available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

# Green love is ugly: Emotions elicited by synesthetic grapheme-color perceptions

*Alicia Callejas*, Alberto Acosta, Juan Lupiáñez*

*University of Granada, Spain*

ARTICLE INFO

*Article history:*
Accepted 9 October 2006
Available online 15 November 2006

*Keywords:*
Synesthesia
Affective reaction
Valence categorization task
Colored word

ABSTRACT

Synesthetes who experience grapheme-color synesthesia often report feeling uneasy when dealing with incongruently colored graphemes although no empirical data is available to confirm this phenomenon. We studied this affective reaction related to synesthetic perceptions by means of an evaluation task. We found that the perception of an incorrectly colored word affects the judgments of emotional valence. Furthermore, this effect competed with the word's emotional valence in a categorization task thus supporting the automatic nature of this synesthetically elicited affective reaction. When manipulating word valence and word color-photism congruence, we found that responses were slower (and less accurate) for inconsistent conditions than for consistent conditions. Inconsistent conditions were defined as those where semantics and color-photism congruence did not produce a similar assessment and therefore gave rise to a negative affective reaction (i.e., positive-valence words presented in a color different from the synesthete's photism or negative-valence words presented in the photism's color). We therefore observed a modulation of the congruency effect (i.e., faster reaction times to congruently colored words than incongruently colored words). Although this congruence effect has been taken as an index of the true experience of synesthesia, we observed that it can be reversed when the experimental manipulations turn an incongruently colored word into a consistent stimulus. To our knowledge, this is the first report of an affective reaction elicited by the congruency between the synesthetically induced color of a word and the color in which the word is actually presented. The underlying neural mechanisms that might be involved in this phenomenon are discussed.



## 1. Introduction

Synesthesia is known as a mixing of the senses in which stimuli from one sensory modality induces experiences typical of a different modality (Cytowic, 2002; Dixon et al., 2000; Mattingley et al., 2001; Robertson, 2001; Beeli et al., 2005). Thus, taste can be experienced as a shape (Cytowic, 1993), or sounds are experienced as specific tastes (Beeli et al., 2005). The most common form, however, involves mixing two features of the same modality, i.e., colors (called photisms) subjectively experienced when perceiving non-colored alphanumerical characters (Day, 2005). Different theories have been proposed to account for this unusual phenomenon including cross-wiring between areas of the brain involved in grapheme form processing and color processing (Ramachandran and Hubbard, 2001b). Since the paths for word processing and color proces-

* *Corresponding author*. Departamento de Psicología Experimental, Facultad de Psicología, Universidad de Granada, Campus Universitario Cartuja s/n, 18071 Granada, Spain. Fax: +34 958 246239.
E-mail address: callejas@ugr.es (A. Callejas).

0006-8993/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2006.10.013

sing seem to be parallel in terms of neural substrates, depending on where the cross-wiring takes place, different types of grapheme-color synesthesia could be accounted for (Ramachandran and Hubbard, 2001b). Ramachandran and Hubbard suggest that a crosstalk taking place in the fusiform gyrus (where grapheme form and color are processed in adjacent areas-visual word form area and V8/hV4–) would be the mechanism underlying lower synesthesia—a form of grapheme-color synesthesia that is of a more perceptual nature. If the crosstalk takes place at higher levels of processing such as the angular gyrus (where both the next stage in color processing and abstract numerical calculation take place), then the resulting phenomenon would be what is called higher synesthesia. In higher synesthetes, associations between colors and graphemes seem to be of a more conceptual level (e.g., driven by the ordinal aspect of the graphemes). These authors have recently provided evidence that hV4 is more active in synesthetes than in controls when looking at synesthesia inducing stimuli (i.e., graphemes) as compared to non-linguistic symbols that did not elicit colors for the synesthetes tested (Hubbard et al., 2005). An alternative theory suggests that synesthesia is not due to cross talk between adjacent areas but instead due to disinhibited feedback from higher multimodal areas (Grossenbacher and Lovelace, 2001). Lastly, a somewhat hybrid model was proposed by Smilek et al. (2001) in which they suggest that a combination of both cross-activation and feedback disinhibition is taking place. They also suggest the existence of different groups of synesthetes although their categorization is based on the synesthetes' subjective experience while that of Ramachandran and Hubbard (2001b) is based on the representational level of the inducer. Smilek et al. propose the terms projector and associator to differentiate those synesthetes that report experiencing colors projected out in space from those who experience the color in their mind's eye (Dixon et al., 2004).

A commonly known but poorly studied feature of grapheme-color synesthesia is the experience of emotions associated with the synesthetic event. Synesthetes experience a sense of certitude that somehow conveys the feeling that their experiences are correct (Cytowic, 1993). More specifically, synesthetes experience a positive feeling when they see a consistent stimulus (i.e., in grapheme-color synesthesia, a letter colored according to the synesthete's photism) and a feeling of discomfort associated with the experience of a mismatch between the physical–external stimuli and the subjective–internal synesthetic perception (i.e., a letter that is not colored according to the synesthete's photism). It has been common in the synesthesia literature to find informal reports by synesthetes about negative emotional reactions associated to the experience of stimuli presented in a color different from their photism (Cytowic, 1989; Ramachandran and Hubbard, 2001b). If a synesthete who sees the word "tree" in blue is presented with the same word colored in pink, he/she will say "This is wrong!". This reaction can vary in intensity from a statement of discomfort to a fairly strong, aversive emotional response.

