Experimental study of phantom colors in a color blind synaesthete

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Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound produces *photisms,* i.e. mental percepts of colors. R is a 20 year old color blind subject who, in addition to the relatively common grapheme-color synaesthesia, presents a rarely reported cross modal perception in which a variety of visual stimuli elicit aura-like percepts of color. In R, photisms seem to be closely related to the affective valence of stimuli and typically bring out a consistent pattern of emotional responses. The present case study suggests that colors might be an intrinsic category of the human brain. We developed an empirical methodology that allowed us to study the subject's otherwise inaccessible phenomenological experience. First, we found that R shows a Stroop effect (delayed response due to interference) elicited by photisms despite the fact that he does not show a regular Stroop with real colors. Secondly, by manipulating the color context we confirmed that colors can alter R's emotional evaluation of the stimuli. Furthermore, we demonstrated that R's auras may actually lead to a partially inverted emotional spectrum where certain stimuli bring out emotional reactions opposite to the normal ones. These findings can only be accounted for by considering R's subjective color experience or qualia. Therefore the present paper defends the view that qualia are a useful scientific concept that can be approached and studied by experimental methods.

R is a 20 year old male who belongs to the rare group of people who have synaesthetic perception. Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound produces *photisms,* i.e. mental percepts of colors. In addition to the relatively common grapheme-color synaesthesia, R presents a variety of synaesthetic associations. Not only numbers and letters but also first names, surnames, persons, town and city names, abstract concepts, natural sounds and music elicit percepts of color in his mind's eye. For example, the town of Granada is "red", hope is "white", intelligence is "yellow", classical music is "dark brown" while electronic music is "purple" and symphonic compositions are "red", both pain and joy are "yellow", love is "red", etc.[1]

Surprisingly, R also suffers from a mild form of color blindness (dichromatic daltonism), thus having difficulty in discriminating between certain shades of red, brown and green. The frequency of color blindness in the general population is 1 to 8%. Even though the proportion of synaesthetes used to be underestimated in the past (e.g., 1 in 20 000; Cytowic, 1989), according to more recent studies, the prevalence numbers are likely to lie somewhere between 1 in 200 (Ramachandran & Hubbard, 2001b) and 1 in 2,000 (Baron-Cohen et al., 1996). Despite the fact that both color blindness and synaesthesia are relatively rare, the combination of the two could actually be more frequent than predicted by chance alone. (For instance, Ramachandran & Hubbard [2001a; 2001b] also report a case of color-weakness and synaesthesia.) If, as hypothesized elsewhere, synaesthesia is linked to the X-chromosome (Bailey & Johnson, 1997), then both conditions might not be independent and we could actually expect synaesthesia to be relatively common among the color-blind.

Seemingly, the sensation of color is a quale (Chalmers, 1996), which in R's case has very distinctive characteristics. The word quale refers to our subjective, introspectively accessible experience, showing aspects that cannot be found in the world external to our minds (Jackson 1982; Searle, 1992; Chalmers, 1996). The question is whether these mental phenomena (qualia) can or cannot be studied within the framework of empirical science. Is it possible to make science of subjective experience and establish correlations between the quale and external objects? Can we explore "what it is like to experience something?" Nagel (1974) believes that there are certain qualities that exist only within one particular point of view, defining an experience for one particular experiencer. Therefore Nagel asks: "What is it like to be a bat?" Although bats cannot tell us about their inner life, R **can** speak, allowing us to access his mental states through introspection. Some authors believe that introspection is not reliable at all. Daniel C. Dennett (1988) tries to demonstrate this by means of thought experiment that involves two coffee experts discussing the flavor of a coffee brand. One of them says that the taste of the coffee is not the same as it used to be (alteration of qualia) but he still likes it. The other thinks that the coffee is the same (qualia has not changed) but he does not like it anymore. According to Dennett there is no way to judge who is right and who is wrong. However, our approach to introspection was a different one. We started the research with a "naïve" attitude of trusting R's verbal reports to see how far we could go looking for behavioral evidence that would support R's subjective descriptions. The goal was not to simply demonstrate R's daltonic-synaesthetic condition, but to combine subjective first-person point of view with empirical evidence in order to find out whether the concept of qualia could be useful in scientific psychology, similar to the way the "magical" notion of power is useful in Newtonian physics to describe empirical phenomena.

Usually thought experiments such as Nagel's Bat or Dennett's Coffee Masters belong to a kind of parallel universe, apart from the realms of empirical science. In our study we try to merge both points of view seeking scientific answers to the enigma of qualia: "What is it like to be R?" The present paper is focused on an aspect of R's synaesthesia that we termed *aura*. Traditionally *aura* is an esoteric concept that refers to a supposed psychic energy field surrounding the bodies of all creatures, being associated with physical and psychological health. We have decided to use this term in relation to R's synaesthesia because of the superficial similarity to his *photisms*. However, we would like to emphasize that R is not an enthusiast of esoteric wisdom and personally prefers to describe his experience in different terms.

When R meets a person, he usually perceives a translucent spot of color in his mind's eye. This aura-like experience is best described as mental imagery and is never projected externally onto the person being perceived. Following Dixon et al. (2004), R could be categorized as an "associator" synaesthete in contrast with "projector synaesthetes" who perceive their photisms as located "out there".

