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A case of color–taste synesthesia

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This is a report on a case of color–taste synesthesia exhibited by an artist painter. This case is unique in that it is not common for color to appear as an inducer or taste as a concurrent. A comprehensive description of this particular case of synesthesia is provided first. The application and results of consistency, psychophysical, and Stroop tests are presented later. Finally, the difficulties encountered with the application of such tests are discussed.

Keywords: Synesthesia; Taste; Color; Art; Stroop.

According to a recent definition, 'synesthesia is a hereditary condition in which a triggering stimulus evokes the automatic, involuntary, affect-laden, and conscious perception of a physical or conceptual property that differs from that of the trigger' (Cytowic & Eagleman, 2009, p. 112). Synesthetic experience is characterizable as a perceptual experience whereby the subject upon perceiving a certain stimulus, e.g., a grapheme (the inducer), has an additional experience in the same or in another perceptual system, e.g., a color or a sound (the concurrent) (Grossenbacher, 1997; Grossenbacher & Lovelace, 2001). So far, there have been 52 types of synesthesia identified (Cytowic & Eagleman, 2009), such as grapheme–color, sound–color, sound–movement, etc. An inducer can also produce a concurrent in more than one perceptual system, e.g., a grapheme can produce the perceptual experience of color and taste. In addition, a type of synesthesia can be bidirectional where, for example, sounds produce synesthetic colors and the perception of colors produce synesthetic sounds. Finally, according to some recent estimates (Simner et al., 2005, 2006) it may be that 1 in 23 people have some form of synesthesia which, if true, would make it a rather prevalent cognitive trait.

This is a report on a case of color–taste synesthesia where color is the inducer and taste is the concurrent. A review of the literature concerning cases of synesthesia involving taste (Ward & Simner, 2003) has shown that taste has featured primarily as an inducer and color as the concurrent. Synesthetic cases where smell and taste are either the trigger or the synesthetic response are not encountered often (Cytowic, 1995). As far as we know, the case reported here is the first detailed case report of this type of synesthesia. Its uniqueness also lies in that color rarely appears as an inducer.

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Additionally, it may contribute to the attempt to find the most appropriate explanation for the mechanism of synesthesia. According to one prominent explanation, synesthesia involves cross-wiring among adjacent neurological areas (Hubbard & Ramachandran, 2005); however, the areas involved in this particular type of synesthesia are spatially distant (Marks & Odgaard, 2005; Ward, Simner, & Auyeung, 2005). We need to discover connections among such areas or we have to find support for any of the alternative explanations that have been offered (Mulvenna & Walsh, 2006).

Our synesthetic subject, TK, is a 72-year-old right-handed male, who is an artist-painter, printmaker, and art teacher.[1,2] His unidirectional synesthesia involves three of the four basic tastes: greens produce bitterness, reds produce sweetness, and yellows produce sourness.[3] No color produces saltiness and colors that do not produce any taste quality are regarded as neutral tasting.[4] No complex synesthetic tastes were present, thus giving support to the claim (Cytowic, 2002) that synesthetic percepts are usually generic and unelaborated.

Our subject seems to have become vividly aware that colors had a 'taste' when he started working systematically with pigments upon entering art school in his early twenties. He does not remember having synesthetic experiences before this period even though he has been painting since childhood.[5] He experiences tastes synestheticaly, mainly when painting and when looking at works of art, but also from perceiving the colors of his surroundings, e.g., the color of trees. The intensity of the synesthetic taste varies with the purity, amount, and intensity of the perceived hues. During his years as an art teacher, while others regarded his descriptions of the taste of colors as metaphorical, he took them to be literally true. He insists that the synesthetic taste involved is a real, and not an imagined, sensation. He did not think, like most other synesthetes, that he was unusual until we started to inquire about his experiences.

TK's synesthetic experiences have a significant aesthetic dimension since they are used for evaluating the aesthetic worth of paintings. A painting is judged in terms of its overall 'taste'. For example, a painting with too many reds will be considered to be 'too sweet' and he will try to make it more neutral tasting, and hence more aesthetically balanced, by changing its colors. A painting is considered aesthetically successful when a balance in its 'taste' has been achieved with the appropriate colors. Besides the hues, additional factors determining the overall taste of a painting, and hence its aesthetic value, are the saturation and brightness of the colors as well as their spatial extent on the canvas, i.e., the larger the area covered by a color, the more intense the synesthetic taste produced. The greater the saturation, brightness, and spatiality of the pigments used, the more difficult it becomes to balance the overall 'taste' of a painting. Our subject believes that his condition has given him an added cognitive advantage, a claim that it is often made by synesthetes (Rich, Bradshaw, & Mattingley, 2005), since he has another means by which he can judge the arrangement of colors in a painting and hence the painting's aesthetic success.[6] For TK a good painting is, chromatically speaking, like a well-prepared meal; its ingredients have to be properly balanced.

When our subject was asked to describe his synesthetic experience, he claimed that the taste was experienced on his tongue but that its phenomenology differed from ordinary experiences of taste at least in one respect, that it was not as strong as the taste produced by food. Although the color of the food initially produces a synesthetic taste, it is subdued by the taste of the consumed food. He cannot determine whether anyone of his parents had similar experiences but he describes his mother as someone who had a great sense of color. He reports that he does not have synesthetic tastes

[1] The initial profile of TK was constructed from various interviews and the questionnaire (a brief description of the questionnaire is provided in footnote 9).