Even though this affective reaction is easily found among synesthetes, no empirical study has been carried out to our knowledge to test whether it is in fact a measurable and reliable phenomenon that influences synesthetes' behavior. Studies have been undertaken to elucidate the possibility that emotions are the inducer of synesthetic experiences (Ward, 2004) so that only words that have an emotional connotation elicit a synesthetic response. Nevertheless, there has not been a study carried out on the emotions elicited as a side effect of the perception of an incongruently colored stimulus in grapheme-color synesthesia.

As Ramachandran and Hubbard suggest (2001b), the idea that synesthetic perceptions could in turn produce emotional reactions is intriguing from a neuroscientific viewpoint and also as it serves as another piece of evidence in favor of their cross-wiring theory since it is known that information processed in the temporal lobe is relayed to the amygdala and other parts of the limbic system (Amaral et al., 1992; LeDoux, 1992).

Therefore, we wanted to study the nature of these affective reactions. Following the logic established in previous publications to differentiate developmental synesthesia from mere associations or metaphors (Cytowic, 2002; Dixon et al., 2000; Ramachandran and Hubbard, 2001a), our first aim was to determine whether these reactions are affective memory associations or an automatic elicitation of emotions caused by the perception of an incongruently colored grapheme.

We investigated the synesthetic perception of emotional words in MA, a psychology undergraduate student, who experiences grapheme-color synesthesia (Lupiáñez and Callejas, 2006). She reports experiencing negative emotions associated to the perception of letters, numbers and words presented in a color different from her photism for them. She describes her feelings by saying, "It is wrong. It's like coming into a room and finding all the chairs upside-down and everything out of place. I can't stand it. It is just wrong". When performing a Stroop experiment to evaluate the automaticity of her synesthesia (i.e., naming the colors of letters and numbers when presented while ignoring her photisms for them), her discomfort could be overtly observed (rapid increase of hand perspiration, difficulty sitting still, constant posture readjustments, etc.). Here we report four experiments where we studied the behavioral influences of these affective reactions.

First, we tried to reproduce the reported affective reaction to incorrectly colored stimuli with an indirect behavioral task. Since MA perceives words as uniformly colored (as opposed to perceiving one color for each letter), in Experiments 1a and 1b, we presented to her and a group of control participants a set of words and asked them to rate their valence according to their semantic meaning. In order to test the influence of the synesthetic colors, we manipulated the color of the words so that it would either match (congruent condition) or mismatch (incongruent condition) the color of the synesthetic experience for each word (Experiment 1a, Evaluation Task). This was compared to an absence of color condition where all the words were presented in black[1] (Experiment 1b, Control Task). A set of 72 words (neutral, positive, anxiety-related negative and anger-related negative words) were presented and participants were required to judge their valence in a 7-point Likert scale.

[1] Informal reports by synesthetes point to black color being considered a neutral color maybe due to the enormous amount of practice acquired by reading texts in black ink.

In Experiments 2a and 2b, we assessed the automaticity of the postulated synesthetic affective reactions. In order to do so, we tried to reproduce the conditions that would lead to a competition between word meaning and color congruency if the affective reactions associated to inconsistent stimuli were automatically evoked when processing a word. Our task was a modification of the Stroop paradigm (Stroop, 1935). Participants were asked to perform a speeded valence categorization on the same positive and negative words they had been previously presented within Experiments 1a and 1b. Again, in Experiment 2a, the words were shown in congruent and incongruent color and in Experiment 2b, the same words were presented in black ink. Using this procedure, we attempted to test our prediction that if the postulated affective reaction is automatic, under time pressure conditions, we should find an interaction between congruency and semantic valence. In a regular Stroop task, the irrelevant dimension of the stimulus is the word meaning whereas the relevant dimension is the color in which the word is presented. In our modified Stroop task, the irrelevant dimension is the color in which the word is presented and ultimately the congruency between that color and the photism for that word, which would lead to a positive or negative affective reaction. The relevant dimension is the semantic (emotional) meaning of the word.

In the Stroop literature, the usual finding is a high level of interference when participants are asked to name the ink color (less practiced task) while avoiding to name the word (a highly practiced task) (MacLeod, 1991; MacLeod and MacDonald, 2000). Therefore, we should only expect to find an interference of congruency on MA's valence categorizations if processing the emotion elicited by color-photism consistency is as automatic as processing the semantic meaning of the word.

## 2. Results and discussions

### 2.1. *Experiments 1a and 1b*

In order to be able to analyze the data from MA together with that of the control group, we used items (words), instead of participants, as the random factor in all the analyses. Since MA ran the evaluation task twice to provide a more consistent estimate, her data from both sessions were averaged after we had verified that the pattern of results was the same for both measurements. The data from the control group were also averaged across participants to arrive at a single score for each item presented.

A mixed 2×2×4 ANOVA was carried out with Group (MA vs. control participants) and Congruency (congruent vs. incongruent) as within-item factors and Valence (positive, neutral, anxiety-related negative and anger-related negative words) as a between-item factor. First, we found that our groups were not different in the overall mean rating for words ($F_{(1,68)}=1.29$, $p=0.261$). As expected, the effect of word valence was significant ($F_{(3,68)}=109.42$, $p<0.001$) and the common pattern of ratings for positive, negative and neutral words was found.

As predicted, color congruency modulated emotional rating in MA but not in the control group ($F_{(1,68)}=90.27$, $p<0.001$). The control group rated congruently and incongruently colored words similarly (mean rating for congruent=−0.61 vs. mean rating for incongruent=−0.59; $F_{(1,68)}=2.04$, $p=0.157$).[2] On the contrary, as can be seen in Fig. 1, MA's emotional ratings were highly influenced by the congruency between the color and the photism (congruent=0.22 vs. incongruent=−1.68; $F_{(1,68)}=85.95$, $p<0.001$). Furthermore, for the congruent color condition they were significantly more positive ($F_{(1,68)}=17.95$, $p<0.001$), and for the incongruent color condition, more negative ($F_{(1,68)}=184.70$, $p<0.001$) than those of the control group.