R claims that this experience is highly consistent over time and cannot be suppressed by will. Even though aura-like photisms do not seem to be a frequent variety of synaesthesia, a small number of similar cases have been reported in the literature (Cytowic, 1989; Ward, 2004). Besides humans activating photisms, R also claims that images or scenes that are either emotionally or esthetically exciting also lead to synaesthetic responses even when no humans are present. Pleasing pictures are typically red while repulsive scenarios elicit a pale green color in his mind's eye. According to R, people's *auras* present a specific pattern: attractive people tend to be red; people that look dirty or sick are green; those who give an impression of optimism and happiness are purple while aggressive and envious people are yellow; old people and people that are uninteresting to R are brown. There are no blue or white people. R often uses his aura photisms to make intuitive judgments about anyone he meets[2], although, as he mentioned during the interview, not all the people necessarily trigger synaesthetic perception.

In summary, R's most distinctive photisms can be categorized in line with their emotional valence: positive emotions seem to be associated with red or purple auras; green indicates something usually repulsive; brown is neutral and yellow shows certain ambivalence, with both joy and aggressiveness associated. As you will see later on, colors can vary in tone and luminosity depending on the triggering stimuli but they always follow the aforementioned pattern.

Our ambition in studying R's color experience can be summarized in the following questions: How does R see "real" colors? (Experiment 1) What is the subjective importance of colors to R? (Experiment 2) Is there any relationship between photisms and real-world objects? (Experiments 2 and 3) What are the main attributes of R's "mental colors"? (Experiment 3) How do they influence R's emotional responses? (Experiments 4 and 5) Can we provide behavioral evidence of R's auras? (Experiment 6) In brief, does R really see the world in a different way? If so, what is it like?

Assessment of R's color identification skills and Color Stroop in R (Experiment 1).

In a pilot study we provided R with 100 randomly selected color samples (out of a color palette consisting of more than 500 hues) and asked him to identify the colors presented. Color patches were presented on a computer screen, using RGB codes to generate appropriate hues. We would like to emphasize that we only asked R to roughly classify the shades in general color categories such as green, red, blue, etc. For example, we considered an answer as "correct" when a "dark olive green" (RGB value: 85;107;47) hue was identified as green or a "firebrick red" (RGB: 178;34;34) was identified as red. Concerning R's typical color identification errors, he usually places variations of orange into green and brown categories. Colors such as "lemon chiffon 2" (238;233;191) and similar colors are "pale green". Hues such as "dark orange 4" (RGB: 139;69;0), "carrot" (237;145;33) and "melon" (227;168;105) are all "lettuce green"; "chocolate" (210;105;30) is also green; and "dark-sea green" (143;188;143) is dark brown. R also confuses variations of grey: "grey 10" (26;26;26) is seen as dark brown, "grey 20" (51;51;51) as burgundy red, "grey 40" (102;102;102) as pale brown, "grey 80" (204;204;204) as green and, finally, "grey 70" (179;179;179) as grey. "Salmon" (198;113;113) and "teal" (56;142;142) are both called "bottle green". "Indian red" (245;204;176) is seen as brown, while "red" (255;0;0) and "red 2" (238;0;0) are identified correctly as red. R does not show major problems with blue hues. However, only specific shades of green, e.g. "cobalt green" (61, 145, 64), are correctly identified.

Additionally, we were interested in testing R for Stroop effect (Stroop, 1935). To do this we used traditional color naming design by presenting words "red", "green" and "blue" on a computer in the center of the screen for 2000 ms or until a response was emitted. The words could be written in a red, green or blue font color. R's task was to identify the color (not the name written) by striking the corresponding key on a keyboard: B for red, N for green and M for blue. The keys were covered with a patch of corresponding color to facilitate the response. In a person with normal color vision you expect longer RT for incongruent trials (e.g. "red" written in the color green) because of the influence of reading automatism that interferes with color identification. However, R has red-green discrimination problems because of his daltonic condition.[3] The experiment design consisted of 10 series of 21 trials, presented on a computer screen using MEL software (Schneider, 1988). The instructions put emphasis on precision over speed.

Surprisingly, we did not find significant Stroop effect ($t=-0.33$, $p<0.79$). Mean RT was 660 ms for congruent trials and 677 ms for incongruent trials. Stroop effect was not found for accuracy data ($t=-0.76$, $p<0.52$). R reached a 13% error for congruent trials and 14% for incongruent trials. Ten control participants (non-synaesthetes with normal color vision) presented significant Stroop effect in RT, $F(1, 9) = 10.13$, $p<0.011$. Mean RTs were 538 ms and 635 ms for congruent and incongruent trials respectively. Accuracy reached a 2 % error for congruent trials and a 4.5 % error for incongruent trials. Summarizing experiment 1, R does not show significant Stroop effect and his color identification skills are far from perfect.

Consistency of aura photisms. Is R's red truly red? (Experiments 2 and 3).

