A Time Course Analysis of the Synesthetic Colour Priming Effect

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A currently unresolved issue in research on synesthesia concerns the extent to which synesthetic experiences arise automatically. To shed light on this issue, we manipulated the stimulus onset asynchrony (SOA) in a synesthetic colour priming task (i.e., 0 ms, 200 ms, 1,000 ms). Results show that 200-ms presentations of synesthetic inducers produce reliable synesthetic colour priming at short SOAs. Based on this finding, we conclude that synesthesia is produced by fast-acting, automatic processes.

Keywords: synesthesia, colour priming, automaticity

Synesthesia is an unusual perceptual phenomenon in which specific physical stimuli consistently induce more than one perceptual experience, either in a separate modality or within the same modality (Rich & Mattingly, 2002). For example, vivid experiences of colour might be elicited by visual symbols like letters, digits, or words (e.g., Dixon, Smilek, Cudahy, & Merikle, 2000; Myles, Dixon, Smilek, & Merikle, 2003), by musical tones (e.g., Marks, 1975; Rizzo & Eslinger, 1989), or by particular odours or tastes (Coriat, 1913). Synesthetic experiences not involving colour also have been described in the literature (e.g., Pierce, 1907), although this manifestation of the phenomenon appears to be much less common (Rich & Mattingly, 2002).

A currently unresolved issue in research on synesthesia concerns the extent to which induced synesthetic experiences arise automatically. Even though most synesthetes report that their synesthetic experiences are not under voluntary control (Rich & Mattingly, 2002), experimental evidence bearing on this issue is far from unequivocal. Sagiv, Heer, and Robertson (2006), for instance, found no evidence for pre-attentive colour perception in graphemic-chromatic synesthesia. They presented two synesthetes with upright or inverted ‘L’s as targets amongst distracters that did not elicit synesthetic experiences (rotated ‘T’s). Sagiv et al. (2006) reasoned that if synesthetic colors are induced prior to attentive processing, synesthetes should be more efficient in detecting upright ‘L’s as compared to inverted ‘L’s. However, such a ‘pop-out’ effect did not occur (however, see Ramachandran & Hubbard, 2001). On the other hand, the hypothesis that synesthetic experiences arise automatically is supported by several studies that employed the so-called synesthetic Stroop task. In this synesthetic version of the classic Stroop task (Stroop, 1935), participants are asked to name the colour of visual stimuli (digits, letters, or words) while ignoring the synesthetic colors they elicit. Performance is then compared between congruent trials (i.e., the synesthetic colour is congruent with the display colour) and incongruent trials (i.e., the synesthetic colour is incongruent with the display colour). In line with the idea that synesthetic experiences are triggered automatically by their graphemic inducers, it is typically observed that synesthetes are faster to respond to congruent trials as compared to incongruent trials (e.g., Mills, Boteler, & Oliver, 1999; Mattingley, Rich, Yelland, & Bradshaw, 2001; Wollen & Ruggiero, 1983).

It is a significant shortcoming of the synesthetic Stroop task, however, that the relevant stimulus dimension (i.e., the to-be-named display colour) and the irrelevant stimulus dimension (i.e., the induced colour) are both temporally and spatially overlapping. This is problematic for two reasons. First, as Stroop stimuli are typically presented until a response is registered, no control can be exerted over the time participants are exposed to the inducer. The extent to which conscious response strategies are adequately controlled for in the synesthetic Stroop task can thus be questioned. Second, given that it takes several hundreds of milliseconds to name the colour of a Stroop stimulus, exposure to inducers in the synesthetic Stroop task is necessarily lengthy in time. Research with this task thus fails to provide any evidence concerning the precise time course of synesthetic experiences.

These problems can be removed by using a priming procedure in which inducers are presented briefly (e.g., 200 ms) prior to the presentation of to-be-named colour patches (i.e., the synesthetic colour priming task). Just as in the Stroop task, it can be hypothesised that synesthetes should be faster to name the physical colour of colour patches that are congruent with the colour elicited by the preceding inducer as compared to colour patches that are incongruent with the colour elicited by the preceding inducer. The advantage of this task is that exposures to the inducers can be manipulated in a controlled manner. Moreover, the synesthetic colour priming paradigm allows for a systematic manipulation of the stimulus onset asynchrony (i.e., the interval between the onset of the prime and the onset of the target, SOA). Because strategic processes are generally assumed to be time consuming (Neely,
1991; Posner & Snyder, 1975), a systematic analysis of synesthetic colour priming at different SOA levels can provide crucial evidence concerning the nature of the processes underlying synesthesia. That is, if synesthetic experiences arise automatically, synesthetic colour priming effects should occur at short SOAs. In contrast, if synesthetic experiences are based on slow-acting, strategic processes, significant synesthetic colour priming should occur at long SOAs only.