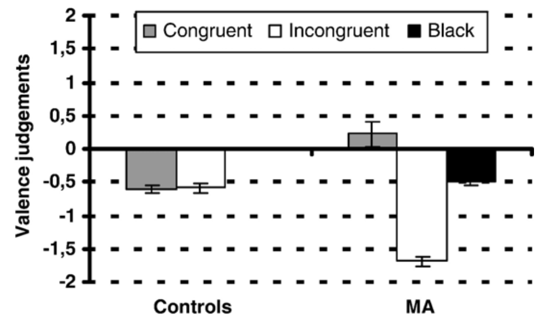


**Fig. 1 – Experiments 1a and 1b. Congruency effect as a function of group. The black bar shows the results for Experiment 1b where all words were presented in black. Error bars denote standard error of the mean.**

Interestingly, however, as can be seen in Fig. 2, this congruency effect was independent of valence ($F<1$). Thus, MA seemed to use two sources of information in order to determine word valence: word meaning and congruency between the presented color and the experienced photism. Needless to say, the same was not true for the control participants.

This congruency effect, which was only observed in MA's ratings, led to other effects. Incongruent colors produced a reduced rating for positive words and a similar rating compared to controls for negative words whereas congruent colors resulted in an increased rating for negative words and a more accurate rating for positive words. This effect produced an overall less extreme rating in MA than in the control group ($F_{(3,68)}=31.66$, $p<0.001$) (see Fig. 2). It is important to note that the main effect of word valence was still significant for both the control group as well as for MA ($F_{(3,68)}=254.86$, $p<0.001$ and $F_{(3,68)}=13.31$, $p<0.001$, respectively). Therefore, we can conclude that MA and the control participants were following the instructions that emphasized ignoring the color and concentrating only on the meaning of the word.

Even though the main effect of valence showed that MA's judgments went in the same direction as those of the control group (i.e., positive words were rated as more positive and negative words as more negative) as shown by the main effect of Valence, in the control experiment (Experiment 1b) we confirmed that her valence ratings would not differ from those of the control participants when color-photism congruency

[2] Considering that the criteria used to select the words was an average rating of 2 for positive words, 0 for neutral and −2 for negative words, the expected mean rating would be −0.5 since there was double the amount of negative words than neutral or positive words.

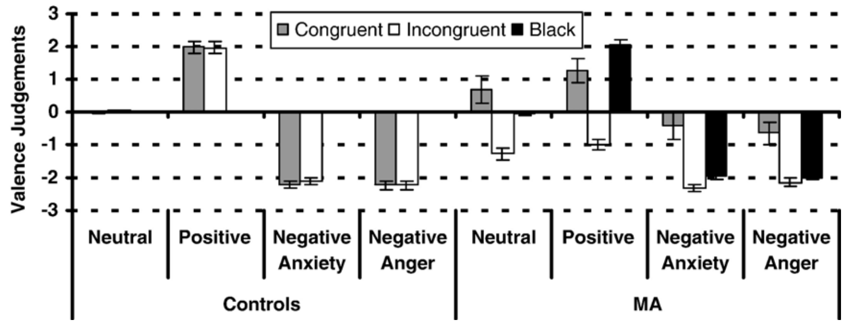


**Fig. 2 – Experiments 1a and 1b. Valence ratings. Mean valence ratings for control group, and MA. Words were presented in a color congruent with MA's photism (grey bars) or in a color incongruent with her photism (white bars). Black bars show ratings for words presented in black (Experiment 1b). Error bars represent the standard error of the mean.**

was controlled. Here we asked her to rate the same set of words all presented in black ink.[3]

As expected, now that only one source of information was present (i.e., word meaning), MA's valence ratings did not differ from those of the control participants ($F_{(2,136)}=2.72$, $p=0.069$).[4] MA rated black stimuli according to their semantic valence comparably to control participants when rating both congruently and incongruently colored words. As shown in Fig. 1, her mean rating for black stimuli was statistically different from her own rating under color-photism congruency conditions ($F_{(2,136)}=65.10$, $p<0.001$). Planned comparisons showed that MA's rating for black stimuli was lower than her rating for congruently colored stimuli ($F_{(1,68)}=14.19$, $p<0.001$) and higher than her rating for incongruently colored stimuli ($F_{(1,68)}=220.24$, $p<0.001$).

### 2.2. *Experiments 2a and 2b*

#### 2.2.1. *Reaction time analysis*

Before analyzing the data and once we had confirmed that MA's pattern was the same in both sessions, we averaged her reaction times across sessions as well as across control group participants. A mixed Group×Valence×Congruency ANOVA was performed on the data using items as the random factor. The first two variables were manipulated within items and the last one between items. Trials with an incorrect response and those with an RT above 2000 ms were excluded from the analysis (7.61% and 0.74%, respectively). The following results were obtained. A main effect of Group ($F_{(1,34)}=11.70$, $p=0.002$) showed that MA was around 50 ms slower than our control group. This could be due to the fact that, under time pressure conditions, this categorization task was more difficult for her than it was for the control group since she had to ignore, not only the color of the words, but also the correspondence between the color and the photism that has been previously found to be automatically activated by the grapheme (Dixon et al., 2002; Elias et al., 2003; Mattingley et al., 2001).

