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The Differences in Visuospatial Attentional Distribution Between Synesthetes and Non-Synesthetes, Identified Through Covert Visual Search

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Abstract

Synesthesia is a condition whereby sensory stimuli evoke unusual additional sensory perceptions and experiences, and can be identified through a visual search task. Grapheme-colour synesthetes have shown increased efficiency in visual search tasks, which some have hypothesized is a result of synesthetic colours drawing attention to the target stimulus, and have likened it to a weakened "pop-out" effect. Visual search has also been used to measure visuospatial attentional distribution, and findings from this method have supported the gradient model of attention, which proposes that cognitive resources are the most concentrated centrally in our visual field, and taper off, such that the perimeters of our visual field deploy fewer cognitive resources. In the first part of this study, an online pilot study was conducted to diagnose synesthetes using a consistency screening and questionnaire. No grapheme-color synesthetes were identified in this pilot. The second part of this study proposes two experiments, the first being an attempt to replicate the increased efficiency in visual search tasks demonstrated by synesthetes. The second experiment aims to identify the differences in attentional gradients between synesthetes and non-synesthetes in a covert circular version of visual search, across three trials types: physically incongruent, synesthetically incongruent, and congruent. Stimuli will be presented in circular arrays of varying eccentricities, and accurate performance on larger circles will reflect flatter attentional gradients. When performance is averaged across trials types, synesthetes are expected to exhibit superior performance and have flatter attentional gradients than non-synesthetes on this task.

Introduction

Synesthesia

Synesthesia is a condition, whereby a sensory stimulus evokes consistent unusual additional sensory perceptions and experiences (Hubbard & Ramachandran, 2005); it has often been overlooked and misinterpreted as a symptom of other mental conditions. While synesthesia has had recent popularity in the media[1] and academia, our understanding of this condition and its inner workings is actually still very limited. Synesthesia has also regularly been misrepresented as something we all experience, where many will understand it to be more of a metaphorical tool (e.g. a food having a “sharp” taste) than a cognitive condition. Unfortunately, because many don’t understand synesthesia, anecdotal evidence (Van Campen, 2014; Cytowic & Eagleman, 2009) suggests that in childhood, many synesthetes either believed that everyone else also perceived the world as they did, or, upon voicing their experiences, they were subsequently met with confusion and/or ridicule. Even in the academic community, synesthesia is still being questioned as to whether or not it is a real, perceptual condition, or if it is a symptom of exceedingly strong memory (Gheri et al., 2008). Nevertheless, today, at least 40 different types of synesthesia have been discovered, including chromesthesia (sound to color) and lexical-gustatory synesthesia (spoken/written words to taste/smell) (Cytowic & Eagleman, 2009).

The most common form of synesthesia, however, is grapheme-colour synesthesia (Cytowic & Eagleman, 2009). Typically, when a person without synesthesia reads graphemes[2], they read them in the colour in which they are written, and experience solely the visual information they are given. A grapheme-colour synesthete, however, may consistently

[1]Famous examples of synesthetes include Joan Mitchell, David Hockney, Billy Joel, and Remy from the film, Ratatouille (Day, 2017).
[2]For the purposes of this study, graphemes will be defined as numbers and letters (Rogowska, 2011).

experience a strong “sense” of a specific colour when reading a grapheme - this color association is known as a photism (Smilek et al., 2003). While the term “sense” may be considered vague in the academic community, it is often used in the context of synesthesia because this condition is entirely unique to its beholder: some individuals may experience synesthetic colours in their “mind’s eye” (associators), where others have reported *seeing* graphemes actually written in their synesthetic colours (projectors) (Rogowska, 2011). One of the most widely-known grapheme-color synesthetes was “Lolita” author, Vladimir Nabokov. In a 1962 interview with the BBC, Nabokov defines his condition as “color hearing” (which we now identify as grapheme-color synesthesia) whereby he would see achromatic letters in color. He then goes on to describe his initials, VN:

> V is a kind of pale, transparent pink: I think it's called, technically, quartz pink: this is one of the closest colors that I can connect with the V. And the N, on the other hand, is a greyish-yellowish oatmeal color. But a funny thing happens: my wife has this gift of seeing letters in color, too, but her colors are completely different. There are, perhaps, two or three letters where we coincide, but otherwise the colors are quite different. (BBC, 1962)

