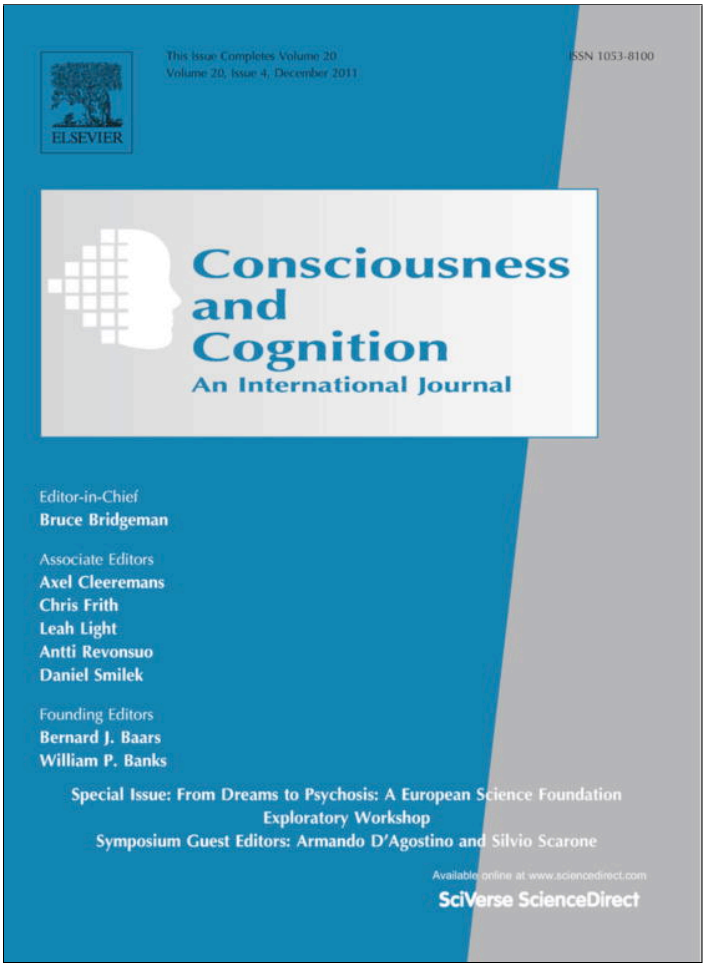
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# The influence of synesthesia on eye movements: No synesthetic pop-out in an oculomotor target selection task

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Recent research on grapheme-colour synesthesia has focused on whether visual attention is necessary to induce a synesthetic percept. The current study investigated the influence of synesthesia on overt visual attention during an oculomotor target selection task. Chromatic and achromatic stimuli were presented with one target among distractors (e.g. a '2' (target) among multiple '5's (distractors)). Participants executed an eye movement to the target. Synesthetes and controls showed a comparable target selection performance across conditions and a 'pop-out effect' was only seen in the chromatic condition. As a pop-out effect was absent for the synesthetes in the achromatic condition, a synesthetic element appears not to elicit a synesthetic colour, even when it is the target. The synesthetic percepts are not pre-attentively available to distinguish the synesthetic target from synesthetic distractors when elements are presented in the periphery. Synesthesia appears to require full recognition to bind form and colour.



## 1. Introduction

Grapheme-colour synesthesia is the phenomenon in which viewing numbers or letters (graphemes) results in the concurrent sensation of colour. A current debate is the degree to which visual attention is necessary for a synesthetic percept to occur. The role of attention has been the focus of recent research and is the root of controversy in this field (Mattingley, Rich, Yelland, & Bradshaw, 2001; Nijboer & Van der Stigchel, 2009; Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001; Smilek, Dixon, & Merikle, 2003). Synesthetic colours have been described to guide attention (Smilek et al., 2003), to conduct perceptual grouping (Ramachandran & Hubbard, 2001) and to improve visual search (Palmeri et al., 2002). This last study revealed in one synesthete that visual search for a target was faster when the synesthetic colour elicited by the target was different from the distractors. Especially this finding was taken as a hint that synesthetic colours arise early enough to effectively distinguish achromatic graphemes from each other. Alternatively, there are other instances where synesthetic colours do not influence performance on visual tasks whereas real colours significantly impact performance on those tasks (Edquist, Rich, Brinkman, & Mattingley, 2006; Gheri, Chopping, & Morgan, 2008; Hong & Blake, 2008; Rothen & Meier, 2009). There is evidence that synesthetic colour percepts are only induced once stimuli are selectively attended. For instance, Sagiv, Heer, and Robertson (2006) argued that synesthesia allows subjects to guide search based on synesthetic colour, but that this facilitatory effect occurs only after attention has been focused on the target. Mattingley, Payne, and Rich (2006, 2001) found that synesthetic percepts were attenuated when attentional resources were directed elsewhere and that synesthesia was completely eliminated when inducing stimuli were unavailable for overt recognition.