Importantly, the predicted second order interaction between Group, Valence and Congruency was found to be significant ($F_{(1,34)}=6.49$, $p=0.016$) showing that, for control participants, Congruency did not affect Valence ($F_{(1,34)}=1.03$, $p=0.317$). However, it did so for MA ($F_{(1,34)}=5.51$, $p=0.025$). As can be observed in Fig. 3A, planned comparisons showed that the time taken to categorize positive words was much longer when they were incongruently colored than when they were congruently colored ($F_{(1,34)}=6.59$, $p=0.015$). Although the pattern of results for negative words was the opposite, the difference between congruent and incongruent conditions was not reliable ($F<1$).

We also analyzed the data from the control experiment with black stimuli and found that MA's performance was similar to that of control participants ($F<1$), whereas it interacted with her own data under color conditions ($F_{(2,68)}=3.70$, $p=0.030$).

In order to further analyze the data, we coded a new variable called Correspondence. The crossing of the two original variables (i.e., semantic Valence and Color-Photism Congruency) provided us with this third variable. Corresponding trials were those where the evaluation of both variables went in the same direction (i.e., positive congruently colored words and negative incongruently colored words). Non-corresponding trials were those where the evaluation of both variables yielded opposite results (i.e., positive incongruently colored words and negative congruently colored words).

We performed a new ANOVA with Correspondence and Group as independent variables and found that there was indeed a significant interaction ($F_{(1,35)}=6.55$, $p=0.015$). For the control group, the difference between consistent and inconsistent words was not significant ($F_{(1,35)}=1$, $p=0.324$), whereas for MA we found that inconsistent words were more difficult to categorize, as shown by much longer reaction times (mean RT=787 ms), than consistent words (mean RT=729 ms), $F_{(1,35)}=5.41$, $p=0.026$.

#### 2.2.2. *Accuracy analysis*

The same ANOVA was carried out for the percentage of errors. MA was more error prone than our group of control

[3] Previous experiments carried out in our lab had shown that in a blocked presentation of black graphemes or words, black was interpreted by MA as a neutral color (i.e., did not produce an affective reaction) whereas the same black stimuli, when mixed within a block of trials with colored words, was interpreted as an incongruent color and thus produced the same pattern of results than incongruent color words.

[4] Although this comparison was not significant, a trend was observed for MA to be less negative in her ratings than the control group. This could probably be due to her previous practice with the task since this experiment was performed after she had participated in Experiment 1a.

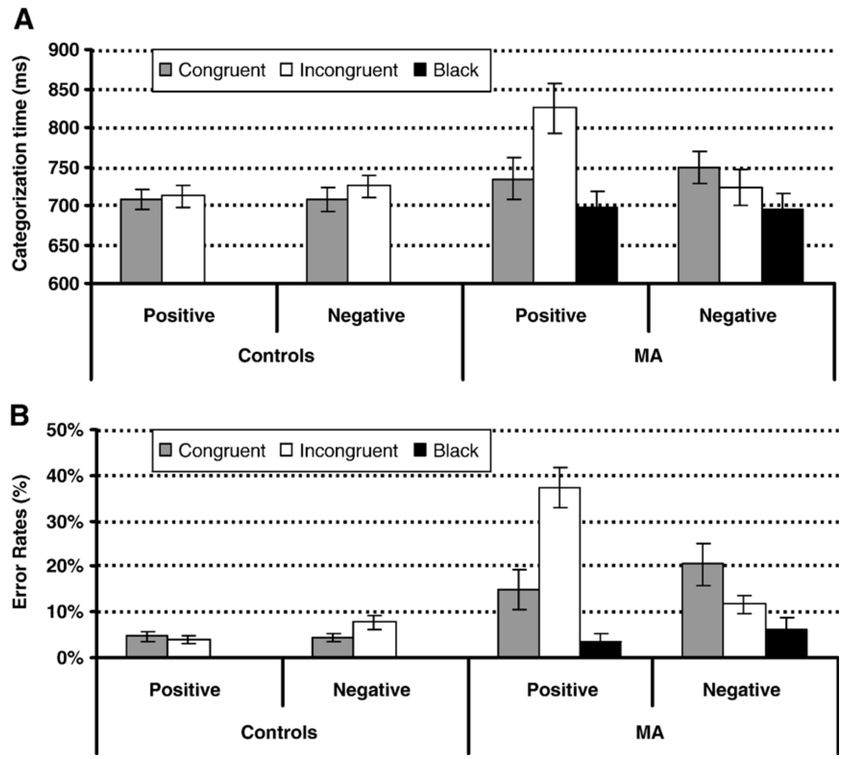


**Fig. 3 – Experiments 2a and 2b. Categorization experiment. Words were presented in a color congruent with MA's photism (grey bars), in a color incongruent with her photism (white bars) and in black color (Experiment 2b, black bars). (A) Mean reaction time data. (B) Mean error rate data. Error bars represent the standard error of the mean.**

participants ($F_{(1,34)}=49.72$, $p<0.001$). Together with the RT data, this suggests that in fact the task was more difficult for her than it was for the other participants, as she had to overcome the incongruence introduced by the coloring of the words.

Although we found no effect of Valence ($F_{(1,34)}=2.33$, $p=0.136$), there was an interaction by Group ($F_{(1,34)}=6.96$, $p=0.012$) in the sense that MA had more trouble categorizing positive words than negative words.

Congruently colored words were more often correctly categorized than incongruently colored words ($F_{(1,34)}=6.75$, $p=0.014$) by both MA and control participants. Nevertheless, the most interesting result was the significant interaction between Valence and Congruency ($F_{(1,34)}=18.64$, $p<0.001$). Incongruently colored positive words seemed to be more error-prone than any other type of word. Adding to this, the predicted second order interaction was also significant ($F_{(1,34)}=33.02$, $p<0.001$). We separately analyzed each group and found that the described pattern of results was only found in MA ($F_{(1,34)}=26.08$, $p<0.001$). Again, more categorization errors were made for positive words when they were incongruently colored ($F_{(1,34)}=27.03$, $p<0.001$) and the opposite pattern was found for negative words. Fewer categorization errors were made for incongruently colored negative words than for congruently colored ones ($F_{(1,34)}=4.01$, $p=0.051$).