As is demonstrated in Vladimir Nabokov’s description of his initials, synesthetes often describe the colors of their photisms with an added specificity that non-synesthetes tend not to express when describing colors. In a study conducted by Simner et al. (2006), grapheme-color synesthetes reported 54 variants of descriptions for the color green, where non-synesthete control subjects produced only 5 variants. It is important to note, however, that grapheme-colour synesthesia is not a visual condition, but rather a perceptual event that occurs during information processing (Palmeri et al., 2002). Though this notion has been disputed and some (Gheri et al., 2008) have suggested that synesthesia is rather semantic or memory-driven, fMRI tests have established that synesthetes also exhibit differences in brain activity from non-synesthetes. When reading graphemes, grapheme-color synesthetes had the same brain activity as non-synesthetes, though synesthetes also exhibited the additional activation of V4, an area in the brain responsible for processing color (Hubbard & Ramachandran, 2005; Nunn et al., 2002).

To date, three main classes of synesthesia have been established: genuine, acquired, and drug-induced (Sinke et al., 2012). Genuine synesthesia is a condition that has been experienced for the duration of one's life and is often genetic, where acquired synesthesia can come into existence after trauma, such as brain damage. Drug-induced synesthesia, on the other hand, can be perceived temporarily as a result of hallucinogen (e.g. LSD) consumption and is typically experienced alongside other acute effects of the drug being consumed (Sinke et al., 2012). With consideration for the ethical implications of analyzing or facilitating acquired and drug-induced synesthesia, only genuine synesthesia will be considered in this study.

Estimates of synesthesia's prevalence remain varied across studies. Simner et al. (2006) found that, out of 500 participants, 22 synesthetes were identified, which yielded a prevalence of 4.4%. The prevalence of specifically grapheme-color synesthesia, however, lay in the 1.1%-1.4% range. Consistent with this finding, the standardized test battery for synesthesia conducted by Carmichael et al. (2015) found the prevalence of grapheme-color synesthesia to be 1.2%, though others have detected a prevalence as high as 7.2%[3] (Rothen & Meier, 2010) and 8.2% (Hill, 2017). These higher estimates of prevalence are likely due to methodological differences, as

[3]Prevalence found from a sample of fine arts students.

some diagnostic materials for synesthesia are less stringent with their criteria than others. As such, for the purposes of this study, grapheme-color synesthesia will be conservatively considered to have an estimated prevalence of 1.4%.

Given that synesthesia is so specific to the individual, it has proven to be difficult to diagnose and, as such, has been a topic of debate among cognitive psychologists as to whether or not this condition even exists. To address this diagnostic challenge, researchers have taken multiple approaches to identify synesthetes, including synesthetic memory tests, perceptual tasks, and questionnaires (Simner et al., 2006; Palmeri et al., 2002). In one of the earlier recorded attempts to diagnose synesthesia, Baron-Cohen et al. (1987) investigated the consistency of a synesthete's grapheme-colour associations over the course of 10 weeks. They conducted this investigation aurally, where the subject was presented with 103 stimuli (both words and individual graphemes) and was asked to say the colour of each word or grapheme[4]. A surprise retest of 10 randomly selected stimuli was conducted 3 hours later; 10 weeks later, another surprise retest that included all 103 items was conducted. In this study, the colours reported for individual items by the synesthete across all tests were identical; this test was also conducted on a control (where the retest was administered only 2 weeks later), who could only recount approximately 17% of items. As this study confirmed, one of the most important diagnostic criteria of synesthesia is consistency, as it demonstrates that a potential synesthete is not choosing associative stimuli (e.g. colors) at random, but rather that they experience these unchanging associations throughout their lives.

[4]Baron-Cohen et al. (1987) used this specific language, however given their research, it is assumed that participants were asked to report the color they *experienced* for each word, not the color in which it was written.