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Recently, Nijboer and Van der Stigchel (2009) examined the role of visual attention using an oculomotor distractor task. Synesthetes were required to make an eye movement to a coloured target, while ignoring either a digit or non-digit distractor. This paradigm was unique in that synesthetes were instructed not to look for synesthetic elements as a target, but to ignore them as a distractor. If the first eye movement was incorrectly made to the distractor, it was qualified as being "captured" by the distractor. Results indicated that the percentage capture by a synesthetic distractor was comparable to the percentage capture by a gray non-digit distractor. Physical colour, however, did influence target selection such that distractors with the same physical colour as the target elicited stronger capture than achromatic distractors. These findings therefore indicate that synesthetic distractors did not divert eye movements away from the target to the same degree as physically coloured distractors.

Another recent study did find evidence that synesthesia influences overt visual attention (i.e. eye movements). Carriere, Eaton, Reynolds, Dixon, and Smilek (2009) revealed that synesthetes fixate congruently coloured letters more often and for longer durations than incongruently coloured letters. Furthermore, they observed in a subsequent visual search task that synesthetes rapidly fixate and identify congruently coloured target letters, but had problems in identifying incongruently coloured letters. This might appear inconsistent with our findings that synesthesia does not influence oculomotor behaviour. It must be noted, however, that in our previous experiment, participants had to ignore the synesthetic element. It is therefore likely that only a small amount of visual attention was allocated to the synesthetic element, because the task was to actively ignore it. It can therefore be argued that an effect of the synesthetic element would have been observed when the task was to search for the synesthetic element. Indeed, in our previous study, we performed a control experiment in which synesthetes were required to report the synesthetic hue when an achromatic stimulus was presented at one of the possible distractor locations (without making an eye movement). Results showed that such a peripheral stimulus did induce a synesthetic colour, showing that a peripheral stimulus can induce a synesthetic experience when a large amount of attention is allocated to it.

To investigate the influence of synesthesia on eye movements, the current study investigated whether a synesthetic element induces a pop-out in the same way as normal colour does when it is the target in an oculomotor target selection task. Participants viewed an array of digits with varying set sizes and were required to make an eye movement to the "odd one out" (e.g. a '2' (target) among multiple '5's (distractors)). Target and distractor stimuli were presented as either all coloured (chromatic), gray (achromatic) or achromatic with one chromatic distractor (mixed). Target and distractors were always differently (synesthetically) coloured.

Participants were not allowed to freely move their eyes across the different elements in the scene, but were only allowed to execute one eye movement to locate the target element. This should be no problem when the target has a distinct colour with respect to the other elements, but would be difficult when there was no distinct feature that allowed for a fast detection of the target. This experiment would therefore reveal whether synesthetic colours resulted in a similar search benefit as physical colours do. To this end, it was investigated whether search slopes for synesthetes in the achromatic condition resemble search slopes in the chromatic condition. In the chromatic condition, the target had a unique physical colour in the visual scene. Therefore, a pop-out effect was expected in both synesthetes and controls, resulting in fast reaction times and high accuracy, irrespective of set size. If synesthetic percepts arise pre-attentively, then the achromatic condition would also show a pop-out effect for synesthetes, because the target would elicit a synesthetic colour experience corresponding to the concurrent colour that the particular participant has for the target digit. Alternatively, if synesthesia requires attention to bind form and colour, as we propose, then the achromatic conditions would not include a synesthetically coloured target. In this case, no pop-out effect would be seen in the achromatic condition for both synesthetes and controls.

The mixed condition, in which the target is achromatic and one distractor is chromatic, allowed for a direct comparison between the strength of physically and synesthetically coloured elements. If the amount of erroneous eye movements executed to the physically coloured element was similar for synesthetes and controls, this would indicate that the presence of a synesthetic target does not modulate the strength of the pop-out effect evoked by the presence of the synesthetic target.

## 2. Method

### *2.1. Participants*

Nine female grapheme-colour synesthetes (mean age = 25, SD = 12.27, age range 17–57; three projectors and six associators) served as paid volunteers. Synesthetes were recruited via an advertisement in a digital synesthesia newsletter. Nine control participants (mean age = 23, SD = 1.32, age range 21–24) were included, who were presented with the specific synesthetic hues on a one-to-one basis. All participants were naïve as to the purpose of the experiment and gave their informed consent prior to their participation in the experiment.

### *2.2. Apparatus*

Eye movements were recorded by an infrared video-based eye tracker (SR Research Ltd, Canada). The Eyelink1000 system had a 1000-Hz temporal resolution and a spatial resolution of 0.5°. The left eye was recorded and analyzed. The participant's head was stabilized using a chin rest. The distance between monitor and chin rest was 65 cm.