Because R's auras seemed to be strongly associated with emotions, we used the International Affective Picture System (IAPS) (Lang et al., 1999) to select appropriate stimuli for bringing out R's synaesthetic response. The current version of the IAPS consists of 832 color images, available in digital format, belonging to various semantic categories: portraits, nudes and erotica, animals, household objects, dead and mutilated bodies, sport and fitness, etc. In order to evaluate the consistency or the photisms, R went through sets 1 through 8, 13 and 14 of the IAPS (approximately 500 images altogether) naming a color of an aura photism for each picture. His responses were 98% consistent over time when he did a re-test 30 days later. The inconsistencies observed (only 2%) were related to "pale brown" and "white" photisms and "green" and "yellow" photisms. However, R reports that this happens occasionally when an image triggers more than one synaesthetic color. For example, the image of an old man with a long white beard (IASP # 0072) is both pale brown and white; the image showing a drug addict taking a shot (IASP # 0197) is "green" and "yellow"; the photography of a black kid

(IASP # 0113) is at the same time red and purple; the image of an elderly man smiling while hugging two youngsters (IASP # 0133) is brown with some areas that are yellow. In these cases R’s response depends on which part of the image is attended and/or what elements of the scene are more dominant. Finally, it must be said that not all the images elicit synaesthetic response (e.g., an image of a cow, # 0020; a closeup of violet flowers, # 0042; an image of mushrooms, # 0048; an image of a fighter plane # 0056; a still life with fruits and food, # 0167).

Before proceeding with our exploration of R’s subjective experience, we considered it necessary to obtain a thorough classification of R’s photisms. During our experimental sessions with R and other synaesthetes we have often encountered a problem related to the subjectivity of color perception (remember that because of his color blindness R had difficulties with discrimination of certain shades of green, brown and red). It is known that even people with normal color vision can present subtle differences in color matching which can be accounted for by genetic differences at the level of the photoreceptors (Winderickx *et al.*, 1992a; Winderickx *et al.*, 1992b). Therefore, how could we possibly know which color R was “seeing” when he reported an orange photism? If you try to imagine a default “orange”, it is very probable that your “orange” is not the same shade as the one that another person sees in his/her mind’s eye (It is even possible that somebody might call “red” or “brown” what you would still consider as “orange”).

To eliminate the problem of subjective color perception, we designed a special computer program developed in the C# language, using the Microsoft Visual Studio 2005 framework, that would display a synaesthetic stimulus (i.e., a photograph) on the left side of the screen and a palette of color shades on the other side. Samples of color were vertically arranged rectangles; both the picture and the color samples were presented on a black background. There was a scroll button next to the color samples that allowed the subject to scroll up and down to see all the shades of a given color.

When designing the program, our primary concern was how to get the appropriate color shades, i.e. what color palette to use. Today’s computer screens can display up to 16 million color shades and obviously we did not want R to go through this amount of samples. We decided to use MIT's Xconsortum RGB color specifications (Walsh, 2005) that had the advantage of being roughly classified into color categories (shades of Black and Grey, Blue, Brown, Grey, Green, Orange, Red, Violet, White and Yellow), while offering a large variety of options for each color shade. We generated specific color shades using standard hexadecimal encoding. To ensure constancy of color perception we used the same monitor (LCD Acer AL1714, 17”, color temperature settings on neutral) during all experimental sessions, as well as maintained constant illumination conditions (fluorescent light).

Information gathered from R during interview sessions allowed us to reduce the number of color shades presented for each stimulus, using shades of the color that R reported as his synaesthetic response (e.g., shades of red for photographs with erotic content). This was a starting point to determine specific colors of R’s photisms.

R’s task was to observe a stimulus on the left side of the screen and then to choose a color sample that was closest to his synaesthetic experience. When clicking on a color sample on the right, a rectangle of the same color appeared a few inches below the stimulus, allowing the subject to see the shade better and reducing possible interference of color contrasts to a minimum. Once R found a color corresponding to his synaesthesia, he clicked on a “next” button, located at the bottom right of the screen, to proceed to the following item. His responses were recorded in a data file, including color name and its hexadecimal encoding.

Following this procedure, R went through a series of pictures selected out of the sets 1 through 8, 13 and 14 of the IAPS (we used images that R had previously marked as the most intense in terms of photism vividness.) In Table 1 you can see the correspondence between aura color categories and specific color shades as chosen by R. Table 2 offers verbal descriptions of the IAPS images that we used, classified by their corresponding aura color shade. This image-color relation was reliable and consistent over time (2 repetitions). In a few words, from then on we would be able to know exactly what color R was speaking about when describing his photisms.

INSERT TABLES 1 AND 2

R’s photism in response to a vision of the sky is red (images 0086, 0156, 0158, 0265, 0325, 0393, 1731, 551, 8186). A red aura is elicited by attractive people (images 0193, 0131, 0379, 0438, 2005, 2025, 2375, etc.) but interestingly enough, it is also triggered by images of a firearm pointing at someone’s head (images 0090, 0327 y 0332). Images of dead bodies (images 0033, 0035, 0075, 0076, 0077, 0138, 0139, 0140, 0179, 0202, 0203, 0204) and frightening or disgusting scenes (images 0005, 1205, 9301 y 0234, 0292) are “green” (as you can see in Table 1, one of the aura shades that R sometimes calls “green” is actually corresponding to “grey11”). Yellow photism is associated with penetration (meaning either sexual penetration or the penetration of something pointy like a knife or a syringe), with pain (images 0201, 0266, 0240, 0251, 0315, 0319, 0331, 0362, 0427, 1525, etc.) and with joy as well (images 0266, 0319 y 0340). Finally, R considers some portraits “green” and unpleasant that are usually evaluated as pleasant by others (images 0021, 0029, 0080, 00135, 00145, 00148, 00149, 0190, 0192, and 0194).