A similar diagnostic method was used by Simner et al. (2006), whereby 1,190 individuals were each presented with 36 graphemes written achromatically and were asked to select the "best" colour (from a provided colour palette) that they would pair with each given grapheme. Once subjects completed all 36 trials, they were immediately given a surprise retest and subsequently, were asked to fill out a questionnaire. This questionnaire contained 6 statements, and participants were asked to rate each statement using a Likert-scale. A range of scores for known synesthetes was established prior to the screening; participants were then scored for consistency across the two tests and were also given questionnaire scores. Through this diagnostic method, they found 13 grapheme-color synesthetes (prevalence=1.1%), 11 of whom were adults. Moreover, those who qualified as synesthetes in the color-matching task were more likely to report having had synesthetic experiences than those who did not, which indicates that diagnoses were consistent across both measures.

While test-retest consistency may otherwise be a sound starting point for diagnosing synesthesia, some have gone further to use perceptual tasks, such as visual search, as a means of diagnosis, as oftentimes these tasks are predicated upon metrics (e.g. response times) that are difficult to "fake". In many perceptual tasks, one is asked to respond as quickly and accurately as possible, so if a particular group of individuals has faster response times than those of controls, it can be assumed that they are inherently more efficient in that task, and not simply trying harder.

Ramachandran and Hubbard (2001) tested two synesthetes, J.C. and E.R., and 20 controls (non-synesthetes) in a perceptual grouping task. In this task, J.C. and E.R. were each provided with a matrix of graphemes written in black against a white background and were asked to report whether the graphemes appeared to be grouped vertically or horizontally.

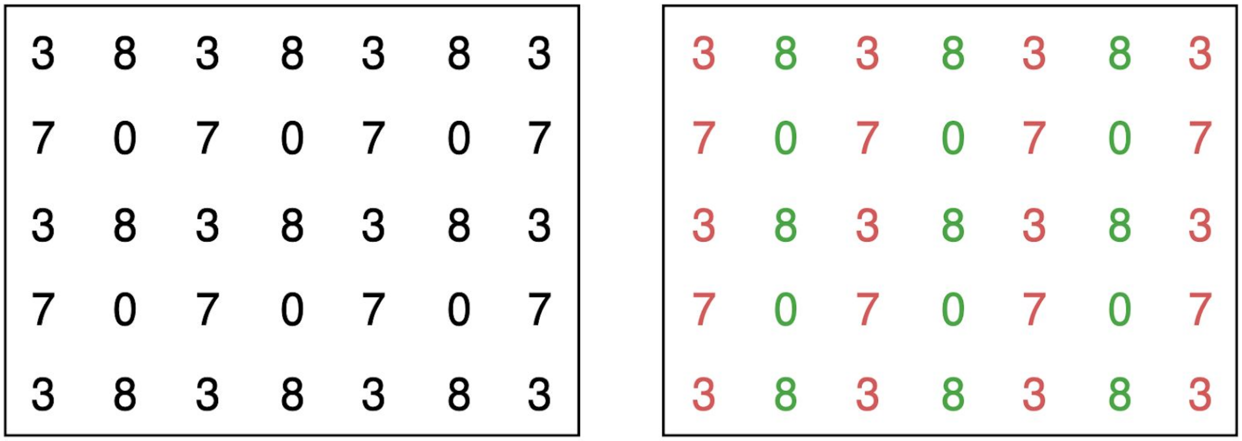

Figure 1. a) Sample matrix from which participants are asked to report grouping orientation. b) An example of how a synesthete would perceive and group these stimuli. In this particular example, the synesthete perceives the color green when reading 8's and 0's, and the color red when reading 3's and 7's (Ramachandran & Hubbard, 2001).

