EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY
2009, 21 (5), 703–723

Psychology Press
Taylor & Francis Group

Congruence or coherence? Emotional and physiological responses to colours in synaesthesia

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Lexical–chromatic synaesthesia is a condition in which letters and/or words elicit percepts of synaesthetic colours, termed photisms. Anecdotal data suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world, e.g., it can be annoying and unpleasant for them to see a letter printed in a colour different than the respective photism colour. For R, a synaesthete subject who participated in the present study, the photisms possess specific emotional values (a red photism is pleasing and attractive, green is repulsive and unpleasant, etc.). In contrast to the anecdotal data, R does not always find the colour–photism incongruence to be disturbing. More importantly, he states that it is the emotional coherence between the stimulus and the corresponding photism that matters. In a series of experiments, we studied this new concept of emotional coherence on three levels—subjective (self-report), behavioural, and physiological, corroborating R's introspective statements. Besides the implications of the concept of coherence itself, the results presented here suggest that even highly subjective cognitive constructs can be approached and measured experimentally, uncovering the workings of the underlying psychophysiological mechanisms.

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This study was supported by a grant from the Spanish Ministry of Education and Science (SEJ2006-09029) to EGM. MH's research activities are supported by a scholarship from AECI, Ministry of Foreign Affairs (Spain). We thank R for his participation.

http://www.psypress.com/ecp DOI: 10.1080/09541440802176292

Keywords: Letter-colour synaesthesia; Emotional synaesthesia; Startle reflex modulation; Physiological responses to colours.

Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound leads to the perception of colours. The first legitimate report on synaesthesia is attributed to Sachs in 1812 (cited in Krohn, 1892; also in Dann, 1998), who described the condition in himself and his sister as a part of a PhD dissertation on his albinism. In the nineteenth century there might have been a dozen of reported cases of possible synaesthetes but these early studies seem to have aroused very little interest (for a review, see Wheeler, 1920). Within the scientific community synaesthesia was "brought into existence" by Francis Galton (1880/1997), who observed that a small number of people had the peculiar capacity of experiencing the stimulation of one sense in a multimodal way, i.e., in two or even more sensory modalities (Ramachandran & Hubbard, 2001b). Unfortunately, many decades after Galton's discovery, "seeing sounds" was still considered a mere curiosity or even a fake. The comeback of synaesthesia to the domain of empiric science occurred a few decades ago, when a number of contemporary researchers have transformed synaesthesia into a scientific reality whose existence can be demonstrated and studied empirically (Hochel & Milán, 2008). Hubbard and Ramachandran (2005; Ramachandran & Hubbard, 2001a, 2001b) emphasised the importance of the investigations into the neural substrates of synaesthesia for our understanding of the organisation of the brain, as well as for the study of more enigmatic properties of the human mind such as the qualia, the language, and the metaphor. The present case study is in line with this previous psychophysiological research, seeking to explore the interplay between photisms and real colours in chromatic synaesthesia. In a series of experiments we sought both behavioural and physiological indexes in order to reveal the influence of synaesthetic perception on a synaesthete's performance and bodily reactions.

The subject of our study, R, is a 20-year-old male who, in addition to the relatively common grapheme–colour synaesthesia, presents a broad variety of synaesthetic associations. Not only numbers and letters but also first names, surnames, town and city names, abstract concepts, faces, natural sounds, and music elicit percepts of colour in his mind's eye (following Dixon, Smilek, & Merikle, 2004, R could be categorised as an "associator" synaesthete). For example, the town of Granada is "red", hope is "white", intelligence is "yellow", classical music is "dark brown", both pain and joy are "yellow", love is "red", etc.[1] R is a unique case of synaesthesia for at least two reasons. First, he suffers from a mild form of red-green colourblindness (see Milán et al., 2007) and, second, he shows an unusual variety of emotional synaesthesia where most of his photisms can be subjectively categorised in line with their emotional valence. When we explored the subject's synaesthetic sensitivity to human faces and visual scenes, an underlying pattern emerged. Pleasing pictures and faces were typically red to R, while repulsive visuals or unpleasant human faces elicited a pale green colour in R's mind's eye. As a general rule, R's most distinctive photisms presented definite emotional logic: Positive emotions seemed to be associated with red or purple colours; green usually indicated something repulsive or unpleasant; brown photisms were triggered by uninteresting or boring objects; blue was emotionally neutral; and yellow was the only colour that was somewhat ambivalent to R, with both joy and pain associated to it. Finally, the association of colours to emotions was also present in R's reactions to real colours (Milán et al., 2008).[2]

The fact that R's emotional responses to colours appeared to be much more pronounced in comparison to nonsynaesthetes was not a surprise. Numerous papers (e.g., Cytowic, 1989, 1993; Ramachandran & Hubbard, 2001b; Ward, 2004) reported strong emotional responses to colours and photisms in synaesthetes. Anecdotal data suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world (Cytowic, 1989; Ramachandran & Hubbard, 2001b). For instance, for a lexical–chromatic synaesthete it can be particularly "annoying" when a letter or a word is presented in a colour incongruent with respect to the photism colour. Such incongruence can lead to a modulation of emotional judgements, as has been reported recently by Callejas, Acosta, and Lupiáñez (2007). In this single-case study, a synaesthete subject, MA, who experienced colours for words, was asked to assess the emotional valence of a set of words, according to their respective semantic meanings. The authors found that for MA incongruently coloured words affected the judgement of emotional valence, leading to a more negative rating with respect to black words or congruently coloured words. Furthermore, the

[1] For the sake of clarity it should be noted that R's lexical-chromatic synaesthesia (colours for words) is independent from his grapheme–colour synaesthesia, i.e., photisms for words are neither a compound of colours for individual graphemes, nor they are tinted with the colour-photisms of the first letter or letters.