A few years ago, Mattingley et al. (2001) adopted this approach. They manipulated the SOA in a synesthetic colour priming task and found significant synesthetic colour priming at the long SOA of 500 ms but not at short SOA levels (i.e., 28 ms and 56 ms). However, in their study, the duration of the primes varied across different SOA conditions: At short SOAs, the primes were presented subliminally (i.e., 28 ms and 56 ms) whereas 500-ms presentations were used at the long SOA. Therefore, even though their studies certainly indicate that overt recognition of inducers is crucial for the occurrence of synesthesia, conclusive evidence concerning the time course of the synesthetic colour priming effect is still unavailable.

For these reasons, we set up a synesthetic colour priming study in which the SOA was manipulated over three levels (0 ms, 200 ms, and 1,000 ms) while keeping the prime duration constant (i.e., 200 ms). Assuming that synesthesia is driven by fast-acting, automatic processes, we expected to observe significant synesthetic colour priming to occur at short SOAs. Before we describe this study, we report the results of an initial study in which we compared performance of 12 synesthetes and 12 nonsynesthetic controls in both a synesthetic colour priming task and a standard colour priming task. The purpose of this study was twofold. First, we wanted to assess the validity of our procedures. Second, we wanted to ascertain that synesthetetic participants were indeed genuinely synesthetic.

**Experiment 1**

**Method**

**Participants.** Participants were 12 individuals with colourgraphemic synesthesia and 12 nonsynesthetic controls. Nonsynesthetic participants (2 men, 10 women) were University of Leuven students, 9 of which participated in fulfillment of course requirements. Synesthetetic participants (4 men, 8 women) were selected out of a group of 37 individuals that responded to an electronic message sent to all students and employees of the University of Leuven (approximately 38,500 addresses). Each synesthetetic participant was asked to assign four letters and/or digits that elicited strong colour sensations. Triplets of these letters and/or digits (e.g., AAA) were used as primes and were always presented in black. Next, synesthetetic participants were asked to indicate the colour of each of these stimuli on a standard electronic colour palette. These idiosyncratically selected colors were then used to construct four squared colour dots (380 pixels wide, 285 pixels high) that were later used as targets. Except for the fact that nonsynesthetic participants were asked to assign arbitrarily chosen colors to arbitrarily chosen prime stimuli, a similar procedure was used to construct idiosyncratic stimulus materials for nonsynesthetic participants. All synesthetetic prime stimuli were presented in black (font: Times, font size: 200).

For the standard colour priming task, four fixed letter strings were used as primes (AAA, EEEE, IIII, and UUU). These prime stimuli were presented in a fixed colour (green, red, yellow, and blue, respectively). Similar to the synesthetic colour priming task, four squared colour dots were used as targets. The colors of these targets were the same as those of the four primes.

All stimuli were presented against the white background of a 19 in. computer monitor (CRT, 100 Hz, 24 bits per pixel, screen resolution 1024 x 768). An Affect 3.0 program (Hermans, Clarysse, Baeyens, & Spruyt, 2003) controlled the presentation of the stimuli as well as the registration of the response latencies. The experiment was run on an AMD Athlon, 1900 computer (64 MB VRAM). An external voice key that was connected to the parallel port of the computer was used to measure response latencies.

**Procedure.** Participants were tested individually in a dimly lit and soundproof room. After the stimulus-selection phase (see above), the two priming tasks were administered. Participants were asked to assign attention to the coloured squares only and to name their colour as quickly as possible.

Each task consisted of 16 trials. In the standard colour priming task, the prime colour and the target colour were identical on exactly half of these trials (congruency). On the other trials, the colour of the primes and the targets were different (incongruency). Likewise, in the synesthetic colour priming task, idiosyncratic target colors matched the synesthetic prime colour (or the arbitrarily assigned prime colour in case of the nonsynesthetic controls) on exactly 8 trials (congruency). On the other trials, the prime-target relation was incongruent. All prime and target stimuli were presented equally often (i.e., four times).

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1 One synesthetetic did not return the retest form.
The sequence of events on any given trial was identical for both tasks. Each trial started with a 500-ms presentation of a fixation cross in the centre of the screen. Five hundred milliseconds after the offset of the fixation cross the prime was presented for 200 ms. Next, the target was presented until the participant gave a response or 2,000 ms elapsed. The experimenter coded whether the microphone was accurately triggered and whether the participant’s response was correct by pressing one of three keys on the computer keyboard. After the experimenter entered the code, the next trial was initiated after a time interval that varied randomly between 500 ms and 1,500 ms.