Typically, the probability of identifying either a vertical or horizontal grouping would be approximately 50%, however this particular experiment was designed to bias non-synesthetes to group graphemes according to their shape, such that graphemes that bore a similar physical resemblance (e.g. 3 and 8) were more likely to be perceived by non-synesthetes as horizontally grouped. Additionally, graphemes in each matrix were specifically selected according to each synesthete's known grapheme-color association (photism), such that graphemes that evoked similar colors (i.e. 0 and 8 both evoking the color green) were grouped vertically. Ramachandran and Hubbard (2001) argued that, if the photisms that grapheme-color synesthetes experienced were truly perceptual (as opposed to semantic or associative), synesthetes would group the numbers according to their synesthetic colors, and this is exactly what they found. The two synesthetes grouped stimuli according to their perceived colors, where most controls grouped items according to their shapes. J.C. and E.R. each had their own control sample, so grouping across control samples differed significantly. Nonetheless, both J.C. and E.R. demonstrated significant grouping differences from their respective control samples. Synesthetes were significantly more likely to group graphemes according to their photisms (i.e. associated colors), where controls tended to group graphemes according to their physical appearance. J.C. and E.R. grouping stimuli according to their synesthetic colors supports the theory that synesthesia is, in fact, a perceptual condition and not one dictated by memorization tools.

Synesthesia and Visual Search

Various types of visual search tasks have also been used to both validate and understand the mechanisms underlying synesthesia. A traditional visual search task involves a participant being asked to identify one target stimulus presented among many uniform distractor stimuli (Neisser, 1964). The idea being that as the number of distractor stimuli is increased, it becomes more difficult to identify the target, i.e. one needs to "search" more. Participant performance is typically measured by response time, such that an increase in the number of distractors is reflected as an increase in the time it takes for a participant to respond (Quinlan, 2003). It should also be mentioned that in a visual search task where one is asked to identify a target stimulus written in a bright color among distractors written achromatically, response times will be low, and consistently low, as the number of distractors increases (Palmeri et al., 2002). Put differently, the slope of the response time would be entirely flat in such a task, regardless of how many distractors are presented - this has often been referred to as a "pop-out" effect. Critically, this effect suggests that color is a preattentive feature, such that color can be processed before explicit attention is directed to it.

Palmeri et al. (2002) used response times from a traditional visual search task to confirm the synesthetic experiences of a synesthete (W.O.). Using the logic of the aforementioned pop-out effect, Palmeri et al. tested whether a synesthete’s photisms were processed preattentively and were cognitively dominant enough to elicit such a pop-out effect in a visual search task where the stimuli are presented achromatically. Given their similar visual characteristics, identifying a target 2 among a series of 5’s (all presented in white against a black background) would typically be difficult for non-synesthetes, however W.O. exhibited significantly faster response times for this task[5]. This is because W.O.’s colour association for 2’s was orange, and was green for the number 5, so when searching for the target, W.O. experienced a “patch” of a different colour (orange) that drew their attention towards the target. Essentially, the 2 “popped-out” in W.O.'s mind, and they were generally able to identify the target more quickly because the target and distractors were synesthetically incongruent.

Contrary to the hypothesized pop-out effect, W.O.’s reaction time slope was not completely flat as the number of distractors increased. Instead, this synesthete’s reaction times lay in between those for a regular visual search task and those for a pop-out, physically chromatic visual search task, each conducted on non-synesthetes. W.O.’s colour perceptions were not strong enough to fully draw their attention to the target, as a target physically presented in a different colour would otherwise be, but these perceptions did help W.O. become more efficient in finding the target. Importantly, when W.O. was tasked with finding a 6 among 8’s, they performed as poorly as non-synesthetes in a traditional visual search task. This is because

[5]Specific statistics were not reported.

the colours that W.O. associated with 6 and 8 were both blue, and thus, were difficult to distinguish from one another in a visual search task, both physically and synesthetically.

Palmeri et al. (2002) suggested that the reaction times demonstrated by W.O. were a result of a kind of “spotlight” where, when attention was directed towards a particular area (such as a cluster of digits), enough cognitive resources were available to bind the synesthetic colour to the target, thus enabling faster recognition and a more efficient search. Rather than explicitly looking at each individual stimulus and rejecting them one-by-one like a non-synesthete might do, W.O. was able to reject *regions* where the target’s associated synesthetic colour was not present. Unlike non-synesthetes, W.O. didn’t need explicit visual attention to be directed at the target in order to recognize it, but rather was able to either rule out an entire area, or identify that the target was located within a particular area. This would suggest that for W.O., synesthetic color-binding occurs preattentively before the grapheme is processed, instead of once the grapheme is attended to and first identified.