[2] Even though colours also have emotional connotations for normal, nonsynaesthete population (e.g., Heller, 2004), they are not as specific as observed in R. Whereas normal people's perception of emotional values of colours tend to be ambiguous (e.g., red can be perceived as erotic and energising, but it can also evoke blood and aggression.), as a general rule R seems to associate certain colours (red, purple, violet) with positive emotions, and other hues (shades of green) are laden with negative affect.

negative affect elicited by the colour–photism incongruence also interfered with a speeded valence categorisation task.

Interestingly, the synaesthete studied by our group mentioned that it was not the colour–photism incongruence that bothered him the most. When discussing visual art, he claimed a strong dislike for specific artistic styles where "the use of colours was completely groundless and incoherent". Nonetheless, he pointed out that he did not expect specific hues (corresponding to his photisms) to be applied in art, following a would-be congruency rule in a straightforward manner. For instance, even though the physical beauty or the strength is red to R, it is "completely acceptable" when such artistic motifs are depicted in purple, orange, or even yellow hues. This is because the emotional values of these colours are not in conflict with the inherently positive feelings associated to the red hue. On the other hand, for R it is "absolutely intolerable" when these themes (physical beauty and strength) are represented in shades of green, because green has the opposite (negative) emotional charge with respect to the colour red. The same "logic" applies to situations when words are depicted in a colour that differs from the synaesthetic concurrent, or even to emotionally neutral stimuli, such as numbers, printed in incongruent colours (e.g., the number 5 is red to R, but it does not bother him if it is printed in different colours as long as the shade is emotionally consistent with the photism).

In summary, if we were to trust R's introspective reports, more than mere congruency mattered. R seemed to be sensitive to the emotional coherence between the stimulus and the corresponding photism. The primary goal of the present experimental series was to determine whether the subjective impact of emotional colour coherence, as reported by R, had any behavioural and physiological correlates. Since we wanted to examine R's emotional dispositions towards colours (real colours and photisms) per se, we used number stimuli as synaesthetic inducers. (It should be noted that numbers do not have any emotional charge for R.) First, we wanted to analyse R's feelings concerning both photisms and colours in a quantifiable manner (Experiment 1). This was achieved using Self-Assessment Manikin (SAM; Moltó et al., 1999; Vila et al., 2001). Second, we wondered whether or not R's emotional dispositions towards colours had any behavioural consequences (Experiment 2). This goal was accomplished by means of an odd/even decision task, where numbers were presented in coloured frames which could be or not emotionally coherent with respect to the photism colour. Finally, we subjected R to a psychophysiological testing that would further corroborate subjective and behavioural measures (Experiments 3a and 3b).

EXPERIMENT 1: EMOTIONAL VALUE OF COLOURS AND PHOTISMS

The main ambition of Experiment 1 was to evaluate R's emotional responses to both real colours and photisms, exploring the interplay between the two. However, before proceeding with the exploration of R's emotional responses to real colours and photisms, it was necessary to obtain a thorough classification of R's synaesthetic colours. This was achieved by means of a customised computer program developed in the C# language, which would display a synaesthetic inducer (a number in this case) on the left side of the screen and a palette of colour shades on the other side. Samples of colours were vertically arranged in rectangles; both the grapheme (in white) and the colour samples were presented on a black background. There was a scroll button next to the colour samples that allowed the subject to scroll up and down to see all the shades of a given colour (see Milán et al., 2007, for a complete description of this procedure). Information previously gathered from R allowed us to reduce the number of colour shades presented for each stimulus, using only shades of the colour that R reported as his synaesthetic response to a given number (e.g., shades of red for the number five). R's task was to observe a stimulus on the left side of the screen and then to choose a colour sample that was closest to his synaesthetic experience. His responses were recorded in a data file, including colour name and its hexadecimal encoding. Following this procedure, R went through the numbers from one to nine. After selecting the colour hues matching his photisms, R was asked to categorise all the shades as emotionally positive, negative, or neutral. In Table 1 you can see the correspondence between the numbers and specific colour shades as well as the associated emotional value. It should be noted that in spite of being Daltonic, R was fairly confident about the colours corresponding to his photisms. The number–colour correspondence was reliable and consistent over time. In a retest 2 weeks later, R selected the same colour hues in 92% of the trials. (Errors typically consisted in choosing the neighbouring shade of the same colour.)

Method

The hues matching R's synaesthetic experience were employed to create coloured frames which would be displayed along with numbers 1 to 9 (except number 7 which was not used because it did not trigger any photism in R). For the frames, we used three positive colours (yellow2/number 3 photism; steel blue3/number 4 photism; red3/number 5 photism), three neutral colours (gainsboro/number 1 photism; firebrick/number 2 photism; grey71/number 6 photism), and three negative colours (brown-black/number 8 photism; ochre/

TABLE 1
Results of the assessment of R's photisms with the corresponding representation in real colours

Number	*Colour name*	*RGB code*	*Colour sample*	*R's subjective colour name*	*Emotional quality of the colour*
1	gainsboro	220,220,220		white	neutral
2	firebrick	178,34,34		red	neutral
3	yellow2	238,238,0		yellow	positive
4	steel blue3	79,148,205		blue	positive
5	red3	205,0,0		red	positive
6	grey71	181,181,181		pinkish grey	neutral
8	—	54,36,1		brown black	negative
9	—	255,255,0		ochre	negative