[2] It has been pointed out that it is not uncommon for synesthetes to be involved with the arts (Ramachandran & Hubbard, 2001; Rich, Bradshaw, & Mattingley, 2005).

[3] The unami taste was ignored by TK and the controls and, as a result, it was not included in the tests.

[4] This feature exhibited by TK is common among the general population of synesthetes. One may have a synesthetic response to some but not all the members of the set that induce a synesthetic reaction (Cytowic, 2002, p. 36).

[5] According to reports, there are synesthetes whose trait was not present in childhood but was acquired later in life (Blake, Palmeri, Marois, & Kim, 2005), especially during adolescence, which is taken to suggest the influence of hormonal changes (Cytowic, 2002). Additionally, if learning plays 'a prominent role in any theory of synesthesia' (Marks & Orgaard, 2005, p. 231) and synesthesia is conceptually and linguistically mediated (Simner, 2006; Ward & Simner, 2003), then given the fact that inducers are normally cultural artifacts, e.g., graphemes, it is possible that synesthesia develops slowly over a period of years as the subject interacts with them. All these factors could explain the late onset of TK's synesthesia.

[6] This is similar to the composer F. Liszt who would ask for more blue color in the performance of a piece (Day, 2005).

when forming mental images of colors or when dreaming.

The phenomenology of TK's experience is similar to a reported case of musical tone intervals–taste synesthesia which also involved simple and generic tastes (Beeli, Esslen, & Jäncke, 2005). This differs from other reported cases of synesthesia that have taste as a concurrent and sounds and words as inducers (Cytowic, 2002; Luria, 1987; Ward & Simner, 2003; Ward et al., 2005). These cases involve complex tastes such as the ones produced by the consumption of a meal. However, in some cases of lexical–gustatory synesthesia foreign words and non-words produce generic tastes (Ward et al., 2005). The phenomenological location of the synesthetic taste of TK is on the tongue. This is also encountered in the case of lexical–gustatory synesthesia studied by Ward and Simner (2003).

METHODS

The Consistency test

Initially we had a videotaped interview of our subject in his studio where he spoke to us about his condition and demonstrated the applications of his synesthesia in relation to his paintings. Subsequently a questionnaire, similar to the one used in another study (Rich et al., 2005), was answered by him.[7] A modified version of it was answered by the control group, which was made up by 5 male painters between the ages of 65–76. The questionnaire did not reveal any unusual characteristics.

We used the Farnsworth-Munsell 100 Hues Test and TK was found to have normal vision. He complained about the hues since he found them to be without intensity and unnatural. In order to show the authenticity of the synesthetic experience we used the method that has been deployed in other studies by which the consistency of responses of the synesthete is established in comparison to non-synesthetes (Baron-Cohen, Wyke, & Binnie, 1987; Harrison, 2001). We devised a preliminary computerized color test[8] in order to validate self-reports of synesthesia by asking for taste-matching judgments on two separate occasions. We asked TK and the controls to match colored squares presented on a computer screen with four generic tastes: bitter, sweet, sour, and salt. The neutral taste was the fifth taste that could be used when the subject did not have any particular taste associated with a color. Each subject was retested 6 months after the date of the first test. The complete dataset resulting from this classification is presented in the Appendix A.

By a rough classification of color stimuli into major categories (red, green, blue, yellow, BW/grey), we found that TK classified the 13 red stimuli primarily as sweet (7 in both sessions), the 11 green stimuli primarily as bitter (5 in the first session and 6 in the second), and the 11 blue stimuli primarily as neutral (10 in both). The 6 yellow and 4 gray/black/white stimuli were classified primarily as neutral in the first session (3 of each) and as sweet in the second session (3 of each).

The responses of control participants were different, in that some were consistent but used more taste options (C1, C2, C4) whereas others were less consistent (C3, C5).[9] Tables 1 and 2 show the number of taste responses (N) for the 45-color

[7] The questionnaire contained four types of questions presented in four sections. The first section was concerned with biographical data such as age, birth date, occupation, etc. The second section contained questions pertaining to the experience of taste synesthesia, e.g., the triggers of the synesthesia, whether there are conditions under which the synesthesia becomes more intense, the way TK evaluated and used such experiences, questions pertaining to family members and synesthesia, etc. The third section raised questions about medical history, e.g., whether there had been any incidents of brain damage, depression, epilepsy, migraines, etc. The fourth section contained questions pertaining to personal characteristics such as the performance of skills, the ability to have premonitory and *déjà vu* experiences, etc. The second section was not answered by the controls.

[8] For the consistency and Stroop tests, we used experiment control software DMDX (Forster & Forster, 2003) version 3.1.2.3. Experiments were carried out on a laptop PC with a 17-inch screen, running Windows XP. For the Consistency test we used 45 colored squares each having 20 cm width and 20 cm height from the RGB color palette.