In the earlier mentioned study conducted by Ramachandran and Hubbard (2001), J.C. and E.R. (both grapheme-color synesthetes) had also been tested and compared to 40 controls in a perceptual grouping visual search task, where they were presented with a series of graphemes in a visual array for 1000ms. Within this array, achromatic distractor and target stimuli were displayed, and participants were asked to identify the embedded shape created by the given series of target graphemes. For a non-synesthete, this task is typically difficult, as one needs to first identify one of the target graphemes, then locate surrounding graphemes, and finally discern which shape they create.

Performance was measured in terms of accuracy, and both synesthetes performed significantly better (mean correct responses was 81.25%) than controls who, on average, were only correct on 59.4% of trials. For J.C. and E.R., this task was relatively easy, as the target graphemes were perceived in a color different to that of the distractors and thus, the target shape presented itself immediately. This experiment supports Palmeri's finding that the binding of synesthetic colors to graphemes occurs automatically and prior to explicit attention. Specifically, synesthetic color associations helped J.C. and E.R. become more efficient and more accurate in a visual search task by drawing their attention to the series of targets and dismissing the need to individually process and reject each grapheme.

In a third single-case study, a grapheme-color synesthete J, along with 7 controls, was tasked with identifying a target digit presented against a background either congruent or incongruent with their synesthetic color associations for the given target (Smilek et al., 2003). The target and distractors were presented in dark grey, making the task difficult for non-synesthetes, as they experienced no pop-out effect to aid them in identifying the target more quickly. Each participant was asked to identify the target as quickly as possible by pressing a specified button on their keyboard. Once this button was pressed, each item (target and distractors) on the screen was replaced with a grey rectangle, and row and column numbers were given along the side of the square where stimuli were presented. Participants were then asked to enter the row and column number of the target they had identified in the earlier task. This task presented 3 stimuli set sizes (7, 13, 19) and performance was measured by response time and accuracy. Smilek et al. hypothesized that J's photisms would attract their attention to the target on incongruent trials, making them faster and more efficient in their visual search, and thus yielding a faster reaction time than controls.

The researchers found a significant interaction between congruency and set size for J, such that, as the set size increased, J was significantly slower on incongruent trials than congruent trials; the slope of J's reaction time on congruent trials was steeper than that of J's reaction time on incongruent trials. This finding further supports the theory that grapheme-color synesthetes can process their photisms prior to directing explicit attention to the stimuli. Additionally, given that reaction time is a reliable metric, superior performance by synesthetes in this perceptual task supports the argument that grapheme-color synesthesia is, indeed, a real condition.

Synesthetic processing has also been tested on a larger scale, but these studies have yielded more puzzling and inconclusive results. In 2009, Rothen and Meier conducted a study on 13 grapheme-color synesthetes and 13 controls, who were asked to complete a visual search task and a memory test. As was true in the experiment conducted by Ramachandran and Hubbard (2001), here, participants were tasked with identifying a shape, which was composed of a series of target graphemes and was embedded in an array of distractor graphemes. This display was shown for 1000ms, after which participants were asked to report which shape was being presented. They conducted an independent samples t-test and found that synesthetes and non-synesthetes do *not* differ significantly in visual search performance. Despite this finding, it was also reported that, in terms of effect size, synesthetes did have an advantage over non-synesthetes (Cohen's d between 0.19 and 0.32). As such, it is not entirely clear as to whether or not synesthetes had a meaningful advantage over non-synesthetes in this embedded shape visual search task. Rothen and Meier suggested that this inconclusive finding could be a result of this being a group experiment, as opposed to a single-case experiment like that of Palmeri et al. (2002) or Ramachandran and Hubbard (2001). Specifically, enhanced performance found in these single-case studies could be due to individual differences of the synesthetes being tested, and may not capture the potential underlying homogeneity in performance between synesthetes and non-synesthetes. It was also posited that there may be subclasses of synesthesia of which we are not aware, *or* that processing differences exist between associators and projectors that have not yet been discovered. Nonetheless, while this particular experiment did not fully support the findings of Palmeri et al., it highlighted the importance of using larger samples when testing differences between synesthetes and controls.