Colors of emotion (Experiments 4 and 5)

Given the typical pattern of R’s photisms, we asked him to choose at least ten pictures for each of the following categories: emotionally positive “red” pictures, unpleasant “green” pictures, and neutral “brown” pictures and “yellow” pictures (see Table 2). In order to evaluate R’s emotional perception of the images, R ran the Spanish version of the Self-Assessment Manikin or SAM (Moltó et al., 1999; Vila et al., 2001), that provided us with ratings for each picture along the following dimensions: valence (unpleasant-pleasant), arousal (low-high) and dominance (dominated- in control). Basically, SAM scales allowed us to put a figure on R’s subjective feelings in relation to IAPS images that we were going to use later on.

Since we were dealing with a single-case design, we used the C statistic (Young, 1941; Suen & Ary, 1989) to assess the horizontal stability of our results and to detect if they showed any evident trend. (It must be mentioned that the C statistic does not indicate the direction of a trend; however this can be inferred from the representations of the data.) In order to analyze SAM scores along aura color categories, we devised a series with ten points taking into account the order in which R evaluated the IAPS pictures. Every point corresponded to the score of one picture in one dimension (valence, arousal or control). With respect to arousal, C was not significant for the within-group comparison of red pictures ($C=0.22$, $p=0.217$), yellow pictures ($C=0.12$, $p=0.33$), green pictures ($C=0.23$, $p=0.20$) and brown pictures ($C=-0.09$, $p=0.62$). In actuality, C was non-significant for all three emotional dimensions in all color categories. The mean scores in valence, arousal and control for red pictures were 6.5, 6.2 and 6.3 respectively on a 1-9 scale. (Ratings are scored such that 9 represents high rating on each dimension, i.e., high pleasure, high arousal, high dominance, and 1 represents a low rating on each dimension, i.e., low pleasure, low arousal, low dominance.) The average SAM pattern for green pictures was 3.7, 6.5 and 4.8. For yellow pictures it was 5, 5.4 and 6.5, and for brown pictures 4.9, 3.3 and 6.7. The results suggested that the images activating same aura-colors were equal in emotional self-assessment. However, we observed a difference in emotional valence between “red” and “green” images ($C=0.77$, $p=0.003$) and also a difference in arousal between "red" and "brown" category images (C=0.66, p =0.009) and between "brown" and "green" images as well (C=0.62, p=0.01). Finally, emotional assessment of the yellow category was not significantly different from the rest. This can probably be attributed to the affective ambiguity of the color yellow.

In conclusion we can affirm that the emotional assessment of the images is robustly correlated with the photisms elicited, rather than with the emotional categories stated in the IAPS manual. Interestingly, pictures 0021, 0026 and 0029, showing a close-up of the same person with a smile, with an angry expression, and with a neutral face, were all "green" (negative) to R. However R pointed out that he perceived the actor's looks as asymmetric and unpleasant independently of the facial expression.[4] The picture 0032 showing a handgun pointing at someone's head is considered esthetic and red by R. Blood-spattered scenarios elicit green auras and are associated with negative valence and high arousal, producing the same emotional pattern as in control subjects. Conversely, the images of the sky that trigger red photisms in R are perceived as positive and exciting, meanwhile they are considered as pleasant and tranquil for the "normal" population. In the end, R's affective responses to images are often hard to predict unless you take into account the relationship between the auras and the emotions in R.

In the Experiment 5, R again answered the SAM questionnaire for some of the IAPS images belonging to green and red categories (five items per category). However, this time the pictures were presented in a frame that was either congruent or incongruent with R's photism. For example, the image 0021 was displayed either with a congruent Olive Drab 3 color frame or with an incongruent Orange Red 3 frame. We analyzed how the congruent/incongruent condition affected the SAM scores. Our results indicated that the arousal scores were higher for congruent frames with respect to incongruent frames in the red category, $F(1, 4) = 10.28$, $p < 0.03$. The same was observed for the valence scale of the green category, $F(1, 4) = 16$, $p < 0.001$. The C statistic was significant in the time series of 5 "no frame-pictures" followed by the 5 pictures of the same photism category, but with congruent colored frames. It occurred for arousal in red pictures (C=0.58, p=0.02) and also for valence in green pictures (C=0.7, p=0.04). The difference between the "no-frame condition" and the "incongruent frame condition" was significant only for the valence scale of green pictures (C=0.48, p=0.04). The average arousal value for red pictures was 6.9 for the frame-congruent condition and 5.6 for the frame-incongruent condition. The average valence for congruent green pictures was 2.8 versus a mean value of 4.2 for green pictures with an incongruent frame. Simply said, the color frames could influence R's affective judgments following R's subjective emotional values of the colors. (See Figure 1.)

INSERT FIGURE 1

Aura Stroop (Experiment 6)

We wanted to see if R's aura photisms could interfere with a color-naming task (a Stroop-like task that we called Aura Stroop). We used 21 pictures selected at random from the Table 2 (five or more pictures per color category). Every image was presented on a computer screen for 3 seconds and followed immediately by a screen-sized color patch. The subject's task was to indicate the color of the patch (yellow, red, green or brown) by striking a key: V for yellow, B for red, N for green and M for brown. The keys were covered with patches of corresponding colors to facilitate the response. All the IAPS images were combined with all the colors. For each color category (yellow, red, green or brown) we randomly picked one specific shade out of the colors that R had selected as corresponding to his photisms in preceding experiments. R ran two sessions of 84 trials each. The experiment was designed with E-prime (Schneider et al., 2002). The instructions emphasized precision over speed.