For numbers 8 and 9, R did not find an appropriate colour equivalent to his photism within the samples offered. He preferred to use Microsoft® Paint colour mixer to get hues exactly matching his photisms. Number 7 is not included because, according to R, it does not induce any synaesthetic response. To view this Table in colour, please visit the online version of this issue.

number 9 photism; desaturated green/RGB: 119,167,89).[3] Each stimulus consisted in a number presented in a coloured frame which was either congruent or incongruent with the photism associated to the number. In addition to the congruent/incongruent condition, we also took into account the emotional values of both the photisms and the colour frames. As a result, the experimental design would include the following independent variables: frame (congruent, incongruent negative, incongruent positive) and photism valence (positive, negative, or neutral). Note that when the frame colour was different (incongruent) with respect to the photism, it could be or not be emotionally coherent with the valence of the photism associated to the inducer. This setup led to three frame–photism combinations, as depicted in Figure 1.

R's task was to evaluate the emotional quality of these stimuli, using a computerised Spanish version of the SAM (Moltó et al., 1999; Vila et al., 2001), which allows to assess a given stimulus on three emotional dimensions: Valence (pleasant–unpleasant), arousal (high–low), and dominance (in control–dominated). 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. Given the objectives of the experiment, only valence and arousal dimensions were included. This allowed for an evaluation of the stimuli as pleasant, neutral or unpleasant (valence) and as producing either low or high arousal. The

[3] In order to put together a smooth experimental design, we added another "negative" colour hue that had been obtained in our pilot experiments, namely a desaturated green shade (RGB: 119,167,89).

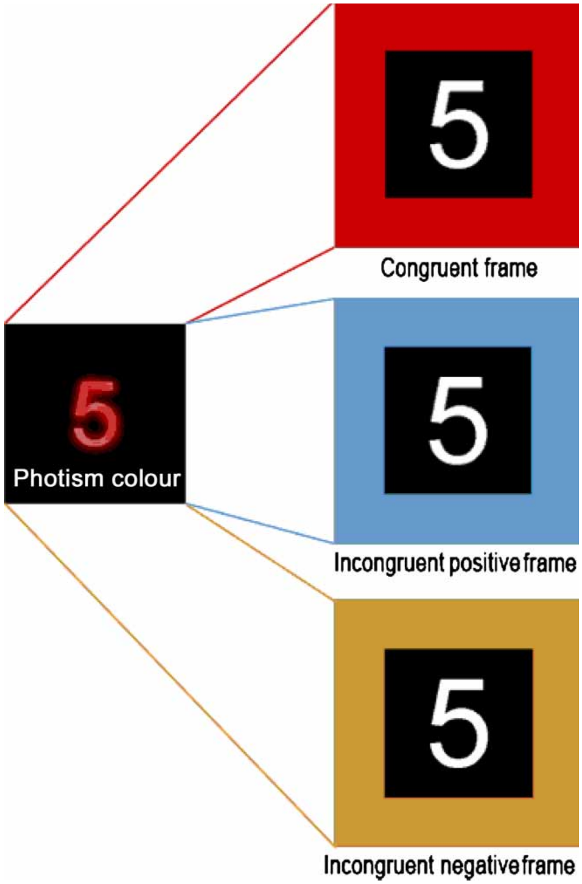

Figure 1. We combined colour frames with number stimuli that were either congruent or incongruent with the photism associated to the number. In addition to the congruent/incongruent condition, we also manipulated the emotional value of the colour frames in such a way, that the valence of the frame could be the same as or opposite to the valence of the photism. In this example, the red photism elicited by the number 5 is perceived as pleasant by R, being emotionally consistent with the blue, positive frame and inconsistent with the ochre frame which is emotionally negative. To view this figure in colour, please see the online issue of the Journal.

resulting scores permitted us to put a figure on R's subjective feelings with respect to the framed number stimuli. The experiment was run on a PC using e-prime (Schneider, Eschman, & Zuccolotto, 2002). Each number stimulus was presented on the screen for 6 s and immediately followed by the SAM questionnaire screen. After responding to the SAM scale by clicking on the corresponding value, the next stimulus was shown on the screen.

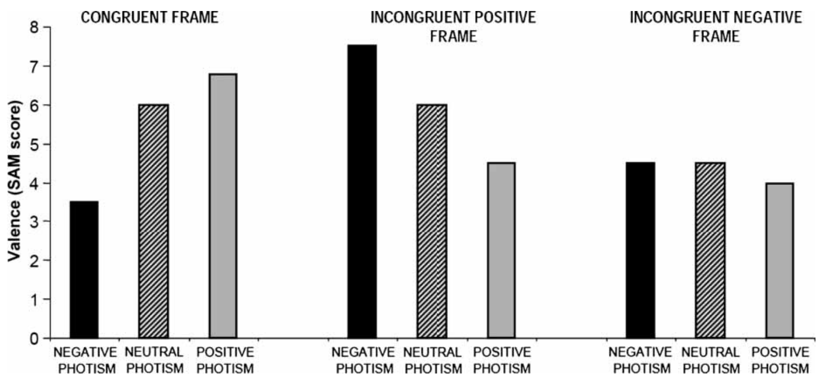

Figure 2. Emotional assessment of framed number stimuli. The incongruence between the colour of the photism and the colour of the frame does not lead to a more negative emotional disposition automatically. When the two valences are not consistent (e.g., a positive photism and a negative frame or a neutral photism and a positive frame), the valence of the frame seems to prevail, shifting the emotional perception in the corresponding direction. When the two valences agree (negative photism and negative frame), the valence score tends towards more central values, i.e., it gets higher for the negative photisms/frames and lower for the positive ones.