Ward et al. (2009) ran a similar study on 36 grapheme-color synesthetes, and found that synesthetes *did* have an advantage over non-synesthetes in an embedded-shape visual search task, but approximately only half of them reported having experienced any photisms during the task. Interestingly, most of the synesthetes who did report experiencing photisms claimed to have seen them for only one third of the graphemes being presented. It should be mentioned, however, that the enhanced performance shown by synesthetes was associated with the proportion of graphemes that were reported to have photisms, as opposed to the number of trials in which photisms were generally experienced. This suggests that there may be stronger and weaker forms of grapheme-color synesthesia. Ward also notes that the fact that synesthetes who did report photisms only reported them for a small portion of the presented graphemes is “inconsistent with the notion that synaesthetic colours are triggered preattentively across a large portion of the visual field, and is more consistent with the notion that synaesthetic colours are induced within a circumscribed locus of attention." (Ward et al., 2009). Actually, this conclusion is very similar to that made by Palmeri et al. (2002), who deduced that the binding of synesthetic colors to graphemes does not occur globally, across the entire visual field, but in a smaller subset of the visual field.

Others have attempted to replicate Palmeri's findings using a larger sample size of 13 grapheme-color synesthetes (Edquist et al., 2006), and also failed to show that they were more efficient in visual search than non-synesthetes. Edquist et al. (2006) argued that significant differences in performance found in single-case studies may be the exception, as opposed to the rule, where synesthetes who did exhibit significant differences from controls may have been statistical outliers. They also reached the conclusion that their findings imply that photisms are not processed early enough to attract attention to a particular grapheme.

Finally, Gheri et al. (2008) conducted a literature review and experiment to emphasize that there are really no perceptual differences between synesthetes and non-synesthetes. They showed 7 synesthetes and 7 controls a 4x4 matrix, and asked the participants to locate the target number, which was the only number that was not repeated in the matrix. Synesthetes experienced two conditions, unique and non-unique. The unique condition was designed so that the target number elicited a photism that was relatively different to those of the distractors; in the non-unique condition, the target evoked a photism that was similar to that of at least one distractor. In theory, having the target share a color with a distractor can impede one's performance, as one's cognitive organization that would otherwise be dictated by shape is now overtaken by color. As with the other visual search studies, performance was measured by response time. The researchers found no significant differences between synesthetes and non-synesthetes in both conditions. Gheri et al. (2008) suggest that this could be a result of synesthetic colors being too weak to affect performance on such a task or that the colors experienced by synesthetes occur at a cognitive level where they cannot influence performance on a visual search task.

Given the existing literature on synesthesia and visual search and the diversity of conclusions being made about this condition, it is particularly important that certain parameters are established before conducting an experiment to test the added visual search efficiency exhibited by some grapheme-color synesthetes. Namely, the scope of the physical area where synesthesia is thought to aid visual search. Several of the previously mentioned researchers put emphasis on the fact that synesthesia does not help visual search globally, but rather when the target is within a few degrees of visual focus (Ward et al., 2010; Palmeri et al., 2002). For that reason, this current study will assess the degree to which grapheme-color synesthesia improves visual search efficiency on a *local* scale. That is to say, this study is not suggesting that a synesthete will immediately identify a target by looking at the presented visual search array at a glance. Rather, it proposes that, when visual attention is allocated to a particular subsection of the array, peripheral processing of photisms occurs and subsequently draws synesthetes' attention even more specifically towards the target grapheme. Before this is addressed, however, it is crucial that existing models of visuospatial attentional distribution and cognitive resource allocation are understood and evaluated.

Visual Search as a Means of Mapping Visuospatial Attentional Distribution

Regardless of whether or not one experiences synesthesia, individuals with normal vision direct visual attention when focusing their vision towards something. Visual attention is characterised by the allocation of visual processing resources to a specific part of the visual field, and the attenuation of these resources in other parts of the visual field (Anderson, 2009). Furthermore, there are several theories that attempt to explain the distribution of visuospatial attention, including the spotlight model and the zoom-lens model (Barriopedro & Botella, 1998; Posner, 1980; Lloyd, 2005), however much of the research examining visual attention supports the gradient model of attention.