We performed two item analyses, one considering the four color categories and another considering the 21 pictures. We found Stroop effect in both cases, $F(1, 3) = 20.92$, $p<.019$ and $F(1, 20) = 23.76$, $p<.0009$ respectively. (See Figure 2.) The mean RT was 620 ms for congruent and 870 ms for incongruent trials. For accuracy, the means difference for congruent (100%) and incongruent trials (92%) was significant, $t=39.68$ ($p=0.00$).

INSERT FIGURE 2

To further support our analysis, we also ran a randomization resampling test with 100,000 samples, using Resampling Procedures freeware (Howell, 2002). This additional test demonstrated the significance of our data, $t = 4.098$ ($p=0.00008$), ruling out the possibility of random effects. In summary, R's aura photisms triggered by visual images seem to produce Stroop interference in color naming. We did not detect any Stroop effects for 10 control subjects (non-synaesthetes with normal color vision) who ran the same task; $F(1, 9)=0.26$, $p<0.61$. Mean RTs were 531 ms and 546 ms for congruent and incongruent trials respectively.

In summary, for R we observed no traditional color Stroop but we found Aura Stroop triggered by imaginary colors. On the other hand, the control subject did not show any Aura Stroop but normal color Stroop effects were present.

General discussion

Before analyzing any theoretical implications of our study, we would like to mention a few methodological aspects. Within the field of color perception research, it is of vital importance to discriminate between "real colors" (i.e., the physical qualities of an object), "perceived colors" (i.e., the quale of color) and "color labels" (i.e., the verbal descriptions of the experience of color). The procedure described in Experiment 3 allowed us to correlate R's verbal reports with "real colors" and subsequently to use this information to study R's subjective experience. We consider this methodological approach as fundamental for experimental exploration of synaesthesia and of qualia in general.

Experimental data suggests that R's photisms are strongly related to emotions, modulating his judgments about people and objects. Albeit rare, emotionally mediated synaesthesia has been reported elsewhere, particularly as a reaction to the affective valence of words and to faces of known persons (Ward, 2004). In fact, a recent theory suggests an existence of hyperconnectivity between limbic regions and cortical areas responsible for color processing in synaesthetes (Ramachandran & Hubbard, 2001b). This could explain both the emotional responses that sometimes accompany the photisms (Cytowic, 1993) and the phenomenon of emotionally triggered auras. Nevertheless, in comparison with the cases reported up to date, R shows a much wider range of "emotional photisms", not limited to the lexical stimuli or the people's faces. More interestingly, while some of R's affective responses follow common patterns, others do not. For example, blood is exciting and of negative emotional valence for R. According to research in color psychology, the relationships between colors and emotions are quiet universal; for most people red is exciting and blue is calming (Heller, 2004). Hence an image of the sky usually has soothing effects on us. However, the latter relationship between an object and an affective response seems to be inverted in R who perceives the sky as stimulating and exciting because of its association with red photism. In this sense, R's peculiar synaesthesia could make Dennett's "inverted spectrum experiment" (Dennett, 1988; see Locke, 1690, for the original inverted spectrum argument) a reality.[5] Dennett's question is: what would happen if we changed someone's brain wiring in such a way that he would see red skies and blue blood? If this person kept using a "red" label for blood and a "blue" label for the sky, the experimenter might not be able to assess the value of the qualia, given that the inverted-spectrum person would behave in all aspects just like we do. The study could not be accomplished by comparing verbal accounts of red and blue objects because the subject would use the same verbal terms as "normal" control subjects. In other words, it would be unattainable for a scientist to show conclusively that two subjects were experiencing different subjective color spectra (Dennett, 1988). In R's case the qualia inversion is not complete, i.e. R perceives the difference between real colors and his photisms. However, the latter are qualitatively different from normal people's experiences and they consistently affect R's reactive dispositions. Therefore, we can obtain differential behavioral measures with respect to the normal population (unaffected by synaesthesia and/or daltonism) and we can also take up Dennett's inverted qualia approach to explore what goes on with R. For example, does R experience arousal when watching the sky? Or is it the other way around and R's reactive dispositions to objects remain unaffected? R's assessment of IAPS images shows that his reactions can vary with respect to normal population, depending on the photism. In some cases images that are either positive or negative for most of us, acquire an opposite affective valence for R. However, we are not dealing with a chaotic cross-wiring between stimuli and responses. R's reactions seem to follow a relatively stable pattern of relationships between photisms and real world objects, where emotion is the key factor. Even if we observe certain variability in R, such as when smiling faces can elicit either red or green aura, emotional connotations remain always the same: disgust is green, sexual attraction and beauty are red, and joy and pain are yellow.

Although our data does not allow for causal inferences (i.e., to distinguish whether an aura is green because the perceived image is unpleasant or vice versa), the experiments show that R's qualia and his reactive attitudes are firmly connected: changes in qualia lead to changes in reactions or the opposite. However, R's qualia are not rigidly linked to the early sensory perception. Following Dennett's distinction between early and late pathways, we can say that there is certain variability in early pathways (associations between items of the same category and photisms). This suggests that reactive judgments are not direct outputs of perceptual functions. On the other hand, there is no variability in late pathways (associations between photisms and emotional reactions). Therefore, Dennett's thought experiment about the coffee masters makes no sense because the quale and the reaction seem to be rigidly connected and cannot change independently.