Even though we also found a significant interaction between Congruency and Valence for the control participants ($F_{(1,34)}=13.72$, $p<0.001$), it was due to the fact that negative words yielded more errors when incongruently colored than when congruently colored ($p<0.001$). As can be seen in Fig. 3B, it is worth noting that this pattern of results is the exact opposite to that found in MA where negative words were more difficult to categorize when congruently colored. Moreover, the magnitude of the difference in the control group was much smaller. Although no clear explanation is available for this significant interaction, it could be due to general color associations in non-synesthetes (Simner et al., 2005) or to other variables such as participant's color preferences (manuscript in preparation).

Regarding the control experiment in which only black colored words were presented to MA (Experiment 2b), we found that her performance was statistically different from that obtained when she responded to congruently and incongruently colored words ($F_{(2,68)}=21.39$, $p<0.001$) and not different from the control group's ($F<1$). Once again, we see how the additional information coming from the color Congruency can account for the differences seen between MA and the control participants.

Lastly, we re-coded the variables and analyzed the percentage of errors as a function of Correspondence and Group. Once again, there was an interaction between both variables ($F_{(1,35)}=30.22$, $p<0.001$) and a deeper analysis showed a large correspondence effect for MA in the same direction as was found for RT: non-corresponding words were more difficult to categorize (mean error=29%) than corresponding ones (mean error=13%) ($F_{(1,35)}=23.27$, $p<0.001$). For control participants, we also found an effect, although again it was in the opposite direction and of a much smaller magnitude (i.e., more errors for corresponding words than non-corresponding words ($F_{(1,35)}=11.03$, $p=0.002$) (see Fig. 3B)).

## 3. Discussion

In Experiment 1, we showed that color Congruency does influence emotionality ratings in parallel with word Valence. MA's ratings were accurate in the sense that she rated words according to their meaning like the control participants. However, she was also influenced by the color in which the word was presented since congruently colored words were rated more positively than incongruently colored words.

The pattern of results observed in Experiment 1 suggests that, in contrast to control participants, MA seems to use two sources of information to judge emotionality of the words: semantics and synesthetic congruency. The absence of an interaction between these two emotionality sources (lack of Word Valence × Color Congruency interaction) suggests an independent activation of them. However, if the color-photism congruency automatically activated an affective reaction, then we would expect it to compete with the meaning of the word in those conditions where both valences are inconsistent (i.e., congruently colored negative words or incongruently colored positive words). This would in turn create a competition that would produce an interference effect.

Experiment 2 was designed to test this hypothesis and we found that in fact, when the task was performed under time pressure, color-photism congruency affected performance in a very interesting way. By presenting words with semantic valence colored either congruently or incongruently with the synesthete's set of photisms, we showed the presence of a bias causing MA to respond faster when there was a consistency between the two dimensions of the presented stimulus (i.e., Valence and Congruence). That is, at least MA, and probably other synesthetes, may be faster at responding to an incongruently colored word than to a congruently colored word depending on the semantic meaning of it.

Converging evidence comes from the analysis of errors. As shown in Figs. 3A and B, MA's reaction time and error percentage were higher in the non-corresponding conditions, especially for positive incongruent words. Given that feedback was provided after each trial, this pattern of data suggests that MA was making a considerable control effort to respond correctly, but the synesthetic valence (particularly the incongruence) exerted an influence to the extent that the correct response could not be controlled at the proper levels. In a standard Stroop experiment, word meaning is taken as the automatic dimension and color naming as the intentional dimension. The subject has to name the color and inhibit the response associated to the potent activation that comes from the automatic processing of the denotative meaning of the word. In our task the intentional response is the connotative meaning of the word, a dimension that has been proved to be automatically processed (Catena et al., 2002). Moreover, the criterion to select the words was based on previous experiments to ensure they were clearly positive or negative. Still, the affect produced by the incongruence of the color in which the word is presented overcomes the activation of the word's meaning and influences the final response. Previous studies have shown that this interference from the affective component of a word in a categorization task is unusual even when the subjects are trait-anxious patients (Pérez-Dueñas et al., 2005, 2006).

The perception of the photism associated to a particular word is highly automatic (Dixon et al., 2000; Lupiáñez and Callejas, 2006). Affective priming studies have also shown participants' ability to automatically extract connotative meaning from words even when they do not have to be consciously evaluated (Fazio et al., 1986). Putting this together, the affective reaction associated with the match–mismatch between a word's photism and the presented color would have to be automatic in order to expect it to interact with the automatic evaluation of the words' connotation. And only if that affective reaction was strong enough would it influence such an automatic processing of words. Moreover, this affective reaction would have to be sufficiently strong to cause a failure of the control mechanisms working to suppress it when a categorization that is based on the connotative meaning of the words is required. It seems then that the assessment of the match between the environment and the subjective experiences known as synesthesia, as well as the affective reaction associated with such evaluation, is a strong and highly automatic side effect of at least grapheme-color synesthesia.[5] Also, in a study to be reported in which the task at hand was an abstract/concrete categorization of these same words, that is, a task that is orthogonal to the affective processing of the word's meaning, we found the same pattern of results where incongruently colored negative words and congruently colored positive words are categorized faster than congruent-negative and incongruent-positive words (manuscript in preparation). It seems as though synesthetes automatically evaluate whether the external physical words fit their internal coloring schema and this evaluation is likely to happen even when it is not relevant to the task at hand.