Results

Participants failed to respond before the 2,000-ms response deadline on 4.43% of all trials. Data from trials on which the voice key was not appropriately activated (3.26%) or an incorrect response was given (1.95%) were discarded. Next, we calculated medians for each experimental condition and each participant. For each task, the data were analysed by means of a 2 (group: synesthetes vs. nonsynesthetic controls) × 2 (congruence: congruence vs. incongruence) analysis of variance (ANOVA).2

As expected, a significant colour priming effect emerged in the standard colour priming task, \( F(1, 22) = 43.87, p < .001, \eta^2_p = .63 \) (see Table 1): Congruent prime-target pairs were responded to faster than incongruent prime-target pairs. Planned comparisons confirmed that this colour priming effect was reliable in the nonsynesthetic group, \( F(1, 22) = 13.10, p < .005, \eta^2_p = .37 \), as well as the synesthetic group, \( F(1, 22) = 24.39, p < .001, \eta^2_p = .53 \). The colour priming effect was not statistically different in both groups, \( F < 1 \).

A completely different pattern of results emerged in the synesthetic colour priming task (see Table 1). In this task, significant priming emerged in the synesthetic group, \( F(1, 22) = 5.36, p < .05, \eta^2_p = .20 \), whereas synesthetic colour priming was completely absent in the nonsynesthetic group, \( F < 1 \). Due to a lack of statistical power, however, the interaction between group and synesthetic colour priming just missed conventional levels of significance, \( F(1, 22) = 3.29, p = .099, \eta^2_p = .13 \).

Discussion

In line with previous studies (e.g., Mattingley et al., 2001), we observed that synesthetes named colour patches faster after the presentation of congruent inducers than after incongruent inducers. In contrast, response latencies of nonsynesthetic controls were unaffected by the presentation of the primes in the synesthetic colour priming task. This pattern of results confirms (a) that our sample of synesthetes consisted of genuine synesthetes and (b) that fundamentally different processes were at play in both groups when performing the synesthetic colour priming task. It is also important to note that both groups exhibited significant priming in the standard colour priming task. This finding clearly shows that the experimental procedures used were sound. It thus seems unlikely (though not impossible) that the absence of priming in the synesthetic colour priming task for nonsynesthetic controls was due to a Type-II error.

More important, the findings of Experiment 1 also suggest that synesthesia is based on fast-acting, automatic processes. Because participants were exposed to the inducers for just 200 ms and the SOA was short (i.e., 200 ms) it seems unlikely that the synesthetic colour priming effect that emerged in the synesthetic sample of participants resulted from conscious strategies. However, to obtain more convincing evidence for this hypothesis, we conducted an additional synesthetic colour priming study in which we manipulated the SOA over three levels (i.e., 0 ms, 200 ms, and 1,000 ms). We selected this variable because strategic processes are generally assumed to be time consuming (Neely, 1991; Posner & Snyder, 1975). A systematic analysis of the synesthetic colour priming effect at different SOA levels can thus provide crucial evidence concerning the nature of the processes underlying synesthesia.

Experiment 2

Method

Participants. Participants were the same as those of Experiment 1 (12 synesthetes, 12 nonsynesthetic controls). Participants started with Experiment 2 after taking a short break.

Design. Participants completed a synesthetic colour priming task in which the SOA (0 ms vs. 200 ms vs. 1,000 ms) was manipulated as a blocked within-subjects variable. Participants completed nine blocks of 16 trials each. The ordering of different SOA blocks within each sequence of three successive blocks was counterbalanced across participants. Synesthetic colour congruency varied as a within-subjects variable within each SOA condition (8 congruent trials, 8 incongruent trials).

Materials. The materials used in the present study were identical to those used in Experiment 1.

Procedure. Each trial started with a 500-ms presentation of a fixation cross in the centre of the screen. Five hundred milliseconds after the offset of the fixation cross the prime was presented for 200 ms. In the 0-ms SOA condition, the target pictures were presented simultaneously with the prime. In the 200-ms SOA condition, the target pictures were presented at the offset of the prime. In the 1,000-ms SOA condition, the target pictures were presented 800 ms after the prime offset. Because of the overlap in the presentation of the primes and the targets in the 0-ms SOA condition, we presented the primes and the targets above one another in all SOA conditions (visual angle = 37.56°). For each trial, it was randomly determined whether the prime was presented above or below the target, thus ensuring locational uncertainty (see Kahneman, Treisman, & Burkell, 1983; Musch & Klauer, 2001; Underwood, 1976). In all other aspects, the temporal characteristics of any given trial were identical to that of Experiment 1.