[9] Specifically, C1 rated red stimuli primarily as sweet (10 in the first session and 7 in the second), green as bitter (5, 6), blue as neutral (7, 8) yellow as sour (5, 4), and grey as neutral (3, 2). C2 rated red as sweet (11, 9), green as bitter (6, 6), blue as neutral (4/tied with sour, 6), and grey as salty (2, 3). C4 rated red as sweet (8, 10), green as sour (8, 7), blue as salty (4, 7), yellow as sour (5, 3), and grey as bitter (3, 2/tied with neutral). As for the less consistent respondents, C3 rated red as sweet in the first session (6) but neutral in the second (9), green as bitter (4) or neutral (4) in the first session but sour (4) or neutral (5) in the second, blue as neutral in both sessions (4, 9), yellow as sour in both sessions (4 each), and grey as neutral in both (2, 3). C5 rated red as neutral in the first session (5) but sweet in the second (7), green evenly divided among sweet, sour, salty and neutral in the first session but primarily sour in the second (7), blue as sweet in the first session (4) but sour (5) or salty (4) in the second, yellow as sour (2) or neutral (3) in the first session but sweet (2) or sour (3) in the second, and grey as neutral in both sessions (4, 3).

TABLE 1
Consistency of taste responses to color stimuli over two sessions for TK and 5 control subjects

		All responses			*Excluding neutral*		
ID	*N*	*C*	*I*	*P*	*C*	*I*	*P*
TK	43	31	12	72.1	14	1	93.3
C1	44	25	19	56.8	18	7	72.0
C2	41	30	11	73.2	27	4	87.1
C3	34	18	16	52.9	7	5	58.3
C4	45	26	19	57.8	25	9	73.5
C5	36	10	26	27.8	5	13	27.8

N, number of taste responses; C, number of consistent responses; I, number of inconsistent responses; P, consistency percentage (%).

TABLE 2
Consistency across sessions per taste response for TK (left) and C2 (right)

	TK: Session 1					*C2: Session 1*				
Session 2	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1 Sweet	6	0	0	0	1	13	0	0	0	2
2 Bitter	1	7	0	0	1	0	5	1	1	0
3 Sour	0	0	1	0	0	1	1	4	0	2
4 Salty	0	0	0	0	0	0	0	0	5	2
5 Neutral	6	3	0	0	17	0	0	1	0	3

Session 1 ratings in columns, Session 2 in rows.

testing set, the number of consistent (identical) responses between the two sessions (C) and the number of inconsistent (different) responses (I), for TK and each control subject, as well as the consistency percentage (P). It is evident that Control 5 is not at all systematic while subject TK and Control 2 are very systematic since they gave the same answers in the two tests. However, the precise form of the systematicity appears quite different for TK and C2. Specifically, TK responded with consistent taste ratings only to a subset of reds and to most greens, giving neutral responses for other hues. In contrast, C2 responded consistently to all color categories and all tastes.

The reliability of the reports presented by the synesthete in comparison to those presented by the controls suggests that he is indeed reporting some experience that is different from that of the non-synesthetes. An important factor that needs to be taken into consideration when evaluating the results is that when the controls were subsequently asked about their beliefs concerning the relations between colors and tastes, they all claimed that they had made the following associations: greens and bitterness, reds and sweetness, yellows and sourness, blues and saltiness, blacks/whites and neutral taste. They also claimed that they did not feel the taste qualities in the mouth and that they just associated colors with particular tastes because these associations where rather common, e.g., blue sea and saltiness. In other words, their associations were in agreement with the correspondences between colors and tastes provided by TK, while adding the correspondence between blue hues and saltiness that was missing in TK's account. Therefore, it seems important that even if all the controls believed in the same associations between colors and tastes, which suggests that there was a high probability that they should obtain a high consistency score, most of them did not manage to be as consistent as TK. This may be taken to suggest that TK's responses were based on his experience whereas the responses of others were based on some beliefs that they had about associations between colors and tastes.[10] The pattern of responses for control C2 is also consistent with this interpretation, as he evidently applied the associations across hues, whereas TK was more selective.

The Stroop test

Another test that is normally used by studies on synesthesia in order to show its automatic nature is some adapted version of the Stroop test (Ramachandran & Hubbard, 2001). We adopted the indirect Stroop test that has been used in a study of sound–taste synesthesia (Beeli et al., 2005) for reasons articulated in their article.

For the first adapted Stroop test, we selected 20 colored squares used in the Consistency test, based primarily on their effectiveness in eliciting a taste response from TK, while ensuring that a range of colors was included. The one yellow square

[10] These results are not unusual since, as Simner and Ludwig (2011) have argued recently, there is an inherent methodological difficulty in showing consistency in some types of synesthesia, such as touch-color synesthesia, due to the presence of high levels of consistency among non-synesthetes with respect to touch and color pairings. The main difference between these two groups is with their phenomenology, that is, the synesthetes experience the colors while non-synesthetes do not. The continuity between the two groups is explained in part by the presence of similar 'rules' that are used by both groups when they match across perceptual modalities. Such 'rules' were clearly present in our case study.

that produced a strong and consistent bitter taste sensation in TK was included 5 times. Grey and blue colors (perceived as neutral) were also used. The selected colors are listed in Appendix B, cross-indexed to their taste responses in Appendix A.