### 2.3. Stimuli and procedure

Synesthetes started by matching the hue of their synesthetic experience of an achromatic digit (2, 5, 6, and 9) onto an achromatic square by adjusting the RGB gun values (see Table 1 for the *xyY* values of all hues used per synesthete). The digit

**Table 1**
*xyY* Values of the specific hues associated with the digit stimuli for each individual synesthete.

| Synesthete | '2' | '5' | '6' | '9' |
|---|---|---|---|---|
| 1 | .292, .590, 8.04 | .248, .242, 19.6 | .166, .098, 0.81 | .578, .359, 1.55 |
| 2 | .243, .323, 43.6 | .433, .495, 35.9 | .514, .431, 18.5 | .435, .478, 29.7 |
| 3 | .389, .454, 41.4 | .287, .309, 51.6 | .381, .531, 37.1 | .363, .445, 51.1 |
| 4 | .381, .473, 47.1 | .300, .587, 4.71 | .610, .346, 2.95 | .375, .379, 0.24 |
| 5 | .411, .512, 39.0 | .212, .271, 32.5 | .178, .133, 0.92 | .490, .404, 1.65 |
| 6 | .409, .510, 41.8 | .159, .089, 5.94 | .373, .344, 25.7 | .401, .340, 7.71 |
| 7 | .407, .519, 45.7 | .293, .604, 13.6 | .289, .243, 31.8 | .385, .397, 22.7 |
| 8 | .445, .485, 17.1 | .253, .292, 40.3 | .610, .346, 3.06 | .375, .379, 0.24 |

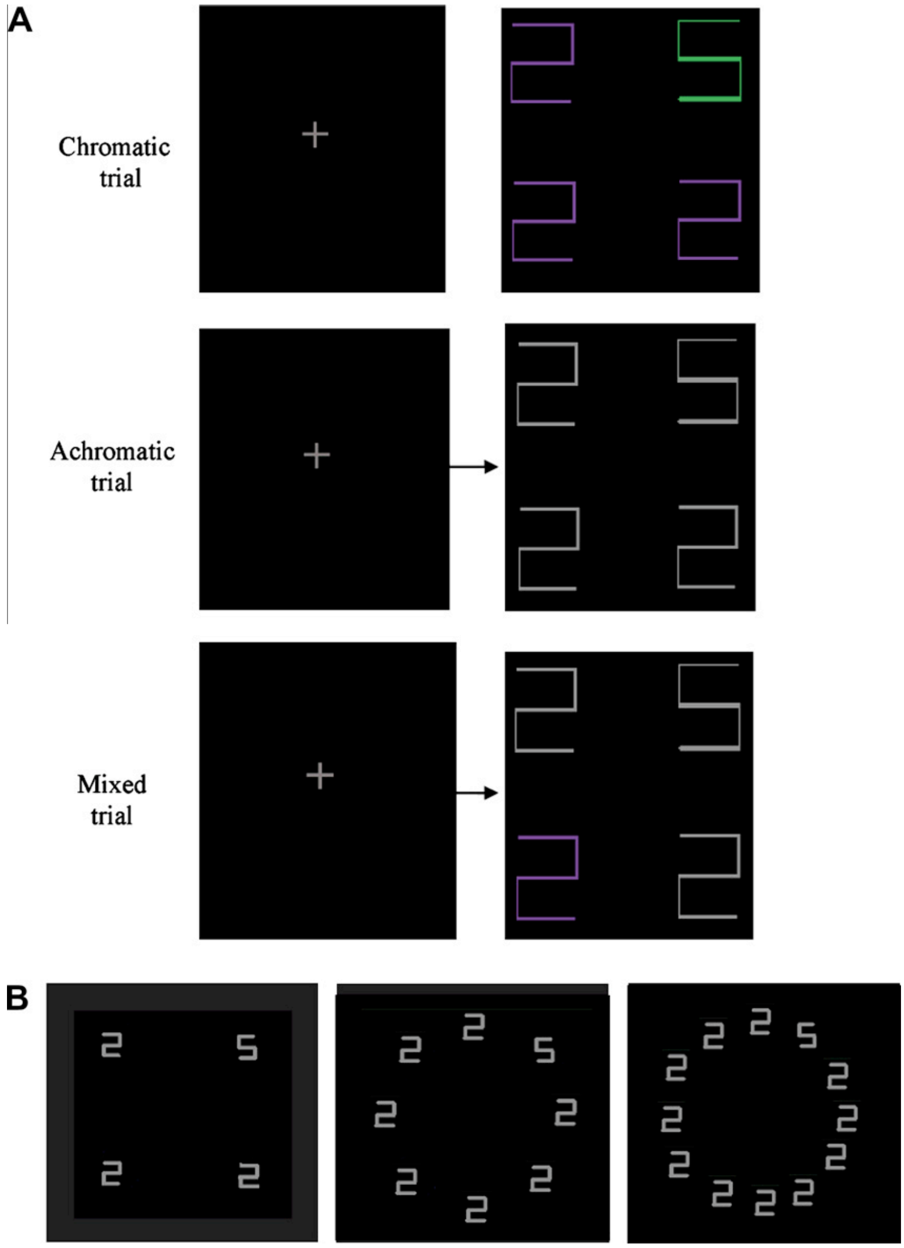



**Fig. 1.** (A) Examples of a stimulus trial for the chromatic, achromatic and mixed configurations. Specific hues used were set by individual synesthetes at start of the experiment; (B) Stimulus configurations for set sizes 4, 8, and 12.

was presented on the left side of the monitor and the hash on the right side. Both were presented on a black background in the font that they would appear in during the experiment.