Results

One synesthete responded extremely slowly on incongruent trials in the 0-ms SOA condition (i.e., 58.33% outliers, see Ratcliff, 1993). The data of this participant were excluded from further analyses. In all other aspects, the data were preprocessed as those of Experiment 1. In total, participants failed to respond before the 2,000-ms response deadline on 1.12% of all trials. Data from trials on which none of the reported effects were influenced by the order in which the two priming tasks (synesthetic color priming task vs. standard color priming task) were administered.
the voice key was not appropriately activated (2.42%) or an incorrect response was given (1.63%) were also discarded.

Greenhouse–Geisser corrections were applied to compensate for violations of the compound symmetry assumption and the assumption of sphericity when testing within-subjects effects involving more than a single degree of freedom. Only corrected p-values are reported.

After calculating medians for each experimental condition, we first analysed the data by means of a 2 (group: synesthetes vs. nonsynesthetes) × 3 (SOA: 0 ms, 200 ms, 1,000 ms) × 2 (congruency: congruent vs. incongruent) ANOVA. The main effect of synesthetic colour congruency was significant, \(F(1, 21) = 17.86, p < .005, \eta^2_p = .46\), and interacted significantly with the group factor, \(F(1, 21) = 12.08, p < .005, \eta^2_p = .33\). As expected the synesthetic colour priming effect was significant in the synesthetic group, \(F(1, 21) = 29.76, p < .001, \eta^2_p = .60\); but not in the nonsynesthetic group, \(F < 1\) (see Table 2).

Next, to evaluate whether synesthetic colour priming in the sample of synesthetes was affected by variations in the SOA, we analysed the data of the synesthetes by means of a separate 3 (SOA: 0 ms, 200 ms, 1,000 ms) × 2 (congruency: congruent vs. incongruent) ANOVA. Besides the significant main effect of congruency, \(F(1, 10) = 15.33, p < .005, \eta^2_p = .61\), this analysis revealed a significant main effect of SOA: Participants responded faster as a function of increasing levels of SOA, \(F(2, 20) = 15.96, p < .001, \eta^2_p = .60\). Although the numeric difference between congruent and incongruent priming conditions increased as a function of increasing SOA levels (see Table 2), this linear trend was statistically unreliable, \(F(1, 10) = 1.14, p > .30, \eta^2_p = .10\). Likewise, the overall interaction between SOA and congruency was also nonsignificant, \(F(2, 20) = 1.39, p > .27, \eta^2_p = .12\).

Crucially, planned comparisons confirmed that the effect of congruency was significant in the 0-ms SOA condition, \(F(1, 10) = 9.06, p < .05, \eta^2_p = .45\); the 200-ms SOA condition, \(F(1, 10) = 5.65, p < .05, \eta^2_p = .36\), as well as the 1,000-ms SOA condition, \(F(1, 10) = 11.80, p < .01, \eta^2_p = .54\).

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Nonsynesthetic group</th>
<th>Synesthetes group</th>
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<tbody>
<tr>
<td></td>
<td>Congruent (15)</td>
<td>Congruent (28)</td>
</tr>
<tr>
<td></td>
<td>Incongruent (30)</td>
<td>Incongruent (24)</td>
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<tr>
<td></td>
<td>CPE (56)</td>
<td>CPE (7)</td>
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<tr>
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<tr>
<td>Synesthetic</td>
<td>531</td>
<td>524</td>
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</table>

Note. Given in milliseconds. Standard error in parentheses.

### Discussion

The findings of Experiment 2 corroborate and extend those of Experiment 1. Unlike nonsynesthetic controls, synesthetes were influenced by brief presentations of monochrome inducers when naming target colour patches. Moreover, consistent with the hypothesis that synesthetic experiences can come about automatically, this synesthetic colour priming effect was unaffected by the SOA.

One might object, however, that the absence of a reliable interaction between synesthetic colour priming and SOA resulted from a lack of statistical power. In this respect, the observation that reliable synesthetic colour priming emerged in the 0-ms SOA condition is crucial. Given that strategic processes are time consuming (e.g., see Neely, 1977, 1991; Posner & Snyder, 1975), this finding clearly demonstrates that synesthetic colour priming can come about under conditions that prevent the operation of such processes. In fact, this conclusion would still hold even if the magnitude of the synesthetic colour priming effect would have increased across SOA levels. Although such a finding would indicate that slow-acting, conscious strategies can contribute to the synesthetic colour priming effect if participants are given more time to process the prime-target relationship, it does not refute the idea that the synesthetic colour priming effect in the 0-ms SOA condition is produced by fast-acting, automatic processes.