From this perspective, the next step in the study of emotions as a side effect of synesthesia would be to discern the mechanisms underlying such processes and whether they are shared by non-synesthetes. Previous studies have pointed to the retrosplenial cortex as an interesting structure worth investigating in this context (Ward, 2004). It has been related to the processing of familiar people as opposed to unfamiliar people and also to the processing of emotional words as compared to neutral words (Maddock, 1999, for a review). Also, this area appears to be active in different studies of brain activation and synesthesia (Nunn et al., 2002; Weiss et al., 2001). Although it has also been related to memory, a recent study showed that, controlled for memory variables, the retrosplenial cortex was found active when categorizing words according to their valence (Maddock et al., 2003). Knowing when these evaluative processes take place could be taken as an index of the processing stage where subjective

[5] Although not reported here, several other synesthetes have been tested and show the same pattern of response times for the categorization task.

colors (photisms) are bound to the percept and consciously experienced.

As previously mentioned, information that arrives at V1 by means of the retina is then relayed to V2, V4 and temporal areas and it subsequently travels to the amygdala (Amaral et al., 1992). Posterior cingulate cortex–retrosplenial cortex does not have direct connections to the amygdala but does connect to other frontal regions also related to emotional evaluation such as the anterior cingulate cortex. It also receives input from the orbital and dorsolateral prefrontal cortex, parahippocampal cortex, superior temporal sulcus, precuneus, claustrum and anterior and lateral thalamic nuclei (Goldman-Rakic et al., 1984; Van Hoesen et al., 1993). The question then would be whether higher synesthetes, whose proposed locus for cross-activation is higher up in the visual processing, next to the angular gyrus, would show the same pattern of responses as lower synesthetes whose proposed locus of cross-activation would be localized around hV4 (Ramachandran and Hubbard, 2001b).

A recent study points to the possibility that some linguistic features of words, such as their emotional valence, are processed very early in time (Ortigue et al., 2004). These authors found ERP differences at around 150 ms for emotional words compared to neutral words when the task at hand was discriminating words from non-words. Another electrophysiological study suggests that information about the meaning of a word can be accessed almost at the same time as information about its form (Pulvermüller, 2001). It could be the case that emotional words also had a special representation and could be accessed faster than equal frequency neutral words. If so, we could then predict that the effect of incongruently colored words would be present only in those cases where photisms were bound to graphemes prior to graphemes' emotional assessment (i.e., only for projector-lower synesthetes; Dixon et al., 2004; Ramachandran and Hubbard, 2001b). If the information is sent before the photism is added to the phenomenological experience or if no photism information is sent (i.e., as in the case of non-synesthetes), the outcome of the evaluation would be the usual one. However, if the words' meaning is not accessed so early in the processing, it might be the case that by the time the word's information is relayed to the emotional centers for its evaluation, it has already been dressed with its corresponding photism in all synesthetes independent of the stage at which the cross-activation is occurring. If the object of evaluation includes the information about the photism, then the evaluative process will have to deal with (a) the semantics of the word itself, (b) the match–mismatch between the two pieces of color information and (c) the relationship between the outcome of the semantic assessment and that of the color-photism matching process. We believe that MA is a higher-associator synesthete. Although informal observations point in the direction of lower-projector synesthetes who show emotional reactions associated to the perception of incongruently colored stimuli, no formal test has been carried out to confirm this. Alternatively, as recently suggested (Ward et al., 2006), it may be the case that the higher/lower distinction (Ramachandran and Hubbard, 2001a,b) and the projector/associator distinction (Dixon et al., 2004) are independent. In this case, we could find lower-associator and lower-projector synesthetes as well as higher-associator and higher-projector synesthetes. It would therefore be possible to find a synesthete that sees colors in the mind's eye and shows the emotional effect while another synesthete that sees the colors out there in space does not show the affective reaction. Future research will uncover whether the lower–higher and the associator–projector distinctions are orthogonal features of grapheme-color synesthesia.

In the area of emotions and synesthesia, more investigation needs to be carried out on the dynamics of this affective reaction. Some questions that need clarification deal with the specific characteristics of the synesthetes showing the emotional reaction. It is also important to decipher the temporal course of stimulus processing when congruently and incongruently colored and the factors influencing the lack of an affective reaction when stimuli are presented in black ink.

Last, we have found that non-synesthetes may carry out a similar affective assessment of irrelevant dimensions when performing the same categorization task. In a series of studies to be reported, we found that non-synesthetes were influenced by their color preferences when categorizing colored emotional words in a manner similar to that shown by synesthetes when categorizing stimuli that were congruently or incongruently colored. This could point to common evaluative mechanisms in both synesthetes and non-synesthetes. Further testing will uncover the similarities between the processes taking place in both groups.

## 4. Conclusion

In these series of experiments, we have shown for the first time to our knowledge, that when a word is presented in a color different from that in which it is experienced by a particular synesthete, the incongruence between the perceptual stimulus and the internal experience gives rise to an affective reaction that biases the synesthete's performance. This affective reaction is automatic and difficult to ignore. Therefore, we can conclude that (a) emotion is part of the set of subjective experiences known as synesthesia and (b) its effects on behavior may be as clear and robust as those produced by the photism itself.

## 5. Experimental procedures

### 5.1. *Experiment 1a*

#### 5.1.1. *Participants*

Our synesthete MA and a group of 11 control participants took part in this experiment. Participants matched MA in age (22) and gender (female) and they were all students of the Psychology Department at the University of Granada. MA performed the experiment in two different occasions while control participants did so only once. This and the following experiments were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All the participants gave their informed consent prior to their inclusion in the study.