Four tests were conducted with each subject, one test for each of the four basic tastes (saltiness, sweetness, sourness, bitterness). The solutions had the following consistency: citric acid (sourness) 20 g l^{-1}, quinine (bitterness) 60 mg l^{-1}, salt (saltiness) 10 g l^{-1}, sucrose (sweetness) 120 g l^{-1}, distilled water (neutral taste). These compounds were mixed in distilled water. The presentation of the solutions was done in the same order for all subjects. The sip-and-spit method, which is often used in psychophysical studies of taste perception (for example see Mojet, Heidema, & Christ-Hazelhof, 2003), was found to be the most convenient. Each subject received 20 ml of each solution in a 50-ml plastic cup. Before a testing session, subjects rinsed with water and expectorated. After each testing session, they ate a piece of cream cracker. There was a 15-minute interval between tests. During the test, subjects were required to identify the color of the square shown on the computer screen and to make the identification as quickly as possible, under these four different conditions. Reaction time was measured as the interval from the appearance of the color to the start of the subject's verbal response.

Subjects were asked to name the color of the presented stimulus into a microphone as fast as possible while maintaining high accuracy. Errors and reaction times were recorded with millisecond accuracy for each trial where the taste was congruent or incongruent with the color presented. The purpose of the test was to determine whether color naming by the synesthete would be slower than color naming by controls when the colors presented elicited a synesthetic taste that was in conflict with the non-synesthetic taste that was already present in the synesthete's mouth. More specifically, we hoped to show that TK's responses were quicker on congruent than incongruent trials whereas the controls were not expected to manifest such a difference.

There was no significant difference on the adapted Stroop test between synesthetic subject and controls (see Appendix B for mean response times). In addition, considering only the 14 colors of the Stroop test for which TK had produced consistent and non-neutral responses in the Consistency test, his average response times were indistinguishable between congruent–taste presentation trials ($M = 1.73$ s, $SD = 0.46$) and incongruent–taste trials ($M = 1.75$ s, $SD = 0.20$). The results are identical if the 'salty' taste and response option are excluded (in which case incongruent $M = 1.76$ s, $SD = 0.24$).[11]

As it has been pointed out by other studies (Ward et al., 2005), the Stroop test may pose problems when we try to draw comparisons across sensory modalities. A Stroop test that may be applicable in one situation may fail to be adapted in another.[12] A particular difficulty associated with this particular version of the Stroop test may be due to the requirement for vocal responses and the open-ended nature of the response, as the subjects (all being artists-painters) seemed reluctant to use plain single-word color names spontaneously in response to the complex presented hues. This weakness was subsequently addressed, specifically for TK, by focusing on a binary distinction among colors and corresponding tastes, as follows.

Further psychophysical tests

The relationship between colors and tastes was further examined in a series of psychophysical tests, focusing on the regions of green and red colors and the corresponding bitter and sweet tastes.[13] A discovery procedure using RGB color picker palettes indicated that maximum taste intensity was achieved for endpoint R and G values (for sweet and bitter taste, respectively). In all subsequent tests, colors were presented against a white background, at TK's preference over a black background.

A color adjustment procedure was implemented in PsychoPy (Peirce, 2007), in which the main dimension under testing (i.e., red for sweetness and green for bitterness) was initialized with a large value (between 242 and 255), while the other two dimensions (green/red and blue) were initialized

[11] Since there are no differences between congruent and incongruent-taste trials in the case of TK, there is no point presenting similar results for the control group.

[12] Other problems with similar uses of the Stroop test have been noted. For example, according to Meier and Rothen (2009), although the synesthetic Stroop test is useful for assessing the strength of semantic associations, it fails to access the content of the synesthetic experience itself.

[13] Follow-up testing was conducted in RGB space on a Sony Vaio PCG 71811M laptop LCD screen at maximum brightness under moderate artificial lighting. Calibrated equipment was precluded due to the requirement for home testing.

with a random value and were adjustable via keyboard arrows. A large color square was presented at the center of the screen, flanked by smaller color squares on all four sides indicating color changes towards higher and lower values on the adjustable dimensions. TK was encouraged to indicate the direction in which the intensity of the taste would increase until no further increase was apparent. In a first series of runs, the main dimension remained fixed, while in a second series the sum of R+G+B was held constant. Figure 1 shows the results of these procedures on the top row, for the sweetness (left) and bitterness (right) adjustments. Each run is displayed by an initial point (small filled black circle) and a final point (larger grey unfilled circle) joined by an arrow (via solid lines for the fixed-main runs; dashed lines for the constant-sum runs). These points plot the adjustable dimensions; the main dimension values are displayed as text next to these points. It is seen that a wide range of red values leads to intense perceived bitterness while a much smaller range of green values is associated with intense perceived sweetness. In both cases, blue values below 50 are required.

A rating procedure was then implemented, in which TK was asked to provide verbally a numerical rating (from 1 = least intense to 10 = most intense) for the perceived taste caused by the displayed color. A single large color square was presented on the screen on each trial. The RGB color range spanned was focused around the regions of intense perceived taste, as previously reported. The three-dimensional graphs in the middle rows of Figure 1 display the results for sweetness ratings (left) and bitterness ratings (right). It is seen that bitterness is generally rated more intense than sweetness, for the available color range, and remains maximally rated over a substantial RGB region. Although sweetness generally decreases as blue increases, some green is again required for maximal sweetness, consistent with the results of the adjustment procedure.