Results

First, we analysed how the congruent/incongruent condition affected the SAM scores. The results revealed that the arousal scores were higher for congruent frames (mean score 6) with respect to incongruent frames (mean score 4.2), $F(2, 10) = 6.67$, $p < .01$. For the valence scores, we found a significant interaction, $F(4, 10) = 8.98$, $p < .002$, between the frame variable (congruent, incongruent negative, or incongruent positive) and the perceived valence of the photisms associated to the numbers (see Figure 2).

More specifically, for the photisms previously categorised as neutral, we found significant differences in valence between the congruent frame condition and the incongruent negative frame condition, $F(1, 5) = 7.5$, $p < .04$, as well as between the incongruent negative frame and the incongruent positive frame condition, $F(1, 5) = 81.2$, $p < .00$. For negative photisms, the following differences in valence were significant: the difference between the congruent frame condition and the incongruent negative frame condition, $F(1, 5) = 22$, $p < .00$; between the congruent frame condition and the incongruent positive condition, $F(1, 5) = 23.33$, $p < .00$; and between the incongruent negative and the incongruent positive frame, $F(1, 5) = 5.95$, $p < .05$. Concerning positive photisms, there was a significant difference between the congruent condition and the incongruent positive frame condition and also between the congruent and the incongruent negative conditions, $F(1, 5) = 8.62$, $p < .03$, and $F(1, 5) = 10.41$, $p < .02$, respectively.

Discussion

These data imply that for R the incongruence between the colour of the photism and the colour of the external stimulus does not straightforwardly lead to negative emotions, as has been suggested elsewhere (Callejas et al., 2007). There is an interplay between the valences of frames and photisms. In our opinion, the pattern observed in our data reflects the workings of an underlying mechanism that we termed emotional coherence. Here (and in the subsequent experiments), the coherence is defined as an interaction between the photism valence and the frame colour valence. Considering the SAM scores, when the two valences are not consistent (e.g., a positive photism and a negative frame or a neutral photism and a positive frame), the valence of the real colour (i.e., the frame) seems to prevail, shifting the emotional perception in the corresponding direction. More specifically, for the combination of a negative photism combined with a positive frame it was 7.5 (more positive with respect to both the congruent frame and the incongruent negative frame conditions). In case of a positive photism and a negative frame the mean valence score was 4 (more negative than in the congruent frame condition). However, it should be noted that for positive photisms the difference between the incongruent negative and the incongruent positive frame was not significant. This might be due to the fact that in those cases where the two valences agree (negative photism and negative frame or a positive photism and a positive frame), the valence score seems to lean towards more central (neutral) values, i.e., it gets higher for the negative photisms/frames and lower for the positive ones. (The mean valence was 4.5 in both cases.)

EXPERIMENT 2: EMOTIONAL INCOHERENCE BETWEEN REAL COLOURS AND PHOTISMS AFFECTS PERFORMANCE

Experiment 2 assessed the impact of emotional coherency onto R's behavioural performance.

Method

The same stimuli as in Experiment 1 were used to design an odd/even decision task. On a given trial a framed number was presented on a computer screen for 3 s. R's task was to decide, as fast as possible, whether the number was odd or even. The responses were emitted by striking a key (N for odd, B for even in Session 1; inversed mapping was used in Session 2). R ran two sessions of 72 trials each (8 numbers $\times$ 3 frames $\times$ 3 trials per condition). The instructions emphasised precision over speed.

Results

We performed an item analysis considering the numbers. The design had the following structure: Photism valence (positive, neutral, negative) $\times$ Frame (congruent, incongruent positive, incongruent negative), i.e., a 3×3 design. A main effect of the frame was observed, $F(2, 26) = 4.54$, $p < .02$, as well as a significant interaction between the photism valence and the frame, $F(4, 26) = 2.71$, $p < .04$ (see Figure 3). Concerning the neutral photisms condition, there was a significant difference between the congruent frame condition and the incongruent negative frame condition, $F(1, 8) = 5.43$, $p < .04$, as well as between the congruent condition and the incongruent positive condition, $F(1, 8) = 27.29$, $p < .01$. In other words, for neutral photisms we observed an increase in RT for the two incongruent conditions with respect to the congruent condition. (The two incongruent conditions

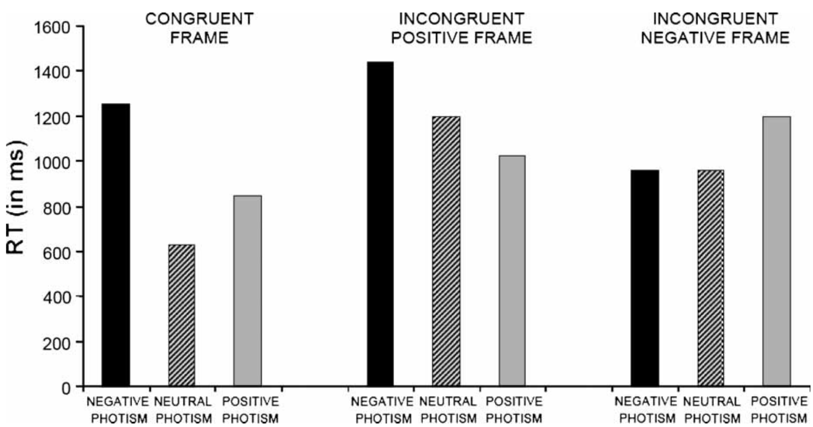

Figure 3. R's reaction times in an odd/even task with framed number stimuli. We observed that the RT performance was negatively affected when the valence of the photism and the valence of the colour frame were not consistent. Interestingly, when the stimuli were emotionally coherent, i.e., of the same valence, the frame–photism colour incongruence did not have any effect upon R's performance.