#### 5.1.2. *Design*

Two variables were manipulated in this experiment: word valence and color congruency. To manipulate word valence, a set of 72 words were used. An equal number of neutral words, positive words, anger-related negative words and anxiety-related negative words were used and the four groups of words were matched in length (number of letters and number of syllables) and subjective familiarity. The words were chosen from a database used in previous experiments in our laboratory so that the mean rating for positive words was +2, for neutral words 0 and for negative words (anger related as well as anxiety related) was −2, in a scale ranging from −3 to +3. Words were presented both in congruent and incongruent color. Congruent colors were those that MA had previously chosen for each word as part of a study to check consistency over time. Incongruent colors were the color-wheel opposites of each chosen color.

#### 5.1.3. *Procedure*

Randomly ordered words appeared at the centre of the screen one at a time and participants' task was to evaluate the valence of each word without time pressure in a 7-point Likert scale by means of a keyboard: +3 very positive, 0 neutral and −3 very negative. A white fixation point was presented against a grey background for 500 ms. It consisted of a cross in the middle of the screen and was accompanied with a reproduction of the responding scale (i.e., the possible rating values from −3 to +3) that was also white and appeared at the bottom of the screen. Following this, the target word was presented replacing the cross and remained on the screen until response. The responding scale was kept in the screen for the full duration of each trial. Stimuli were presented on a 15-in. monitor connected to a Pentium computer. Presentation of stimuli as well as data recording was carried out using MEL software (Schneider, 1988). A total of 432 trials were run in three blocks of 144 trials each (72 congruent and 72 incongruent).

### 5.2. *Experiment 1b. Valence control task*

#### 5.2.1. *Participants*

Only MA participated in this experiment.

#### 5.2.2. *Design and procedure*

In the baseline black version of the task, the same number of trials was used but this time, all the words were presented in black color against a grey background. The procedure used for this experiment was the same as in the previous study. Since there was double the amount of trials per experimental condition, the experiment was run only once.

### 5.3. *Experiment 2a. Categorization task*

#### 5.3.1. *Participants*

Again, MA and a different set of 11 non-synesthete undergraduate students participated in this experiment. They were again matched for age and gender to our synesthete participant.

#### 5.3.2. *Design and procedure*

Only the 18 positive and 18 anger-related negative words were used in this experiment. Again, all words were presented both in congruent and incongruent color. Twelve blocks of 36 trials were run.

Participants had to categorize the words as being either positive or negative according to their meaning. A speeded response was required by pressing, as fast as possible, one of two buttons depending on the valence of the word (i.e., positive or negative).

Again, a white fixation point was presented against a grey background and was followed by the target word. The word was presented until response was given. Both speed and accuracy were emphasized. Furthermore, a feedback (a tone) was delivered for incorrect responses in order to ensure that the categorization was done according to the meaning of the word, and not depending on the color in which it was displayed. Again, MA performed the experiment twice while control participants did it only once.

The design of this experiment was a 2 (Group; MA vs. control group) × 2 (Color-Photism Congruency; congruent vs. incongruent) × 2 (Valence; positive vs. negative). The first two variables were manipulated within items, whereas the last one was manipulated between items.

### 5.4. *Experiment 2b. Categorization control task*

#### 5.4.1. *Participants*

Only MA took part in this experiment.

#### 5.4.2. *Design and procedure*

For the baseline black version of the task, everything was the same as in Experiment 2a except that now all the words were always presented in black color against a grey background. Again, the experiment was run only once.

## Acknowledgments

Authors would like to thank MA for her kind disposition to be a subject of extensive research. This research was supported by the Spanish Ministerio de Educación y Ciencia through a predoctoral grant (to AC) and research grants (BSO2002-04308-C02-02 and BSO2003-07292 PSCE to JL and AA, respectively).

## REFERENCES

Amaral, D.G., Prince, J.L., Pitanen, A., Carmichael, S.T., 1992. Anatomical organization of the primate amygdaloid complex. In: Aggelton, J.P. (Ed.), The Amygdala: Neurobiological Aspects of Emotion, Memory and Mental Dysfunction. Wiley, New York.

Beeli, G., Esslen, M., Jäncke, L., 2005. When colored sounds taste sweet. Nature 434, 38.

Catena, A., Fuentes, L., Tudela, P., 2002. Priming and interference effects can be dissociated in the Stroop task: new evidence in favor of the automaticity of word recognition. Psychon. Bull. Rev. 9 (1), 113–118.

Cytowic, R.E., 1989. Synesthesia: A Union of the Senses Springer-Verlag, New York.

Cytowic, R.E., 1993. The Man Who Tasted Shapes. Putnam, New York, New York.

Cytowic, R.E., 2002. Synesthesia: A Union of the Senses, 2nd ed. MIT, Cambridge, MA.