In 1989, LaBerge and Brown proposed that visual spatial attention was not simply a "spotlight" where attention abruptly stopped past its perimeter. Instead, they presented a more nuanced explanation for how we allocate our visual attention: cognitive resources are the most concentrated centrally in our visual field, and taper off in a sort of gradient, whereby in the perimeters of our visual field, fewer cognitive resources are deployed until they fade out and are no longer engaged. They described this top-down process as the mind filtering visual information in one's visual field, where this filtering takes place more quickly and efficiently in particular areas to which more cognitive resources are directed. According to Marisa Carrasco, a researcher in visual spatial attention, there are two types of visual attention: endogenous and exogenous (2018). Endogenous attention is analogous to the strong concentration of cognitive resources being deployed and is a voluntary process through which we can purposely monitor information; exogenous attention is defined as involuntary and automatic processing of information and can be reflected in the gradient model as the peripheral, weak allocation of cognitive resources.

Carrasco estimates that exogenous attention is a fleeting process that peaks at only 100ms and subsequently decays, where endogenous attention takes about 300ms to be deployed. Moreover, vision is required in order to deploy both types of attention, which can either be employed overtly (through explicit eye movement) or covertly (attending to an area without eye movement) (Carrasco, 2018).

Brefczynski-Lewis et al. (2009) have tried to outline this attentional gradient using retinotopic mapping to identify which parts of the brain are activated when attention is visually allocated to a particular area. Using a colour scale to indicate neural response, they found that cortical attentional enhancement, a measure of cognitive attentional resources, is generally the most pronounced where the attended target is located. Moreover, this study found that with an increase in eccentricity[6] from the target, cortical enhancement decreased, which is consistent with the gradient model of attention. Notably, this study also found that these gradients did differ across participants systematically, suggesting that individuals with different psychological or neurological conditions (such as synesthesia) could also have significantly different attentional gradients from the rest of the population.

This variation in gradients was examined by Robertson et al. (2013), who found that individuals with autism exhibited a sharper gradient of visuospatial attention than controls did. Participants were asked to attend to a fixation point and report specific characteristics of a stimulus presented in the periphery of their visual field. Prior to this stimulus display, a brief[7] cue was shown to capture the attention of participants, and stimuli were subsequently presented at varying distances from the subtle cue. They found that individuals with autism performed better

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[6]Used to describe the circular distance from the center.
[7]This cue was displayed for 67ms, which within the threshold for exogenous attention (Carrasco, 2018)

than controls on trials where stimuli were closer to a cue, and performed worse than controls where stimuli were further from the cue. This was reflected in a steeper slope for autistic individuals relative to controls, where performance was plotted against distance from the cue; this steeper slope was interpreted as a sharper gradient of attention. The differences in attention revealed by Brefczynski-Lewis et al. (2009) and Robertson et al. (2013) indicate that attentional gradients vary across people and systematically vary across different neurological and psychological traits; but could this be related to the performance of other cognitive tasks?

Visual search tasks have also been used to better understand the spatial distribution of attention. In 1998, Wolfe, O'Neill, and Bennett designed a visual search task in which stimuli were presented at various eccentricities, and participants were asked to report, as quickly and accurately as possible, whether or not the target was present among distractors. The results of this experiment revealed that, as the distance of the target location increased from the central fixation point, response times increased and accuracy decreased; this finding is now known as the "eccentricity effect". That is to say, more attention (and thus, cognitive resources) was deployed towards the central fixation point, and attentional resource deployment gradually reduced towards the periphery of the visual field, which is consistent with the gradient model of attention.

Turatto et al. (2004), have used this circular version of visual search to examine how attention is deployed through stimulus-driven attentional capture - the summoning of visual attention using various cuing and feature manipulations. 28 subjects were shown a central fixation point before being shown a set of stimuli, where each stimulus was framed with a circle and presented in a circular array. This particular study analyzed covert attention by displaying the visual search task for only 180ms, such that eye movements could not aid the performance of participants. Subjects were asked to identify whether or not a target stimulus (presented among distractors) was present, and responded using two specified buttons on a keyboard. Each stimulus was a line presented at one of various angles, and participants were tasked with identifying the target, a vertical line. The visual search task also used a "singleton" element designed to draw the covert attention of participants to a particular area - an example of a singleton stimulus would be one element presented in red among elements (including the target) presented in green. In this case, the singleton was a red circle framing whichever stimulus lay inside it.