did not differ significantly.) For positive photisms, the effect of the frame was significant, $F(2, 6) = 5.43$, $p = .04$. However, we only detected significant interference in the case of the negative incongruent frame, i.e., when there was incoherence between the photisms valence and the frame valence. The difference between the negative incongruent condition and the congruent condition was close to significant, $F(1, 3) = 7.72$, $p = .06$. For negative photisms, the effect of the frame was not significant. On the other hand, when the incongruent negative frame condition was analysed across the three photism conditions, we found that the RT was longer for the positive photisms than for the neutral photisms, $F(1, 13) = 9.27$, $p = .009$, and the negative photisms, $F(1, 13) = 4.85$, $p = .042$. Therefore, we can assume that the combination of the negative photism and the incongruent positive frame interfered with R's performance. (Note that the latter is again a case of incoherence between the frame valence and the photism valence.)

Discussion

As a general rule we observed that the RT performance was negatively affected by the incoherence between the valence of the photism and the valence of the colour frame or, as we might also say, facilitated by the emotional coherence. This can be understood best by examining the pattern in Figure 3. For the incongruent conditions the photism which is of opposite valence with respect to the frame (e.g., a positive photism and a negative frame) always leads to the longest RT. On the other hand, when the colours are congruent with the photism, R's performance seems to be negatively affected by colours perceived as emotionally negative.

EXPERIMENT 3: COLOURS, PHOTISMS, AND THE STARTLE RESPONSE

The startle reflex (SR) is a bodily reaction in response to a sudden unexpected stimulus, such as a flash of light, a loud noise, or a quick movement near the face. In laboratory experiments a white noise of 95–105 dB, 50–500 ms duration and an instant rise time is usually used to produce the typical pattern of motor and physiological reactions (Martín, 2006; Vrana, Spence, & Lang, 1988). SR is a reflex action implemented within a more general defence system of the organism (Landis & Hunt, 1939). One of its main and most widely studied components in humans is blinking. Due to its overall high consistency and uncomplicated detection it is frequently used as a general index of SR, being measured through an electromyography (EMG) of the left orbicular eye muscle.

The modulation of the SR (its amplification or reduction) when viewing affect-laden images, is one of the most robust experimental effects within the SR research. The SR is typically enhanced by exposition to photographs of unpleasant visuals, while it is diminished when viewing photographs with emotionally positive content (Bradley, Cuthbert, & Lang, 1990, 1991; Lang, Bradley, & Cuthbert, 1990; Lang, Bradley, Cuthbert, & Patrick, 1993). The same effect is obtained with video sequences, reading of emotionally charged texts, and also with nonvisual stimuli such as sounds and smells (Martín, 2006). The main objective of Experiment 3 was to explore the possibility of SR modulation with photisms and real colours.

Lang (1995; Lang, Bradley, & Cuthbert, 1997) explains the aforementioned SR modulation in terms of motivational priming, as a result of emotional congruence (or incongruence) between two motivational forces. Namely, both the white noise and the unpleasant images used in laboratory SR experiments activate a defence system seeking to avoid aversive stimuli. Unpleasant photographs induce in the viewer a motivational stance that is in line with the defensive response triggered by another aversive stimulus (i.e., the white noise), therefore resulting in an amplified SR. On the other hand, positive stimuli (e.g., pleasant images, smells or music) act in the opposite direction, inducing appetitive motivation, which reduces the subject's psychophysical responses to aversive stimulation. Davis (1989, 1992; Davis, Hitchcock, Rosen, & Gordon, 1988) provided evidence supporting the idea that the same brain structures are involved in the defensive motivational system and in the SR. Several studies pointed out that the amygdala (part of the defensive system) is the principal responsible for the SR being modulated by fear (Everitt, Dickinson, & Robbins, 2001; LeDoux, 1990, 1995, 1996). A number of neural pathways allow the amygdala to control different types of response within the autonomic nervous system. More specifically, the SR seems to be modulated thanks to a pathway terminating in the caudal pontine reticular nucleus (Davis, 1997; Fendt & Fanselow, 1999).

Ruiz-Padial, Sollers, Vila, and Thayer (2003) demonstrated that, in addition to the blinking reflex, cardiac response was another significant correlate of the SR and a useful index for observing the emotional modulation effects in SR experiments. However, even though heartbeat frequency is sensitive to the emotional valence of stimuli, it is usually more complicated to obtain cardiac response measures of the SR modulation, because these effects require simultaneous activation of both the sympathetic and the parasympathetic nervous systems. In the experiment that follows, we used the heart rate phasic response as an index of the cardiac component of the startle reflex in order to study the influence of colours and photisms on R's SR.

Method

The same stimuli as in Experiments 1 and 2 were used, but there was an additional white frame condition, which served to study the influence of photisms per se. R was presented with the numbers 1, 2, 4, 5, 6, 7, and 9 with a congruently coloured frame, an incongruently coloured frame, or a white frame. (At this stage of our experimental series, we decided to eliminate the number 3 because R mentioned that he perceived the associated photism—yellow—as being "somewhat incongruent" with the number shape itself, which was slightly disturbing for him and could therefore contaminate the results.) Each stimulus appeared on a computer screen for 6 s. The SR inducing sound (white noise) was randomly presented within the time interval from 2.5 to 4.5 s. The total of experimental trials was 96 (24 per condition); in addition there were 9 trials where no sound was presented and 9 trials with no image, in order to eliminate habituation. Dependent variable was the heart rate change, operationally defined as beat-to-beat alterations in R's heart rate with respect to a baseline obtained during a 3 s period previous to the stimulus onset. The measure of heartbeat alterations was based on R peak detection. The heart rate change was obtained by measuring the heart period and transforming it into average heart rate every 300 ms.