Day, S., 2005. Some demographic and socio-cultural aspects of synesthesia. In: Robertson, L.C., Savig, N. (Eds.), Synesthesia: Perspectives from Cognitive Neuroscience. Oxford Univ. Press, New York.
Dixon, M.J., Smilek, D., Caudahy, C., Merikle, P.M., 2000. Five plus two equals yellow. Nature 406, 365.
Dixon, M.J., Smilek, D., Wagar, B.M, Cudahy, C., Merikle, P.M., 2002. Five plus two equals yellow: perceptual and conceptual aspects of synaesthesia. Brain Cogn. 48, 236.
Dixon, M.J., Smilek, D., Merikle, P.M., 2004. Not all synaesthetes are created equal: projector versus associator synaesthetes. Cogn. Affect. Behav. Neurosci. 4, 335–343.
Elias, L.J, Saucier, D.M, Hardie, C., Sarty, G.E., 2003. Dissociating semantic and perceptual components of synaesthesia: behavioural and functional neuroanatomical investigations. Cogn. Brain. Res. 16, 232–237.
Fazio, R.H., Sanbonmatsu, D.M., Powell, M.C., Kardes, F.R., 1986. On the automatic activation of attitudes. J. Pers. Soc. Psychol. 50, 229–238.
Goldman-Rakic, P.S., Selemon, L.D., Schwartz, M.L., 1984. Dual pathways connecting the dorsolateral prefrontal cortex with the hippocampal-formation and parahippocampal cortex in the rhesus-monkey. Neuroscience 12 (3), 719–743.
Grossenbacher, P.G., Lovelace, C.T., 2001. Mechanisms of synesthesia: cognitive and physiological constraints. Trends Cogn. Sci. 5 (1), 36–41.
Hubbard, E.M., Arman, A.C, Ramachandran, V.S., Boynton, G.M., 2005. Individual differences among grapheme-color synesthetes: brain–behavior correlations. Neuron 45, 975–985.
LeDoux, J.E., 1992. Brain mechanisms of emotion and emotional learning. Curr. Opin. Neurobiol. 2 (2), 191–197.
Lupiáñez, J., Callejas, A., 2006. Automatic perception and synesthesia: evidence from color and photism naming in a Stroop-negative priming task. Cortex 42 (2), 204–212.
MacLeod, C.M., 1991. Half a century of research on the Stroop effect: an integrative review. Psychol. Bull. 109 (2), 163–203.
MacLeod, C.M., MacDonald, P.A., 2000. Interdimensional interference in the Stroop effect: uncovering the cognitive and neural anatomy of attention. Trends Cogn. Sci. 4 (10), 383–391.
Maddock, R.J., 1999. Retrosplenial cortex and emotion: new insights from functional imaging studies of the human brain. Trends Neurosci. 22, 310–316.
Maddock, R.J., Garrett, A.S., Buonocore, M.H., 2003. Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. Hum. Brain Mapp. 18, 30–41.
Mattingley, J.B., Rich, A.N., Yelland, G., Bradshaw, J.L., 2001. Unconscious priming eliminates automatic binding of color and alphanumeric form in synesthesia. Nature 410, 580–582.
Nunn, J.A., Gregory, L.J., Brammer, M., Williams, S.C.R., Parslow, D.M., Morgan, M.J., Morris, R.G., Bullmore, E.T., Baron-Cohen, S., Gray, J.A., 2002. Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. Nat. Neurosci. 5, 371–375.
Ortigue, S., Michael, C.M., Murray, M.M., Mohr, C., Carbonnel, S., Landis, T., 2004. Electrical neuroimaging reveals early generator modulation to emotional words. NeuroImage 21, 1242–1251.
Pérez-Dueñas, C., Acosta, A. Lupiáñez, J. (August, 2005). Attentional Biases in Subclinical Trait Anxiety: Inhibition of Return in an Emotional Categorization Task. Poster presented at the XIV ESCOP conference. Leiden, Netherlands.
Pérez-Dueñas, C., Correa, A., Lupiáñez, J., Acosta, A., Tudela, P., 2006. Sesgos atencionales en personas ansiosas: implicación de mecanismos de captura o desenganche? In: Contreras, M.J., Botella, J., Cabestrero, R., Gil, B. (Eds.), Lecturas de Psicología Experimental. UNED, Madrid.
Pulvermüller, F., 2001. Brain reflections of words and their meaning. Trends Cogn. Sci. 5, 517–524.
Ramachandran, V.S., Hubbard, E.M., 2001a. Psychophysical investigations into the neural basis of synesthesia. Proc. R. Soc. Lond., B Biol. Sci. 268, 979–983.
Ramachandran, V.S., Hubbard, E.M., 2001b. Synesthesia—A window into perception, thought and language. J. Conscious. Stud. 8 (12), 3–34.
Robertson, L.C., 2001. Color my i's blue. Nature 410, 533–534.
Schneider, W., 1988. Micro experimental laboratory: an integrated system for IBM PC compatibles. Behav. Res. Methods Instrum. Comput. 20 (2), 206–217.
Simner, J., Ward, J., Lanz, M., Jansari, A., Noonan, K., Glover, L., Oakley, D., 2005. Non-random associations of graphemes to colours in synaesthetic and non-synaesthetic populations. Cogn. Neuropsychol. 22 (8), 1069–1085.
Smilek, D., Dixon, M.J., Cudahy, C., Merikle, P.M., 2001. Synaesthetic photism influence visual perception. J. Cogn. Neurosci. 13 (7), 930–936.
Stroop, J.R., 1935. Studies of interference in serial verbal reactions. J. Exp. Psychol. 18, 643–662.
Van Hoesen, G.W., Morecraft, R.J., Vogt, B.A., 1993. Connections of the monkey cingulate cortex. In: Vogt, Gabriel (Eds.), Neurobiology of Cingulate Cortex and Limbic Thalamus. Birkhäuser, pp. 249–284.
Ward, J., 2004. Emotionally mediated synaesthesia. Cogn. Neuropsychol. 21 (7), 761–772.
Ward, J., Sagiv, N., Li, R., (2006, April) What's Right and What's Wrong About the Projector–Associator Distinction? Paper presented at the annual UK Synesthesia Association Meeting, London, UK.
Weiss, P.H., Shah, N.J., Toni, I., Zilles, K., Fink, G.R., 2001. Associating colours with people: a case of chromatic-lexical synaesthesia. Cortex 37, 750–753.