As we have seen in Experiment 1, R shows no Stroop effect which is probably a consequence of his daltonism. Interestingly the photisms triggered by IAPS images do lead to a

Stroop-like interference. Now we can turn to a philosophical question: Do the colors exist in the real world (i.e., are they physical qualities of objects) or are they only a projection of our minds (i.e., do they constitute a subjective quality)? R experiences both real colors (bottom-up processing) and mental, synaesthetic colors (top-down processing). How do these two sources of color experience interact to set up R's color perception? Current research suggests photisms produce cortical activation patterns in a very similar way as real colors do. For example, Hubbard et al. found that when looking at letters and numbers, fMRI responses in color-selective areas (V4) were larger for grapheme-color synaesthetes than for control subjects (Hubbard et al., 2005). The central issue is what kind of processing can lead to discrimination between different color categories. Churchland (1989) describes a possible mechanism by which the human visual system comes to recognize colors: when a newborn first sees a color, a specific neural pattern is set up within V4. Let us say that "blue" corresponds to X-oscillation in V4, "red" is equivalent to Y-oscillations, etc. In R's case, due to his daltonic condition, the patterns for red and green must be very similar in the same way as the patterns for a dark red and just a slightly darker red can be indistinguishable for a normal person. In other words, R's Y-oscillation would be common for red and green, making two neighboring shades impossible to differentiate. What happens when R observes a sky? We can expect that there is an X-oscillation due to the blue color of the sky and a Y-oscillation due to the red photism. The latter is followed by a positive emotional response of pleasant arousal.[6] However, what happens when a blood-spattered scene triggers a green photism? In R's brain the oscillations for red and green should be impossible to distinguish. In theory, it could be that the oscillations for real colors of red and green were alike while the patterns for red and green photisms were different. However, following Churchland's approach, this explanation seems less plausible. We consider that both the red of the blood and the green photism activate a Y-oscillation. So how can we explain that the same oscillation pattern can lead to positive feelings in the case of the "red" sky and negative ones for "green" blood? It is possible that color categories in V4 are not established only by experience but they are intrinsic to some extent. Perhaps color perception is also dependent on interconnections of V4 with other brain areas, such as structures involved in emotional and verbal processing. (See also speculations put forward by Ramachandran & Hubbard, 2005, based on their observations of a color blind synaesthete S.S.)

In conclusion, the approach of the present study to phenomenological experience is an instrumentalistic one. We think that the notion of quale provides an explanatory power to describe and understand R's emotional reactions to the outer world. R as a subject is unique in at least two ways. First, although he suffers from a perceptual impairment of color vision that most likely leads to the absence of color Stroop effect, his synaesthetic condition produces an unusual Stroop elicited by phantom colors. Secondly, the pattern of R's emotional reactions linked to photisms demonstrates that in any case, an inverted spectrum is a real possibility. The case study that has been presented raises further questions about the emotional value of colors both in synaesthetes and normal population. Are colors an intrinsic category hardwired in the brain? Is there a general pattern of emotional significance in relation to these categories? We expect future research to inspect the plausibility of these hypotheses.

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Figures and tables

Table 1: Correspondence between R's photisms and real colors

Category	*Selected color shades within each category*	*Color**	*RGB code*	*R's verbal description*
Red photism	Shade 1: Red3		205,0,0	Intense red - sexual and esthetic
	Shade 2: OrangeRed3		205,55,0	Power red
Green photism	Shade 1: OliveDrab3		154,205,50	Sick green
	Shade 2: OliveDrab1		192,255,62	
	Shade 3: Grey11		28,28,28	Disgusting green or brown-fear
	Shade 4: Chartreuse4		69,139,0	Lettuce green
Yellow photism	Shade 1: Yellow		255,255,0	Pointy/sharp yellow – pain, joy and shine
	Shade 2: Light Yellow		255,255,224	Pale yellow
Brown photism	Shade 1: Tan4		139,90,43	Pale brown

* It must be stressed that the color samples may not be 100% accurate due to color shifts in printing.