The following equipment was used. (a) Grass polygraph with a 7P4 preamplifier to record the electrocardiogram at lead II. (b) Coulbourn audio system (modules S81-02, S84-04, S82-24, and S22-18) to generate the white noise and present it binaurally through earphones (Telephonic TDH Model-49). (The sound intensity had been calibrated with a sonometer Bruel and Kjaer, model 2235, and an artificial ear Bruel and Kjaer, model 4153.) (c) Pentium 4 PC was used to present visual stimuli. (The PC was interconnected via serial port RS 232 with a second, Pentium 2, PC which registered the polygraph signal.) (d) Advantech card (model PCL812PG), with digital input–output functions and a 12 bit analog-to-digital converter, operated by the Pentium 2 PC, to control the experimental session through the VPM software (Cook, 1997).

Results

The experimental design included the following variables: frame (incongruent positive, incongruent negative, congruent and white frame), photism valence (positive, negative and neutral), and register time (16 time points, 1 every 300 ms). General ANOVA revealed a significant interaction of the three variables, $F(90, 180) = 1.37$, $p < .03$. In order to study particular interaction effects, the heartbeat timeline was split into two segments: Stage

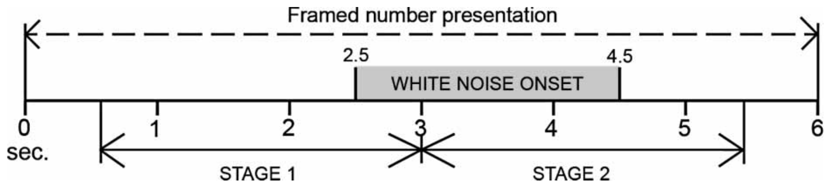

Figure 4. Schematic timeline of a trial in Experiment 3. The framed number stimulus was presented during 6 s; the onset of the SR inducing sound (white noise) occurred randomly within the time interval from 2.5 to 4.5 s. R's heart rate was registered every 300 ms during the Stage 1 (eight records) and the Stage 2 (eight records).

1 (the first 8 measurements) and Stage 2 (the remaining 8 measurements). Because the white noise was presented randomly within the time from 2.5 to 4.5 s, Stage 1 mostly contained measures recorded before the white noise onset, whereas the Stage 2 mostly included measures recorded during and after the white noise presentation (see Figure 4).

The resulting design had an additional variable called Stage (1 or 2) with a nested register time variable consisting of eight measurements (eight per stage, one per 300 ms). In order to determine the presence of the cardiac startle response (CSR) in R, we studied the interaction between the stage and the register time variables. The variables frame and photisms valence allowed us to explore the modulation of the CSR.

Given the complexity of the design, we divided the analysis in two parts. First, we considered the data from the white frame and the congruent frame conditions in order to analyse the influence exerted by the photisms and the real colours in terms of heartbeat variability. Second, we wanted to study the effect of emotional coherence between the photism valence and the colour frame valence. With this aim in mind, we contrasted the incongruent positive frame condition with the incongruent negative frame condition.

The effect of colours and photisms on the Cardiac Startle Response. The analysis included the following variables: frame (congruent or white frame), photism valence (positive, negative and neutral), stage (1 and 2), and register time. The interaction of all four variables was significant, $F(7, 14) = 5.59$, $p < .003$. The CSR modulation, considered here as a function of photism valence, only appears in the congruent frame condition. In this condition, the interaction between the photism valence (positive or negative), the stage, and the register time was significant, $F(15, 30) = 2.45$, $p < .01$. There is no such modulation effect in the white frame condition. In other words, the photisms do not alter R's cardiac startle response while the real colours do (see Figure 5).

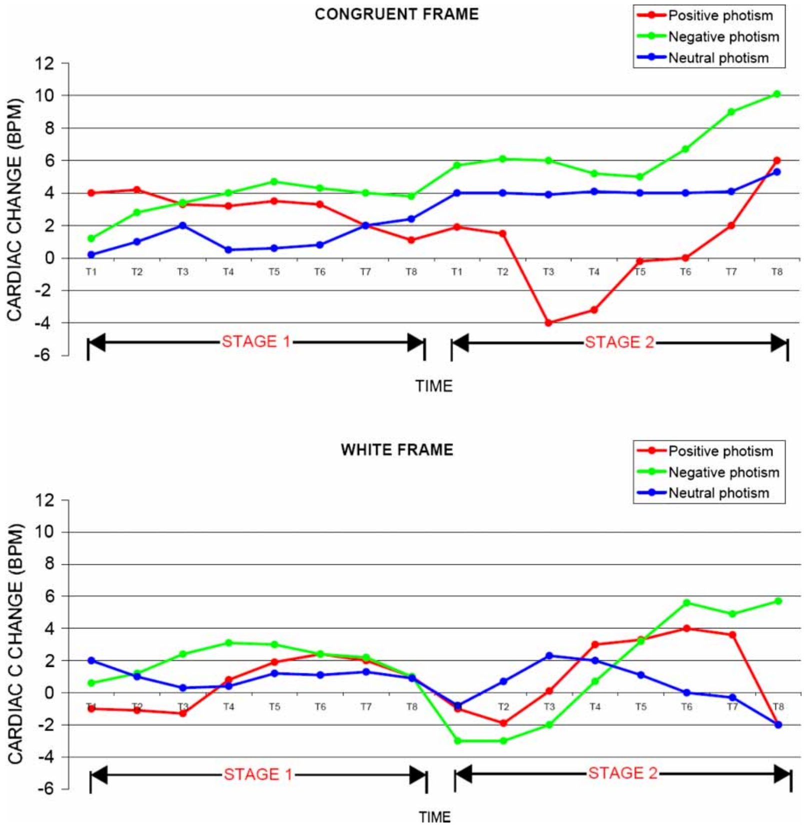

Figure 5. Modulation of the cardiac startle response by colour frames congruent with the photisms. The congruent colour frames shape the synaesthete's cardiac response in line with their emotional valence. Positively perceived colours attenuate the SR while the negative ones enhance it. The photisms by themselves (white frame condition) do not seem to exert any modulation of the heartbeat. To view this figure in colour, please see the online issue of the Journal.