The effect of size on perceived taste was examined in a similar rating procedure in which color squares were presented in the center of the screen in one of three sizes, defined by proportions (tenths) of the shorter (vertical) screen dimension. RGB values here spanned a somewhat wider range, intended to disentangle potential interactions between hue and size. As shown on the bottom row of Figure 1, larger color stimuli produced more intense taste ratings but only for color values leading to appreciable taste ratings in the first place. The effect of size was tested statistically by linear regression of the taste rating onto the (rescaled and centered) RGB and size values, including an interaction between the main dimension (red or green) and size. Total adjusted R^2 was .51 for sweetness and .53 for bitterness (df = 47, both $F>10$). There was a significant positive effect of size on rating ($\beta = 0.27$ for sweetness, $\beta = 0.34$ for bitterness, both $p < .005$), which was larger for higher values of the main dimension (significant interaction of size with red, for sweetness, and with green, for bitterness; both $\beta = 0.20$, $p < .04$).

Finally, a follow-up Stroop procedure was implemented in DMDX (Forster & Forster, 2003) to investigate the interaction of synesthetic, color-induced taste sensations with non-synesthetic taste stimulation, in the restricted color region determined above. In each trial, a single 500×500-pixel square was presented in the middle of the screen and TK was asked to respond by pressing the bottom left key on the laptop keyboard for 'green' and the bottom right key for 'red', as quickly as possible without making mistakes. Three green (RGB: 20-225-5, 35-240-20, 50-255-35) and three red (225-20-5, 240-35-20, 255-50-35) colors associated with intense taste sensations were used. Each color was presented 6 times, in pseudorandom order, for a total of 24 trials per run. Following a few practice runs for familiarization with the procedure and stabilization of response times, TK completed four consecutive runs under alternating taste stimulation.[14] Overall mean response time was 537.4 ms ($SD = 110.1$).

Following examination of data distribution on quantile plots and removal of 7 outliers (less than 320 ms or greater than 700 ms), results were analyzed by linear regression, with color, taste, and run as predictors. There was a significant interaction of color with taste ($p = .0499$)[15] consistent with interference between color-induced and non-synesthetic taste sensations. There was also a marginal three-way interaction, suggesting difference between runs. Probed individually, the interference effect approached significance in the first pair of runs ($\beta = 85.8$, $p = .055$) but not in the second pair ($\beta = -47.7$, $p = .402$). Participant fatigue due

[14] The solutions used were the same as in the previous Stroop test, i.e., quinine (bitterness) 60 mg l^{-1} and sucrose (sweetness) 120 g l^{-1} mixed in distilled water. Similarly, the sip-and-spit method using 20 ml of each solution in a 50-ml plastic cup was deployed.

[15] Complete results table in Appendix C.