The experiment began with 24 practice trials followed by 24 blocks of 24 trials, amounting to 576 trials. Each trial began with a grey fixation cross presented for 350 ms, followed by the stimuli display until a response was made or for 2000 ms.

Stimuli consisted of a target-distractor display of 2s and 5s or 6s and 9s ($1.3 \times 1.1°$ of visual angle). These digits were adopted in order to avoid shape pop-out. Three stimulus conditions were used: "achromatic" (light gray), "chromatic" (physically coloured target and distractors; colours were always congruent to the matched synesthetic hues for every individual synesthete (and the matched control)) or "mixed" (achromatic target and distractors with one congruently coloured chromatic distractor; see Fig. 1A). The conditions were interspersed throughout the experiment.

Stimuli were displayed on an imaginary circle (radius 12.4°) with one target (e.g. 2) amongst varying set-sizes of three, seven, or eleven distractors (e.g. 5s) (see Fig. 1B). The locations of the stimuli were fixed for each set size (i.e. there were four potential target/distractor locations when the set size was four). The distance between each stimulus was equal within each set size (set size 4: 17.55°, set size 8: 9.50°, set size 12: 6.76°). When set size was 12 in the mixed condition, the chromatic distractor was never presented at the adjacent location of the target to ensure that the saccades could be accurately qualified as being landed either on the target or the chromatic distractor. Trials were counterbalanced for set size, condition, and stimuli.

Participants were instructed to fixate the central fixation cross until stimuli onset and then to make one eye movement as quickly and accurately as possible to the "odd one out"—the digit that differed in numerical value from the others. It was stressed that they were required to make only one eye movement to locate the target. For each synesthete a control performed the same experiment using the synesthetic hues of their matched participant.

### 2.4. Data analysis

If saccade latencies were shorter than 80 ms, longer than 1500 ms, or 2.5 standard deviations from the participant's mean latency, the trial was excluded. To determine whether an eye movement landed on either the target or the chromatic distractor, we determined a criterion that enabled us to disentangle between these two types of eye movements. We measured the minimal distance between the target and the chromatic distractor (9.50°) and divided that distance into halve. This distance was subsequently used as criterion to determine the direction of the eye movement. When the first eye movement landed within 4.75° of the centre of the target location, it was considered a "correct" response and included in the saccade latency calculations. When the first eye movement landed within 4.75° of the centre of the chromatic distractor, it was considered "captured" by the chromatic distractor.

A Repeated Measures Analysis of Variance was performed for accuracy and saccade latency of eye movements with set size (four, eight, twelve stimuli) and condition (chromatic, achromatic, mixed) as within-subject variables and group (synesthetes versus controls) as a between-subject variable. Additionally, percentage of capture by the real colour distractor in the mixed condition was analysed with set size as within-subject variable and group as a between-subject variable. When significant interactions were found a Bonferroni post hoc test was employed.

## 3. Results

The mean average of excluded trials was 5.75%. Two percent of trials were excluded due to inadequate fixation of the central fixation cross. Due to poor performance (i.e. below chance level for each set size (10%, 6%, and 7%)) in the mixed condition one synesthete (a projector) and matched control were excluded from the full data analysis.

### 3.1. Accuracy

A main effect of set size was found ($F(2, 28) = 54.487$, $p < .001$), indicating that with smaller set sizes, accuracy was higher (Bonferroni corrected pairwise comparisons: $p < .001$). No difference was obtained between synesthetes and control participants ($F(2, 28) = 1.403$, $p = .263$).

A main effect of condition was found ($F(2, 28) = 67.125$, $p < .001$), with highest accuracies for the chromatic stimuli and lowest accuracies for the mixed stimuli (Bonferroni corrected pairwise comparisons: $p < .001$). Again, no differences were obtained between synesthetes and control participants ($F(2, 28) = 1.082$, $p = .353$).