The effect of photism–colour valence coherence. The analysis included the following variables: frame (incongruent positive or incongruent negative), photism valence, stage, and register time. The interaction between the frame, the photism valence and the stage was significant, $F(2, 4) = 10.04$, $p < .02$ (see Figure 6). The analysis of the CSR (the interaction between the stage and the register time variables), computed separately for the incongruent positive and the incongruent negative colour frame, was significant for the negative frame condition only. In this condition the SR was affected by the photism valence, $F(14, 28) = 2.22$, $p < .05$ (see Figure 7).

When the numbers are presented in incongruent positive colour frames, negative photisms lead to heartbeat deceleration during Stage 1. In Stage 2,

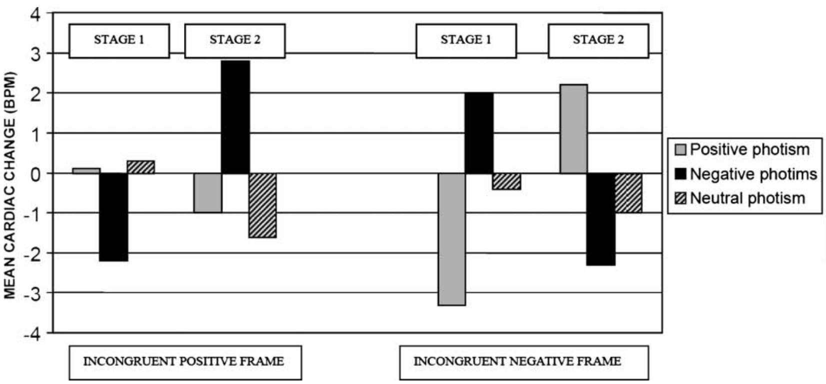

Figure 6. Mean cardiac change (with respect to baseline) observed in response to a startle producing sound, as a function of emotional valence of photisms (induced by number stimuli) and incongruent colour frames. Note that cardiac startle response is inhibited for both the positive and the neutral photisms in the incongruent positive frame condition. A similar pattern is observed for the negative and the neutral photisms in the incongruent positive condition.

R's heartbeat is strongly accelerated showing normal SR pattern. The positive and neutral photism conditions do not show any significant cardiac changes when the aversive noise is presented, i.e., there is no sign of CSR in these experimental conditions.

For the negative colour frames, positive photisms lead to distinct heartbeat deceleration during Stage 1, followed by a fast acceleration, i.e., the cardiac startle response is present. Negative photisms seem to lead to an opposite pattern, i.e., first they accelerate R's heartbeat but in Stage 2 R's heart slows down. This could be interpreted in terms of a CSR inhibition.

Discussion

Upon contrasting the results of the two incongruent conditions it appears that when the photism and the colour frame are emotionally coherent (i.e., of the same valence), R's CSR becomes weaker, independently of the emotional valence. Apparently the emotional coherence has an assuasive effect on R. On the other hand, when the photism and the colour frame are of opposite valences, the CSR is clearly present.

Despite the fact that we have observed significant differences between the different conditions, the interpretation of the results is quite complex. This is because the modulation of heart rate involves both the sympathetic and the parasympathetic nervous systems. In consequence, a downward modulation (i.e., attenuation) of the cardiac response may be attributed to at least two causal mechanisms: (a) an appetitive motivational system triggered by a