### General Discussion

The present research aimed at uncovering the time course of the synesthetic colour priming effect. After having established the validity of our priming procedures (Experiment 1), we manipulated the SOA over three levels (i.e., 0 ms, 200 ms, 1,000 ms; Experiment 2). In line with the hypothesis that the synesthetic colour priming effect is produced by fast-acting, automatic processes, we observed that 200-ms presentations of synesthetic in-

### Table 2

<table>
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<th>SOA</th>
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<th>Synesthetes group</th>
</tr>
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</tr>
<tr>
<td></td>
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<td>Incongruent (38)</td>
</tr>
<tr>
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<td>522</td>
</tr>
<tr>
<td>200 ms</td>
<td>529</td>
<td>560</td>
</tr>
<tr>
<td>1,000 ms</td>
<td>526</td>
<td>586</td>
</tr>
</tbody>
</table>

Note. Standard error in parentheses.
Les résultats ont montré que les expériences synesthésiques ont été produites à deux moments de temps différents (0 ms et 200 ms). Ceci concorde avec les résultats de Mattingley et al., 2001, Mills et al., 1999, Wollen & Ruggiero, 1983. En comparaison avec ces études, nos procédures garantissent que les participants ont été exposés aux incitants dans un contexte contrôlé et standardisé (voir ci-dessus). En conséquence, il est peu probable que les stratégies de réponses conscientes aient contribué aux effets observés, à moins qu'elles ne soient importantes dans les conditions de SOA de courte durée.

Mattingley et al. (2001) ont aussi examiné l'effet de prémunition de la couleur à différentes conditions de SOA (c.-à-d., 28 ms, 56 ms, ou 500 ms). En comparaison avec ces études, ils ont échoué à obtenir une prémunition de la couleur dans les conditions de SOA de courte durée. Cependant, dans les études de Mattingley et al. (2001), la durée de l'incitant et le SOA variaient en prime. Cela dit, dans les conditions de SOA de courte durée, les incitants ont été présentés subliminairement (c.-à-d., 28 ms et 56 ms, respectivement), tandis que les présentations supraliminaires des incitants étaient utilisées dans la condition de SOA de 500 ms (c.-à-d., 500 ms). Les résultats de cette étude démontrent que la prémunition synesthésique peut être obtenue à des SOA supraliminaires que les présentations supraliminaires des incitants sont utilisées.

L'idée que la prémunition synesthésique à des SOA de courte durée est conditionnelle sur la conscience de l'incitant et que la conscience est en contradiction avec notre conclusion que la prémunition synesthésique peut être observée dans un contexte automatique. En effet, il est indiqué par Moors et de Houwer (2006), que la définition et la conjugaison automatique requièrent un approche base-directielle, décompositional. Selon leur point de vue, les différentes automatismes (c.-à-d., inconscient, efficace, rapide) peuvent être conceptuellement et logiquement séparés et devraient être étudiés indépendamment de l'autre. Les résultats de cette étude démontrent que la prémunition synesthésique est automatique au sens où elle repose sur des processus rapides et ne requiert pas l'activation des processus stratégiques. De plus, une recherche supplémentaire est nécessaire pour examiner d'autres caractéristiques automatiques de la prémunition synesthésique de couleur.

Une question non résolue dans le domaine de la synesthésie concerne le degré d’automatisme de l’apparition des expériences synesthésiques. Afin de faire la lumière sur cette question, nous avons manipulé l’asynchronie d’apparition du stimulus (SOA) dans une tâche d’amorçage de couleur synesthésique (c.-à-d., 0, 200, 1000 ms). Les résultats ont montré que les présentations de 200 ms des incitants de synesthésie produisent un amorçage de couleur synesthésique consistant avec les SOA courts. En vertu de ce résultat, nous concluons que la synesthésie est produite par des processus rapides et automatiques.

Résumé

Une question de recherche non résolue dans le domaine de la synesthésie concerne le degré d’automatisme de l’apparition des expériences synesthésiques. Afin de faire la lumière sur cette question, nous avons manipulé l’asynchronie d’apparition du stimulus (SOA) dans une tâche d’amorçage de couleur synesthésique (c.-à-d., 0, 200, 1000 ms). Les résultats ont montré que les présentations de 200 ms des incitants de synesthésie produisent un amorçage de couleur synesthésique consistant avec les SOA courts. En vertu de ce résultat, nous concluons que la synesthésie est produite par des processus rapides et automatiques.

Mots-clés : synesthésie, amorçage de couleur, automaticité

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