful construction of materials may be required to reveal them.

Finally, we have shown that tactile sensations come to be associated to colors in non-random ways, and in ways that reflect, to some extent the intuitive cross-modal correspondences generated by non-synaesthetes. This type of prediction is inherent in what we have described as the continuity hypothesis (e.g., Harrison & Baron-Cohen, 1997). This states that synaesthetes and non-synaesthetes might occupy opposite ends of a shared continuum of cross-modal experience, with synaesthetes experiencing consciously what non-synaesthetes feel only intuitively. Ludwig and Simner (2011) showed that non-synaesthetes share intuitive cross-modal mappings across touch and color, and that these associations match smoother, softer and rounder objects to more luminant colors, and smoother and softer objects to more saturated colors (see also Ward et al., 2008). In a similar way, we found that the touch–color mappings of our synaesthete EB were also non-random, and that they patterned like the touch–color mappings of non-synaesthete controls in two ways. Firstly, EB significantly mapped softer objects to more luminant colors, and the same significant correlation is found in non-synaesthetes. Secondly, EB mapped qualities of rough–smoothness to qualities of chroma. Interestingly, this latter type of association is found only within non-synaesthetes when they are children (Ludwig & Simner, 2011). In other words, the adult state of touch–color synaesthete EB is closely tied to the childhood state of non-synaesthetes, and this type of relationship is predicted by the neonatal synaesthesia hypothesis (e.g., Maurer & Mondloch, 2005), which suggests that adult synaesthesia is a remnant of normal childhood states.

For smoothness–chroma mapping, EB's associations were in the opposite direction to those of controls (EB mapped more saturated colors to rougher rather than smoother surfaces). In this way, EB appears to rely on broadly the same types of underlying rules as non-synaesthetes, although the directionality of effects may differ. Importantly, this type of fluidity also appears within groups of non-synaesthetes. Marks (1974) explored the cross-modal correspondences between vision and audition in non-synaesthetes, and found a similar type of alternating directionality. Marks showed a systematic relationship between the visual dimension of brightness and the auditory dimension of loudness, but noted that some (non-synaesthete) adults match increasing loudness to increasing lightness, whereas others systematically match it to increasing darkness. Moreover, Marks found that some participants changed the direction of their mapping over time (Marks, 1974). In other words, there is a dissociation between whether two dimensions come to be associated in cross-modal mapping at all, and the directionality with which those dimensions associate: across synaesthetes and non-synaesthetes, and within non-synaesthetes alone, the direction of mapping can be relatively fluid.

Finally, we point out that EB also showed a non-significant numerical trend towards mapping smoother objects to lighter colors, an effect found also in non-synaesthetes, and one that Ward et al. (2008) suggested might also be found in EB. Our study here showed that this slight numerical trend did not hold up to statistical scrutiny. It is not clear whether more linear data was generated by EB when tested by Ward and colleagues (and they do not report statistics), although it is possible that minor variations over time in EB's color concurrents might sometimes afford her a stronger matching between smoothness and luminance on different testing dates. Alternatively, it may be that these particular dimensions are not, for synaesthete EB, systematically paired in any way. If so, this might have interesting consequences for the neonatal synaesthesia hypothesis, since, while one touch–color pairing (smoothness–chroma) remains stable in EB, as it appears in non-synaesthete children, another touch–color pairing (smoothness–luminance) appears to have followed a similar developmental trajectory as older controls, and diminished. Ludwig and Simner (2011) found that smoothness-luminance mappings exist in non-synaesthete adults, but that they decline with age, and our participant EB is indeed at an age (50 years) when associations may start to show declined. In other words, it is possible that EB had either explicit or implicit associations between smoothness and luminance which declined by the same mechanisms inherent in the neonatal hypothesis. With this proposal, the current paper provides the first application of the neonatal hypothesis not simply to the age-related loss of synaesthesia between infancy and adulthood in non-synaesthetes (e.g., Maurer & Mondloch, 2005) but also to the loss of synaesthesia in older synaesthetes (see Ludwig & Simner, 2011 for related arguments).

To conclude, the present study has demonstrated a novel variant of touch–color synaesthesia, which reflects certain correspondences between the senses of touch and vision in all people. Future research into the mechanisms underlying this phenomenon might reveal greater knowledge about the breadth of synaesthetic experiences, as well as informing us about the development of cross-modal perception in the population at large.

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