A significant interaction between set size and condition was obtained ($F(2, 28) = 18.270$, $p < .001$): in the chromatic condition, no effect of set size was obtained, whereas in the achromatic and mixed conditions, all set sizes differed from each other ($t(15) > 4.007$, $p < .001$). This interaction was comparable for synesthetes and controls ($F(2, 28) = .754$, $p = .560$; see Fig. 2). As can be seen in Fig. 2, two synesthetes appear to perform worse than the controls in the chromatic condition, set size 12. We used Crawford and Garthwaite (2002) statistics to test the accuracy scores of these synesthetes to the control group and found that only with set size 12, their scores were significantly lower ($t(7) = 3.111$, $p = .009$;

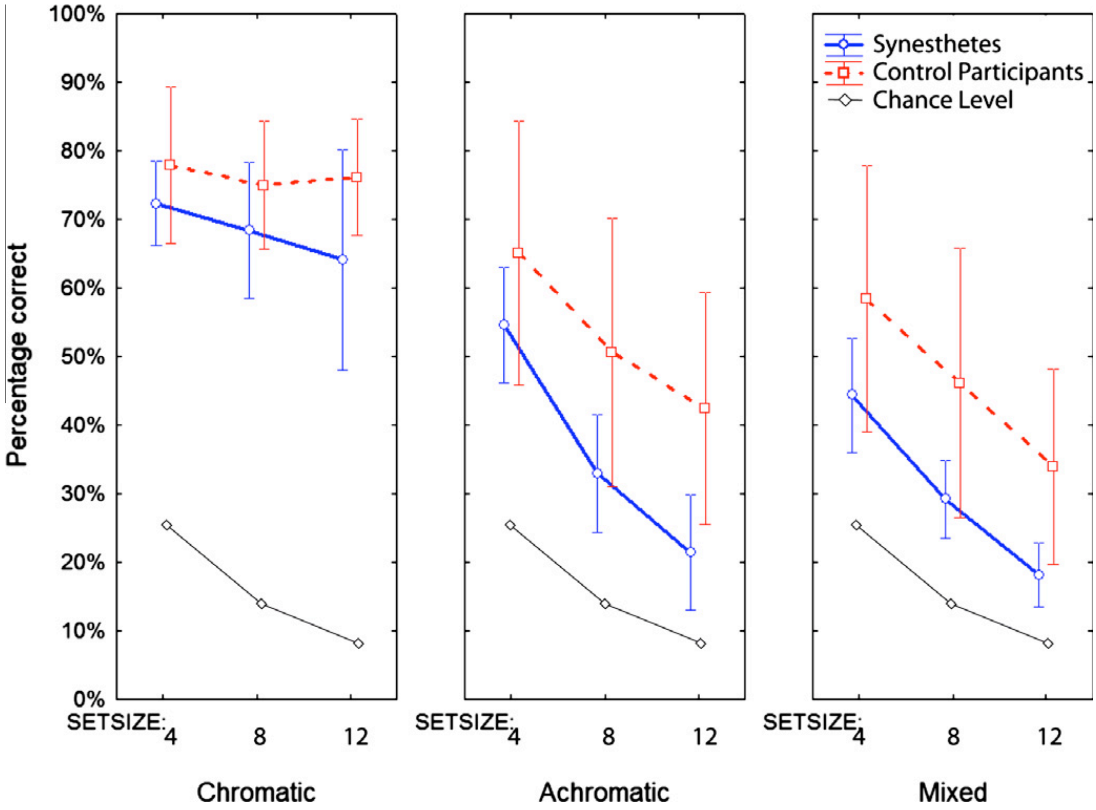



**Fig. 2.** Accuracies per set size (4, 8, 12) per condition (chromatic, achromatic, mixed), split for synesthetes and controls. Error bars represent 95% confidence intervals.

estimated percentage of the control group falling below synesthete's score: 2.37%; and $t(7) = 4.337$, $p = .003$; estimated percentage of the control group falling below synesthete's score: 0.17%)[1].

### 3.2. Saccade latency

No effect of set size was found ($F(2, 28) = 1.063$, $p = .359$). No difference was obtained between synesthetes and control participants ($F(2, 28) = .243$, $p = .786$).

A significant main effect of condition was found ($F(2, 28) = 35.669$, $p < .001$), indicating that latencies were lower in the chromatic condition compared to the achromatic (Bonferroni corrected pairwise comparisons: $p < .001$) and mixed conditions (Bonferroni corrected pairwise comparisons: $p < .001$). Again, no differences were obtained between synesthetes and control participants ($F(2, 28) = .256$, $p = .776$).

A significant interaction between set size and condition was obtained ($F(2, 28) = 4.782$, $p = .002$). This interaction was comparable for synesthetes and controls ($F(2, 28) = 1.822$, $p = .137$; see Fig. 3). This interaction should be interpreted with caution, as accuracies were low in the achromatic and mixed conditions for both synesthetes and controls.

### 3.3. Percentage distractor capture

As can be seen in Fig. 4, the capture data clearly shows an effect of the coloured distractor on performance. This was most evident in the condition in which the set size was 12. In this condition, the percentage capture in both groups was around 17%. Given that there were 12 elements in the display, this is twice the percentage capture that would be expected when the distractor would have no effect (1/12 = 8.3%). Note that the actual percentage of capture when the distractor would have no effect is probably much lower, because the target was one of the elements besides the distractor. As can be seen in Fig. 2, a high percentage of eye movements was executed to the target in this condition (around 40%).

No significant effect of set size was found on the percentage capture ($F(2, 28) = 1.371$, $p = .270$). No differences between synesthetes and control participants were obtained ($F(2, 28) = .355$, $p = .705$).