Table 2: IAPS images used in Experiments 4 through 6

Category:	***Images (IAPS code and verbal description):***
Red photism	**Shade 1**: 0090 – hand holding a handgun, 0131 – closeup of a male face, 0157 – planet Earth, 0193 – young woman in a colorful sari, 0222 – close-up of a cello, 0321 – spacecraft in space, 0327 – hand holding a handgun, 0332 – man with a pistol pointing to his head, 0379 – young muscular mulatto, 0438 – nude of a young black woman, 0478 – set of military automatic knives, 2005 – portrait of a young man smiling, 2025 – portrait of a good-looking young woman, 2375 – portrait of a good-looking mulatto woman, 4537 – young man with a tattoo on his back
	Shade 2 : 0086 – landscape with rocky mountains covered with snow, 0156 – sky with plenty of white clouds, 0158 – desert landscape, intense blue skies, 0265 – sky with plenty of white clouds, 0325 – sky with plenty of white clouds, 0380 – muscular young man working out, 0393 – man walking on the top of a mountain, blue skies, 0434 – close-up of a white man kissing a smiling black woman on her cheek, 0446 – naked young couple resting on a white bed, 0455 – climber on the top of a mountain, snowed rocky hills in the background, 1731 – African landscape with two lions next to a pond, white clouds, 2278 – Indian American woman and a kid, 4503 – portrait of a muscular black man, 4676 – naked young couple embracing, 5551 – sky with plenty of white clouds, 5661 – aesthetic picture of a cavern wall, 6311 – young good-looking woman with a junkie look, smoking, 8186 – sky surfer above mountains, in action
Green photism	**Shade 1 and 2**: 0021 – young man smiling, 0026 – young man with an aggressive facial expression, 0029 – young man with neutral expression, 0080 – erotic take of a naked young woman with her genitals exposed, 0096 – blue umbrella (opened), on the floor, 0135 – mid-aged couple riding on bicycles, smiling, 0137 – sweaty fat older man holding a mug of beer, 0145 – young woman in a wet elastic t-shirt coming out of the sea, 0148 – naked sporty man standing, with his genitals exposed, 0149 – naked man sitting on a balcony, 0166 – close-up of an antique watch, 0168 – mid-aged man in a library, working on a computer, 0190 – portrait of a mid-aged man with neutral expression, wearing a beret, 0192 – trio of smiling elderly man dressed in black tuxedos, 0194 – portrait of a man with neutral expression
	Shade 3 : 0005 – tarantula spider, 0033 – mutilated human head, 0035 – mutilated dead body 0075 – half naked man with badly burnt body, 0076 – mutilated corps, 0077 – mutilated bloody hand, 0117 – burnt dead animal, 1205 – close-up of a tarantula spider, 2981 – man carrying a head of a deer, covered with blood, 3068 – corps mutilated beyond recognition, 9301 – toilet splattered with feces, 9471 – Dunkin' Donuts building destroyed by fire
	Shade 4 : 0121 – close-up of a snake with a wide-open jaw, 0138 – mutilated human head, 0139 – close-up of human eyes suffering from some serious ophthalmologic illness, 0140 – infant head with a malformation syndrome, 0179 – two Asian health workers carrying an unconscious blood-coverer woman, 0197 - drug addict taking a shot, 0198 – detail of a man urinating, 0199 – extremely skinny, naked black man rubbing his face against the rear of an animal, 0202 – mutilated human head, 0203 – close-up of a female face with bruises, 0204 – naked female torso with a long operation scar on the abdomen, 0233 – randomly scattered trash, 0234 - toilet splattered with feces, 0292 – toilet full of vomit, 0360 – dead animal decomposing, 0361 – nuclear cloud
Yellow photism	**Shade 1 :** 0049 – close-up of coniferous needles, 0201 – a kid with a yelling expression 0240 – fishermen cutting fish, 0251 – kid being treated by a dentist, 0266 – city landscape with fireworks, 0315 – a mid-aged man in a white shirt covered with blood, yelling, 0319 – explicit photography of a sexual intercourse of a young couple, 0331 – close-up of a woman with a knife on her throat, threatened by a man, 0322 – fireworks, 0362 – men standing around a burning cross, dressed in a Ku-Klux-Clan outfits, 0427 – close-up of a canine head with wide-open jaws, 0476 – stylized photo of a male with syringes tied to his head, 1419 – bird next to a nest with two baby-birds, 1525 - close-up of a canine head with wide-open jaws, 8485 – man running away from a burning F1 car
	Shade 2 : 0009 – white water bird, 0092 – facility with white rockets pointing to the sky, 0103 – modern urban architecture, 0180 – man working, dressed in an protective clothing and a gasmask, 0340 – fork with spaghetti above a steaming pot full of Italian food, 0400 – cloth placed on an ironing board, 0422 – exploding fighter airplane in the air
Brown photism	**Shade 1:** 0057 – empty woven basket, 0059 – book on the floor, 0071 – bearded mid-aged man, 0072 – very old man with white beard and a hat, 0093 – rolling pin, 0212 – massive wooden armchair with leather straps for fixating one's arms and legs, 0220 – pushcart, cartons and piles of paper in an office, 0274 – dustpan, 0294 – dirty kitchenware, 0309 – kid sitting behind a chessboard, 0397 – empty cup on a wooden surface, 0399 – empty plate on a wooden surface, 0401 – wooden chair on the floor 0462 – stool, 0463 – hammer