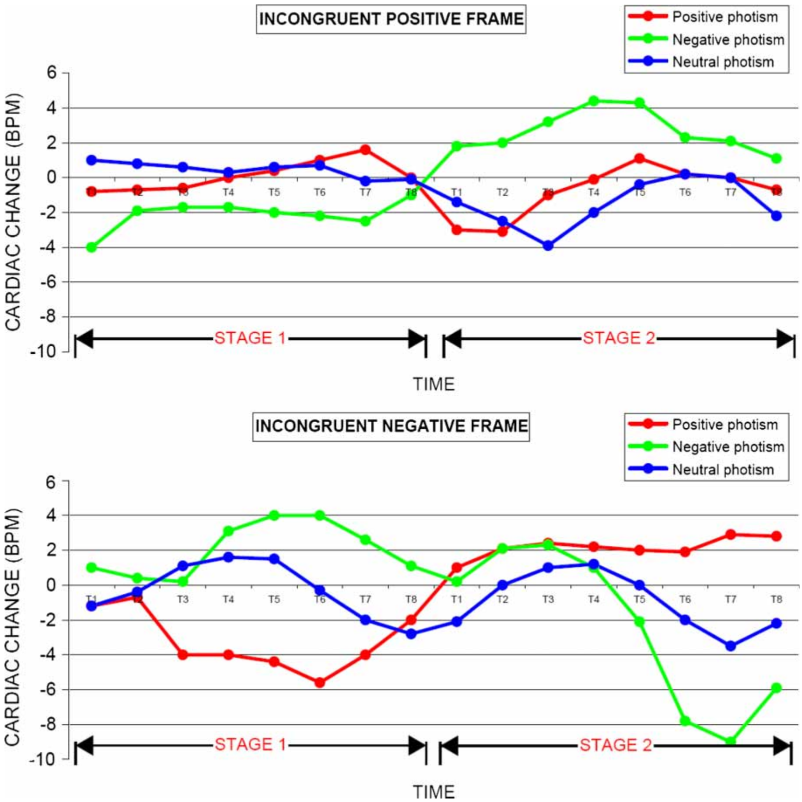

Figure 7. Modulation of the cardiac startle response by colour frames incongruent with the photisms. Distinct cardiac response patterns are observed as a function of emotional valence of the photisms that interacts with the valence of the colour frames. To view this figure in colour, please see the online issue of the Journal.

positively perceived stimulus, or (b) a mechanism of attentional orientation triggered by the fact that a salient stimulus captures the subject's attention. In any case, differential physiological measures were obtained across different experimental conditions, i.e., the trials with emotionally incoherent stimuli had a differential effect on R's cardiac response when compared to conditions perceived as emotionally coherent by R.

GENERAL DISCUSSION

For R, both the real colours and the synaesthetically triggered percepts of colour have an implicit emotional message which can influence R's affective dispositions towards people and visual scenes (Milán et al., 2007). 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). Moreover, even in those cases where synaesthesia is not directly mediated by emotions, it is quite common for synaesthetes to experience the congruency between the synaesthetically and the normally perceived features of the outer world as "correct" or even pleasant. The opposite may apply to situations of incongruity, particularly in those situations when a photism and a real colour of the inducing stimulus do not agree; this is usually experienced as unpleasant and annoying (Cytowic, 1989; Ramachandran & Hubbard, 2001b). A study by Callejas et al. (2007) confirmed earlier informal reports by showing that the perception of an "incorrectly" coloured word affected the judgements of emotional valence.

The present case study explored the influence of (real) colour–photism incongruity on three levels: subjective, behavioural, and physiological. However, in contrast to the study by Callejas et al. (2007), our experimental design was also aimed at examining the influence of R's emotionally tinted synaesthesia. More specifically, it was inspired by R's subjective claims concerning his perception of certain stimuli as "emotionally incoherent". The resulting data suggest that the synaesthete's emotional perception of colours modulates the effect of incongruity (between real colours and photisms). In R's case both real colours and photisms can influence behavioural and physiological indexes in a way determined by the affective valences of colours and/or photisms. Different colour hues (coloured frames) shaped R's subjective assessment of the synaesthetic inducers, they affected his reaction times in a behavioural task and modulated his cardiac startle response to an aversive sound. The impact of incongruity between colours and photisms is not straightforward because it seems to interact with R's emotional perception of colours. More specifically, the pattern of his behavioural as well as physiological reactions is determined by the presence (or absence) of emotional coherence between the respective emotional valences of photisms and real colours.

Despite the fact that the results presented here may be compelling, there is at least one empirical effect that may raise doubts concerning our interpretation of the data. R's subjective assessment of the stimuli in Experiment 1 indicated that the emotional valence of the real colour prevails in the presence of emotional incoherence between photisms and coloured frames. On the other hand, behavioural data (Experiment 2) as well as the cardiac response measure (Experiment 3) suggest that emotional incoherence always has a negative impact, interfering with R's performance and enhancing his SR. Such apparent inconsistence in the data might be explained by the different nature of these experiments. Experiment 1, which involves direct, subjective assessment of the stimuli, consists of a more cognitive and conscious interpretation of synaesthetic inducers by the subject. On the other hand, both the behavioural task and the physiological measure bring out the influence of coherence on R's actions and bodily reactions. Consequently, certain differences in the outcome of these qualitatively different measures are to be expected.

Finally, there is a series of empirical and theoretical issues that will require further investigation. First, it would be interesting to explore whether the behavioural and physiological effects related to emotional coherence are also present in other synaesthetes or whether it is an idiosyncratic feature of R or, eventually, it is only present in emotionally conditioned synaesthesias. In addition, it is also possible that similar mechanisms take place in nonsynaesthetes when confronted with colours in a context that may induce an "emotional conflict". For instance, the word "joy" printed in dark blue colour could be perceived as "emotionally incoherent" (due to the association of dark colours with depressive states) and eventually lead to similar effects as observed in R. Second, as we mentioned in the introduction to this paper, for R the concept of coherence extends to the field of aesthetic judgements. Simply put, he generally likes artworks that he perceives as coherent and he hates those where the use of colour, from R's point of view, is arbitrary and incoherent. Further research in this respect could allow for a completely new cognitive, behavioural, and perhaps even neuropsychological approach to the domain of aesthetic judgement, which is generally very hard to grasp in a scientific manner.

As a final point we would like to emphasise the connection of the results with the notion of qualia, i.e., subjective, nontransferable, first-person experiences (e.g., Chalmers, 1996; Jackson, 1982; Searle, 1992). The present study suggests that even such an idiosyncratic subjective concept, the emotional coherence of colours, can lead to empirically measurable outcome: It affects both R's performance and his bodily reactions. The pattern of R's reactions would hardly make sense unless we made reference to his unique, first-person point of view concerning colours. Hence, it seems reasonable to affirm that the concept of qualia, so frequently overlooked by mainstream science, is a necessary ingredient for understanding of the outcome of behavioural, psychophysiological, and neurological studies on synaesthesia.

Original manuscript received November 2007
Revised manuscript received March 2008
First published online July 2008

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