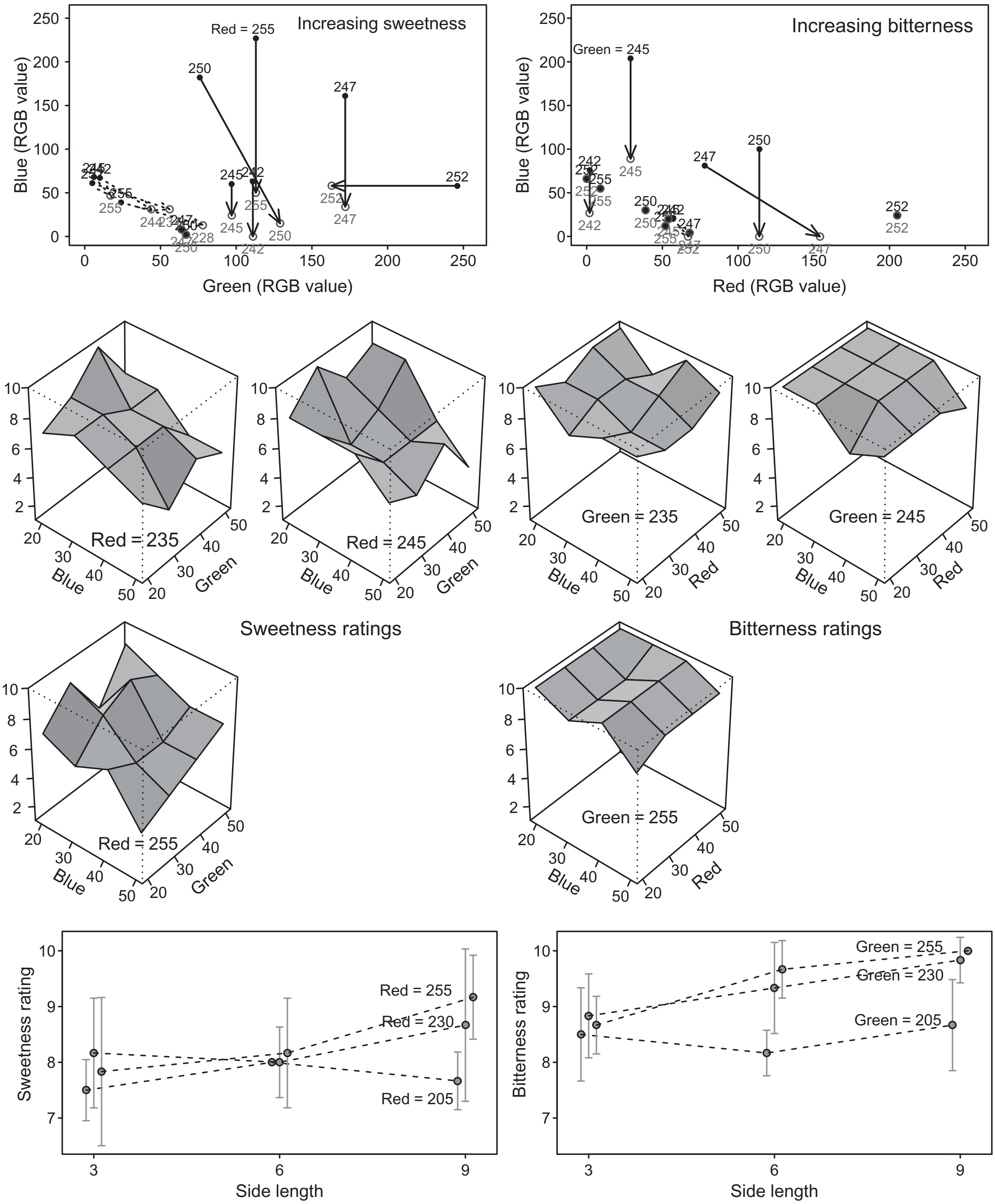

Figure 1. Results of psychophysical testing of TK in RGB space. Sweetness judgments are displayed on the left, bitterness on the right. Top row: Color adjustment procedure towards increasing taste sensations (initial and final RGB values indicated by arrows; see text for details). Middle rows (3D panels): taste intensity ratings for the indicated ranges of RBG values. Bottom row: taste intensity ratings as a function of visual stimulus size (in tenths of the vertical dimension of the PC screen). Each point plots the average of six combinations of the secondary color dimensions, while the main dimension is indicated above each rightmost point. Error bars show standard deviation.

to prolonged testing prevented further investigation to determine whether habituation or instability was the source of the inconsistency.

GENERAL DISCUSSION

As far as the Consistency test is concerned, the reports presented by TK were more reliable than those presented by the controls. Although the controls believed in the same associations between colors and tastes, as a group they did not manage to be as consistent as TK. With regard to the first Stroop test, using verbal responses for a wider range of color stimuli, there was no significant difference between synesthetic subject and controls and there were no differences between congruent and incongruent–taste trials in the case of TK. However, in the second Stroop test, using button-press responses for a pair of color categories only, there was some evidence for interference in the response times of TK, consistent with a lack of distinction among color-induced (synesthetic) and non-synesthetic taste sensations. Although a Stroop effect has been demonstrated following associative training (Meier & Rothen, 2009), necessitating more extensive documentation of experiential authenticity beyond just a Stroop effect, a purely associative account does not seem tenable for our findings, as there is no obvious history of structured reinforcement schedules favoring specific color–taste associations.

Some additional considerations concerning the Consistency test are as follows. The fact that TK did not conform to the expected pattern of response with respect to the color blue, i.e., that blue did not produce a salty synesthetic taste, may be taken as another characteristic suggesting the authenticity of his synesthesia. The link between blue and saltiness is an expected one, given that it is an association that was felt to be 'natural' by the controls and one that TK could have made since he has been brought up in a country where the sea, exhibiting primarily blue hues, is a rather dominant element in most aspects of one's life. As further testimony to authenticity, psychophysical exploration of two color regions inducing intense tastes in TK indicated that the red hues associated with most intense sweetness were neither indiscriminate nor centered around the prototypical 'pure' red (to the extent that is approximated in the RGB gamut) but, rather, some region of RGB values including nonzero B and, particularly, G components.

We believe that the reason why TK did not obtain 100% consistency across the initial and subsequent sessions is that he was often presented with hues that were not bright enough for eliciting a synesthetic response at a significant level of intensity. As a result, his responses differed for these hues across testing sessions. For example, RGB color 255-191-85 which is an orange, in the first session was found to be neutral while in the second session, it was found to be mildly sweet. Additionally, he complained that computer colors, particularly the yellows, lacked the intensity and saturation of pigment colors.

There are also difficulties facing the viability of the Stroop test with respect to this particular case of synesthesia. As Smilek and Dixon (2002) have pointed out, although both synesthetes and trained non-synesthetes can show the same results in the Stroop test, these results should be interpreted in terms of the subjective reports of the participants. This suggestion seems to be rather appropriate in this particular case. When during the initial interview our subject was asked about the difference between synesthetic taste and ordinary taste he claimed that synesthetic tastes, although perceptually real, were different from ordinary tastes in that they were weaker in intensity (in the first Stroop test, with a wide color range) or stronger (in the second Stroop test, with focused colors). The solutions given to our subject during the first Stroop test were, according to him, so strong that they suppressed the synesthetic taste and, as a result, there could be no jarring effect between the solution taste and the synesthetic taste. In the second Stroop test, having established RGB values of maximal induced taste sensation, the non-synesthetic tastes may have been insufficient to produce a large effect, so only a weak effect was achieved, thanks to the two-alternative forced-choice method leading to lower variability. It seems that, if we were to obtain the jarring effect between the two tastes we would have to experiment with different solutions until the appropriate amount for each substance was discovered, with respect to particular taste-inducing hues, i.e., and 'appropriate' in this case means 'capable of producing a Stroop effect'. However, such experiments, besides being methodologically problematic, were prohibitive since they would be too hard on our elderly subject.