[1] First we hypothesised this might have to do with the specific synesthetic hues that these synesthetes associated with the digits used in this experiment. Their matched controls, however, would then have had the same (low-level, visual discrimination) problems and should have performed worse than the rest of the controls. This is not the case, which suggests that these particular synesthetes found it difficult to make an eye movement to the target in the chromatic condition, set size 12, within our set criteria.

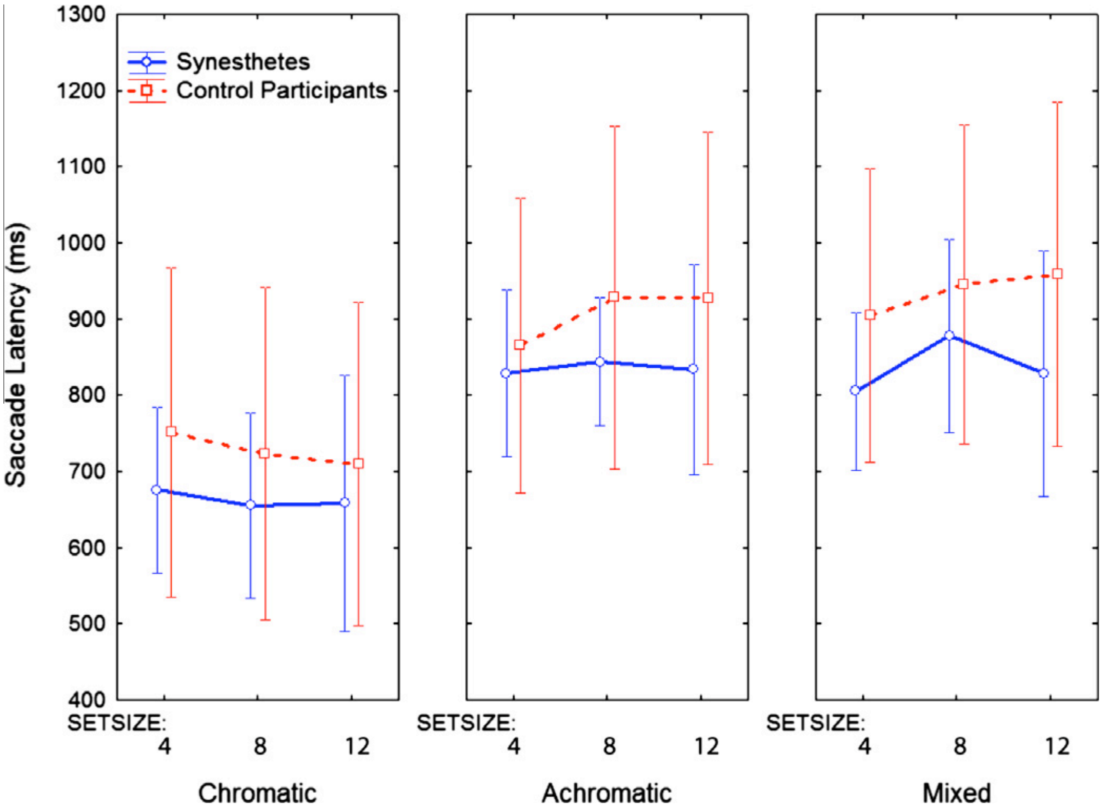



**Fig. 3.** Saccade latencies per set size (4, 8, 12) per condition (chromatic, achromatic, mixed), split for synesthetes and controls. Error bars represent 95% confidence intervals.