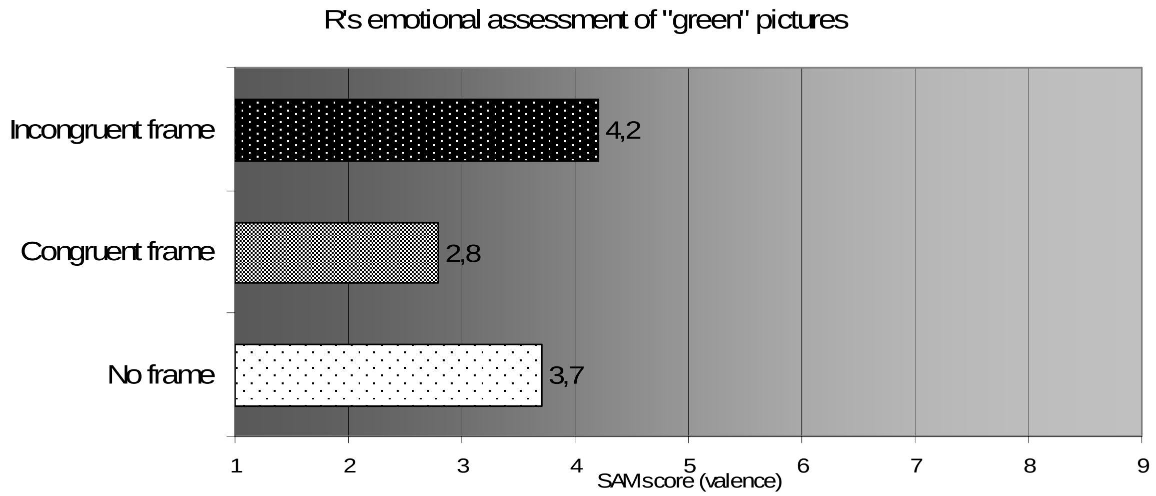

Figure 1: R’s subjective perception of emotional valence of IAPS images is influenced by color frames. An incongruently colored frame leads to a slightly more positive evaluation of the otherwise negative green-aura pictures, while a congruent frame makes them even more negatively perceived.

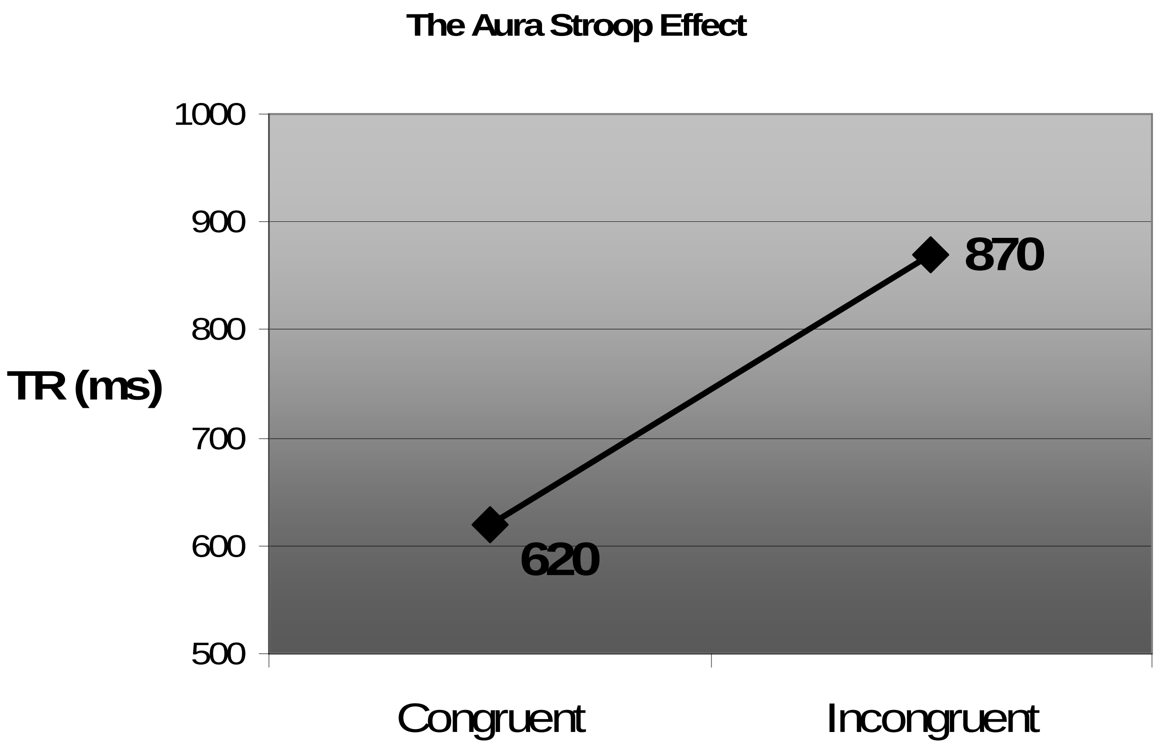

Figure 2: The Aura Stroop Effect. In Experiment 6, each of the 21 IAPS images were presented on a computer screen for 3 seconds and followed immediately by a screen-sized color patch. R's task was to indicate the color of the patch. When the hue was incongruent with the aura associated to the picture stimulus, R took significantly longer to respond.

Footnotes

[1] It should be noted that this cognitive-conceptual synaesthesia cannot be explained purely by standard graphemic/phonemic processes, i.e. R's concept-color and name-color associations are not predictable on the basis of the graphemes or phonemes making up the word. R's friend Luis is red despite the fact that there are no "red letters" in his name.

[2] R reports that very rarely the color elicited is not consistent with his knowledge about a person (e.g., a good friend bringing out "negative", green color photism). Since this kind of "color contradictions" is highly unpleasant, he tries to suppress or at least not to attend to the photism. (The feeling could be compared to a situation where a close person suffers from halitosis. It might be very uncomfortable, but people normally do not change their attitude towards the person in question.)

[3] R also presents relatively common grapheme-color photism. However, synaesthetic color of words or numbers consisting of more than two graphemes usually is not associated with the photisms of individual graphemes. R does not report any incongruent specific photisms related to the words "red", "green" and "blue".

[4] This suggests that certain low level features like symmetry might play a role in R's synaesthesia in addition to the emotional valence.

[5] R's "inversion" is in terms of relations between objects and emotions (e.g., "exciting sky"). We would like to stress, that common associations between colors and emotions are preserved in R: red is exciting for him as well as it is for normal population.

[6] According to R, the vision of the sky produces an intense mental activation that he experiences as very pleasant. This kind of arousal is similar to the excited state of mind when R is engaged in his favorite artistic activity - painting.