Another difficulty relates to the fact that our synesthetic subject and controls are artists-painters. Their task during the Stroop test was that of identifying the color on the monitor screen as quickly as possible. However, it was important for them, due to their profession, to find the correct name of the hue presented; for them, generic names were not good enough.[16] They thought carefully about the hue's appropriate name, thus increasing their response time quite significantly. That is, their responses were far from being automatic and fast. As a result, we could not obtain any significant response differences between the controls and the synesthetic subject. This weakness was effectively addressed in the second Stroop test, in which TK's average response times was about 540 ms (compared to 1750 ms in the first test).

These observations reveal that there are some weaknesses in the original Stroop test, which may make it difficult to apply in some cases of synesthesia such as the one examined in this article. Although we did not manage to obtain all the results that would unequivocally show that TK was indeed having the synesthetic experiences that he was claiming to have, we believe that the development of more sensitive experimental tools may help us to account for such cases.

As far as the psychophysical tests are concerned, we were able to determine the color regions associated with two intense tastes. Results of the adjustment and rating procedures were highly consistent and reliably indicated that red values play relatively little role in bitter sensations, given sufficiently high values of green, whereas the reverse was not true, as some green (but not too much) was required or intense sweetness, in addition to sufficiently high values of red. The red–sweet/green–bitter associations and corresponding induced sensations are not, therefore, entirely symmetric. Moreover, larger color stimuli were reliably rated as more intense-tasting, consistent with subjective reports of the induced tastes of color displays, even though the size of the computer-displayed stimuli was relatively small. That the size effect was limited to the hues associated with the highest ratings may serve as further testimony of the genuine character of the synesthetic experience, as the observed interaction would have been difficult to produce by either guessing or verbal association.

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[16] They are not that different from synesthetes who have color as a concurrent and who are very particular about the description of the hue that they experience (Blake et al., 2005).

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APPENDIX A
CONSISTENCY TEST

Taste ratings of the RGB color stimuli by TK and 5 control subjects in two sessions (S1 & S2)

	RGB stimulus				*Subject TK*		*Control 1*		*Control 2*		*Control 3*		*Control 4*		*Control 5*	
Trial No.	*r*	*g*	*b*	*Color*[a]	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*
1	0	0	0	BW	5	5	5	2	–	5	2	2	2	2	5	2
2	127	95	85	R	–	1	1	1	1	1	1	5	5	1	5	1
3	42	63	255	B	5	5	4	5	3	5	–	5	5	5	1	3
4	255	255	0	Y	2	2	3	3	1	1	3	3	3	3	3	3
5	0	127	0	G	5	5	2	2	2	2	5	5	3	3	5	3
6	42	255	255	B	5	5	5	5	5	3	5	5	3	5	–	3
7	85	127	85	G	5	1	2	2	3	3	5	5	3	1	4	5
8	204	204	255	B	5	5	1	1	–	4	–	5	1	5	5	5
9	255	31	0	R	1	1	1	1	1	1	5	5	1	1	5	1
10	127	159	255	B	5	5	4	5	5	5	–	5	1	4	1	4
11	42	95	170	B	5	5	4	5	3	5	5	5	2	4	–	4
12	42	255	170	G	2	2	4	4	2	3	5	5	3	3	1	4
13	42	223	255	B	5	5	5	5	3	3	5	–	2	4	5	4
14	170	63	0	R	1	1	1	1	1	1	1	5	2	1	–	2
15	212	95	0	R	1	1	3	3	1	1	1	5	1	1	5	1
16	42	95	0	G	5	5	5	2	2	2	–	5	2	5	–	4
17	170	95	0	R	1	1	1	3	1	1	1	5	1	1	–	3
18	212	0	85	R	5	5	1	1	1	1	2	1	1	2	5	1
19	212	191	170	R	5	5	1	1	4	4	5	5	1	1	–	5
20	230	230	0	Y	2	2	3	3	3	1	3	3	3	5	–	3
21	212	255	170	G	2	1	3	1	4	4	5	3	4	5	3	5
22	255	223	85	Y	5	1	3	3	1	1	3	3	3	3	5	1
23	255	127	85	R	1	5	3	1	1	1	1	5	1	1	4	1
24	85	159	170	B	5	5	5	1	3	3	1	5	4	4	1	3
25	170	0	255	B	2	2	5	1	5	5	5	–	2	2	–	3
26	42	191	170	G	5	5	5	5	3	3	2	5	3	5	1	3
27	128	128	0	G	2	2	3	3	2	2	3	3	3	3	–	3
28	127	159	0	G	2	2	3	2	2	2	3	2	3	3	4	3
29	255	63	255	R	5	5	1	5	1	5	5	1	2	1	4	1
30	255	191	85	Y	5	1	1	1	1	1	5	1	3	1	5	1
31	170	159	170	BW	5	1	5	1	4	4	5	5	2	2	5	5
32	255	255	255	BW	5	1	5	5	4	4	5	5	1	5	5	5
33	85	255	85	G	2	2	2	2	2	2	2	3	3	3	5	3
34	127	0	0	R	5	2	1	2	1	1	–	1	2	2	3	2
35	0	128	128	B	5	5	5	5	5	5	–	5	4	4	1	3
36	212	159	85	R	1	1	3	1	1	1	5	5	1	1	5	1
37	212	31	255	R	2	5	1	5	1	5	2	1	2	2	3	2
38	255	223	0	Y	3	3	3	3	1	1	3	3	3	3	3	3
39	255	223	170	Y	5	1	3	5	4	4	5	5	1	5	5	5
40	131	131	131	BW	–	1	–	5	2	4	–	5	2	5	5	5
41	42	191	0	G	5	2	2	2	3	2	2	2	1	3	3	3
42	85	223	85	G	5	2	2	3	4	5	2	3	3	3	3	3
43	42	0	170	B	5	5	5	5	4	5	–	5	4	4	2	4
44	0	0	128	B	5	5	5	5	1	–	–	5	4	4	2	2
45	170	0	0	R	1	1	1	5	5	–	1	5	1	1	1	2