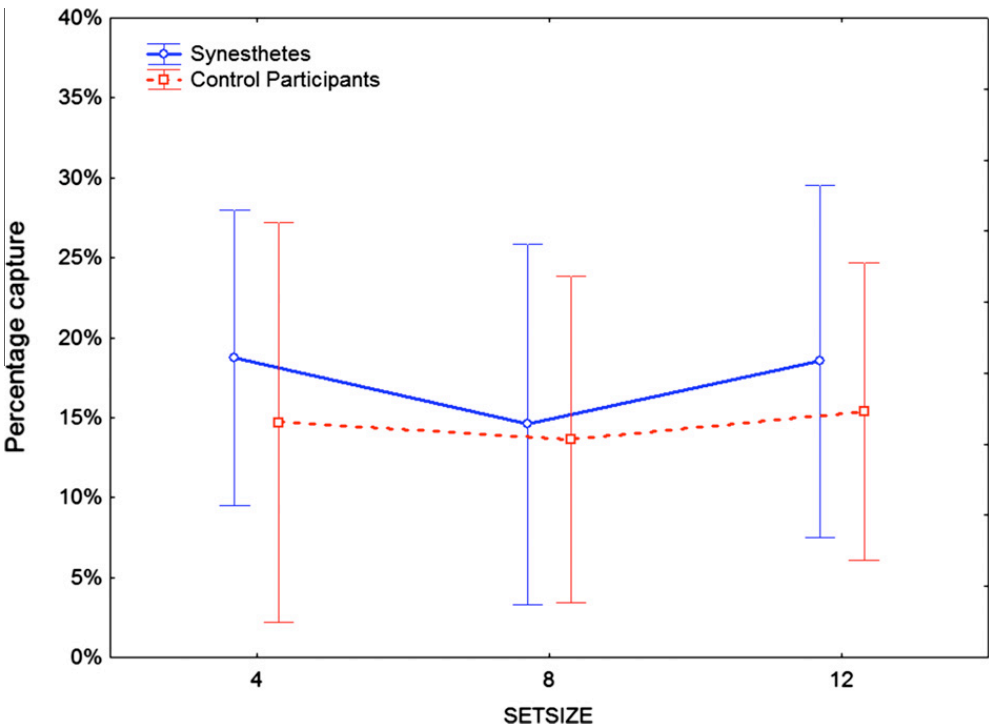



**Fig. 4.** Percentage capture per set size (4, 8, 12), split for synesthetes and controls. Error bars represent 95% confidence intervals.

## 4. Discussion

In the present study, the influence of grapheme-colour synesthesia on eye movements was investigated with an oculomotor target selection task. A group of synesthetes and a control group were required to make one, direct eye movement to the target surrounded by multiple distractors, as fast and accurately as possible. The target was a digit that differed in numerical value from the other elements ("odd one out"). Target and distractor stimuli were presented as either all coloured (chromatic), gray (achromatic) or achromatic with one chromatic distractor (mixed). Eye movement accuracy and latencies were measured.

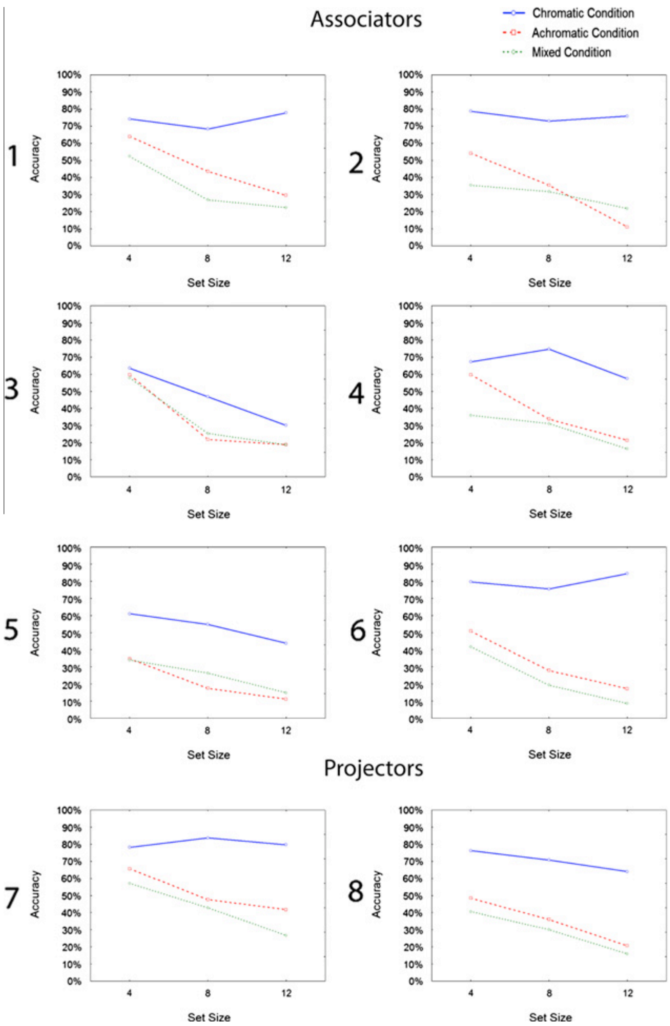
Results revealed that synesthetes and control participants showed comparable patterns in accuracy and saccade latencies for the different conditions. For the chromatic condition, highest accuracies and shortest latencies were obtained compared to achromatic and mixed condition. In the chromatic condition, the target had a unique physical colour in the visual scene. The finding that there was no effect of set size in the chromatic condition indicates that the physically coloured target resulted in a pop-out effect. As expected, this effect was similar for the synesthetes and the control group.

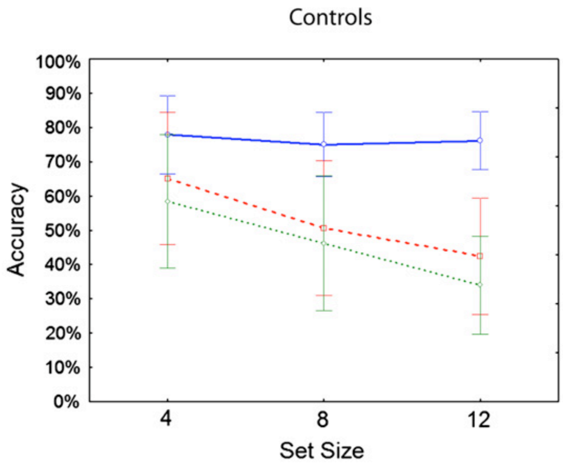
Such a pop-out effect was absent in the achromatic condition in which all elements were gray. In contrast to the chromatic condition, accuracy decreased with increasing set size. Although this was expected for the control group, the finding that a pop-out effect was absent for the synesthetes indicates that a synesthetic element does not elicit a synesthetic colour when it is the target in an oculomotor target selection task.

Additionally, the groups did not significantly differ on the percentage capture by the real colour distractor in the mixed condition, in which one chromatic *distractor* was presented. Furthermore, the percentage capture was not influenced by set size. Again, none of the synesthetes outperformed the controls in the achromatic condition. The high percentage capture in the mixed condition revealed that the real colour distractor was more salient than the synesthetic target. In other words, the presence of the synesthetic target did not influence the strength of the pop-out effect evoked by the presence of the synesthetic target.

One might argue that the lack of an effect between the synesthetes and the control group in this experiment could be due to the majority of synesthetes being associators. It could be that the effect was only present for the two included projectors. When we look at the individual data (see Appendix A), however, no differences between associators and projectors can be observed.

The present results demonstrate that the synesthetic element does not induce a pop-out effect in an eye movement task. This shows that synesthetic colours do not behave as real colours, because they do not pop-out, even when they are the tar-




| Condition | | Chromatic | | | Achromatic | | | Mixed | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Controls | Set Size | 4 | 8 | 12 | 4 | 8 | 12 | 4 | 8 | 12 |
| 1 | | 0.87 | 0.93 | 0.94 | 0.85 | 0.80 | 0.57 | 0.75 | 0.57 | 0.59 |
| 2 | | 0.86 | 0.73 | 0.73 | 0.39 | 0.27 | 0.18 | 0.35 | 0.35 | 0.16 |
| 3 | | 0.94 | 0.83 | 0.82 | 0.89 | 0.81 | 0.78 | 0.87 | 0.90 | 0.55 |
| 4 | | 0.60 | 0.72 | 0.83 | 0.25 | 0.16 | 0.17 | 0.15 | 0.13 | 0.11 |
| 5 | | 0.58 | 0.56 | 0.73 | 0.59 | 0.46 | 0.47 | 0.57 | 0.33 | 0.30 |
| 6 | | 0.87 | 0.77 | 0.68 | 0.75 | 0.40 | 0.32 | 0.61 | 0.37 | 0.26 |
| 7 | | 0.68 | 0.67 | 0.60 | 0.66 | 0.53 | 0.46 | 0.69 | 0.43 | 0.40 |
| 8 | | 0.83 | 0.78 | 0.76 | 0.83 | 0.62 | 0.42 | 0.68 | 0.63 | 0.34 |
| Average (95% CI) | | 0.78 (0.66; 0.89) | 0.75 (0.66; 0.84) | 0.76 (0.68; 0.85) | 0.65 (0.46; 0.84) | 0.51 (0.31; 0.70) | 0.42 (0.25; 0.59) | 0.58 (0.39; 0.78) | 0.46 (0.26; 0.66) | 0.34 (0.20; 0.48) |

**Fig. A1.** Overview of individual accuracies of the synesthetes per set size (4, 8, 12) per condition (chromatic, achromatic, mixed).

get of a search task. These results might seem inconsistent with the findings of Carriere et al. (2009) who showed that synesthesia does influence oculomotor behaviour. This inconsistency might be explained by differences between the two studies. In the current experiment participants were not allowed to freely move their eyes across the different elements in the scene, but were only allowed to execute one eye movement to locate the target element. Although participants were actively searching for a synesthetic target, they were restricted in the elements that they could select as the target location for their eye movement. This was no problem when the target had a distinct colour with respect to the other elements, but was difficult when there was no distinct feature that allowed for a fast detection of the target. This is in contrast to the study by Carriere and colleagues, in which participants were not restricted in the number of eye movements they were allowed to execute.

On the basis of the reasoning above, it seems like synesthetic percepts are not available to distinguish the synesthetic target from synesthetic distractors when they are presented in the periphery. This explanation is consistent with the results of Laeng, Svartdal, and Oelmann (2004). They only observed fast reaction times to synesthetic targets when the target was within a few degrees of visual angle from fixation. In contrast to normal colours, synesthetic colours only arise early enough to effectively distinguish achromatic graphemes from each other when they are fixated. Because it is known that best attentional processing takes place at the site of fixation (Findlay & Gilchrist, 2003), the need for visual attention and full recognition of the grapheme for synesthesia is becoming unambiguously apparent. In conjunction with other research that manipulated attentional resources (Mattingley et al., 2001, 2006), synesthesia seems to require visual attention and full recognition to bind form and colour. According to this view, synesthesia only influences oculomotor behaviour when the grapheme is fully recognized.

## Appendix A

See Fig. A1.

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