1, sweet; 2, bitter; 3, sour; 4, salty; 5, neutral.
[a]A rough subjective classification of stimuli into shades of red (R), green (G), blue (B), yellow (Y), and grey (BW).

APPENDIX B
FIRST STROOP TEST

Response time (in seconds) for naming of the color stimuli by TK and 5 control subjects, averaged over the four taste solution contexts

		RGB stimulus				*Subject*	*Control subjects*						
Trial No.	*Cons No.*[a]	*r*	*g*	*b*	*Color*[b]	*TK*	*C1*	*C2*	*C3*	*C4*	*C5*	*M*	*SD*
1	4	255	255	0	Y	1.46	1.80	1.43	1.37	1.09	2.01	1.54	0.36
2	36	212	159	85	R	2.20	1.76	1.64	2.36	1.95	2.24	1.99	0.31
3	9	255	31	0	R	1.73	1.45	1.38	1.33	1.41	1.39	1.39	0.04
4	33	85	255	85	G	1.84	1.42	1.56	1.55	1.71	1.29	1.51	0.16
5	23	255	127	85	R	1.73	2.16	2.02	–	1.96	1.88	2.00	0.12
6	20	230	230	0	Y	1.88	1.53	1.43	1.56	1.86	1.37	1.55	0.19
7	45	170	0	0	R	1.82	2.20	1.75	1.91	1.43	1.27	1.71	0.37
8	35	0	128	128	B	1.67	1.96	2.05	2.01	1.86	1.50	1.87	0.22
9	30	255	191	85	R	2.12	2.25	1.99	2.18	2.31	2.18	2.18	0.12
10	4	255	255	0	Y	1.64	1.80	1.33	1.50	1.05	2.01	1.54	0.38
11	4	255	255	0	Y	1.53	1.59	1.55	1.42	1.37	1.21	1.43	0.15
12	25	170	0	255	B	1.34	2.00	1.34	1.32	1.37	1.22	1.45	0.31
13	38	255	223	0	Y	2.02	1.91	1.38	1.59	2.14	1.59	1.72	0.30
14	34	127	0	0	R	1.84	2.05	1.83	1.78	1.82	1.15	1.73	0.34
15	4	255	255	0	Y	1.67	1.66	1.54	1.74	1.70	1.61	1.65	0.08
16	31	170	159	170	BW	1.85	1.87	1.36	2.16	1.71	1.36	1.69	0.34
17	17	170	95	0	R	1.51	2.01	1.99	2.18	1.66	1.81	1.93	0.20
18	27	128	128	0	G	2.02	0.93	1.87	1.80	1.77	1.59	1.59	0.38
19	4	255	255	0	Y	1.73	1.72	1.74	2.07	1.68	2.15	1.87	0.22
20	44	0	0	128	B	1.33	1.40	1.38	1.46	1.00	1.23	1.29	0.18

[a]Corresponding stimulus in consistency test.
[b]A rough subjective classification of stimuli into shades of red (R), green (G), blue (B), yellow (Y), and grey (BW).

APPENDIX C
SECOND STROOP TEST

Results of linear regression analysis (report of R function lm), with response time as a dependent variable and color (red vs. green), taste condition (sweet vs. bitter solution), and session (runs 1–2 vs. runs 3–4) as predictors.

```
Call: lm(formula = rt1 ~ color * cond * sess, data = d)

Residuals:
     Min       1Q   Median       3Q      Max
-214.608  -41.308    3.633   53.982  149.560

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                 632.43      55.32  11.432   <2e-16
colorgreen                 -133.18      77.64  -1.716   0.0901
condsweet                   -60.88      78.23  -0.778   0.4388
sess                        -36.21      34.54  -1.048   0.2976
colorgreen:condsweet        219.20     110.14   1.990   0.0499
colorgreen:sess              34.51      49.48   0.697   0.4875
condsweet:sess               18.98      48.85   0.388   0.6987
colorgreen:condsweet:sess  -133.42      70.52  -1.892   0.0621

Residual standard error: 82.75 on 81 degrees of freedom
Multiple R-squared: 0.2558,Adjusted R-squared: 0.1915
F-statistic: 3.978 on 7 and 81 DF,  p-value: 0.0008764
```