Generally, when the position of a singleton and the target coincide in traditional visual search tasks, response times and accuracy remain the same as set size (the number of distractors) increases. This particular case is consistent with the pop-out effect because the singleton, presented in a different color from all other stimuli, brings one's attention towards it and thus the target, enabling a more efficient identification of the target. Put differently, the singleton element eliminates the need to serially search through distractors to identify the target. Interestingly, in this study where stimuli were presented in a circle and increased set sizes were designed as larger circles with more stimuli, accuracy actually decreased as the set size increased. Participants were more accurate in identifying the target when it was close to the center and surrounded by fewer distractors, and less accurate as the distance between the target and the center (as well as the number of distractors) increased. This suggests that attentional resources tapered off as the distance between the target/singleton and the central fixation point[8] increased, such that

[8]A synthetic replication of the center of one's visual field.

attentional resources were more concentrated towards the center than in the periphery, once more supporting the gradient model of attention.

Thus far, however, little to no research has been conducted on the visual attention of synesthetes, specifically whether or not the distribution of their visuospatial attention is consistent with the gradient model of attention, or if their gradients differ from non-synesthetes. This introduces the current study being proposed.

Current Study

The findings and conclusions of Palmeri et al. (2002) and others put into question the allocation and strength of the cognitive resources of grapheme-colour synesthetes when faced with a grapheme-identifying task. Like non-synesthetes, synesthetes are capable of identifying a stimulus through endogenous attention. However, when looking for a target stimulus in a visual search task, it is hypothesized that synesthetes filter out large groups of stimuli because they have exogenously processed and bound colors to graphemes, prior to explicit attention being allocated to these graphemes. If this is indeed the case, the exogenous attention of synesthetes carries an additional characteristic - photism binding - that is strong enough to differentiate their performance from that of non-synesthetes. As is supported by the gradient model of attention, this exogenous attention is deployed in the periphery of one's visual field, the area around which endogenous attention is deployed.

To test whether or not this is true, the visuospatial attentional distributions (attentional gradients) of both synesthetes and non-synesthetes need to be mapped and examined. To do so, one must first identify synesthetes: this study will administer a pilot screening using test-retest diagnostics and a questionnaire, both of which were used by Simner et al. (2006). Thereafter, both synesthetes and non-synesthetes will be tested on a visual search task replicating that used by Palmeri et al. (2002). Finally, to map out attentional gradients, a circular covert visual search task similar to that used by Turatto et al. (2004) will be administered, whereby eccentricity is increased instead of set size. If grapheme-color synesthetes perform better than non-synesthetes on this task, it would imply that synesthetes have a flatter gradient of attention than that of non-synesthetes in visual search tasks involving grapheme identification.

Pilot Study

The first part of this study consists of a pilot screening, the purpose of which was to replicate the prevalence of grapheme-color synesthesia found by Simner et al. (2006). Moreover, due to the COVID-19 pandemic, this screening was conducted online to adhere to social distancing measures. Given this constraint, this pilot screening is also testing whether or not Simner et al.'s diagnostic methodology translates to a digital platform. If this screening does not identify any grapheme-color synesthetes, changes to this screening and the addition of other diagnostic measures need to be implemented so that a large-scale study can be conducted. According to numerous studies (Simner et al., 2006; Carmichael et al., 2015) estimating the prevalence of grapheme-color synesthesia, 1-1.4% of the population experience this condition. As such, this pilot screening is hypothesized to identify one synesthete (out of a sample of approx. 100).

Method

Participants

Participants (n=103) were recruited through Prolific, an online data collection platform. The scope of this study was limited to individuals in the United States who were fluent in English in order to ensure that nuances in the given instructions were understood and graphemes were familiar enough to potentially elicit photisms. Only individuals with normal or corrected-to-normal vision, including not having color blindness, were considered for this study; this information was gathered by Prolific from each participant when they created their account. Each respondent was compensated at a rate of $10.44/hour.

Apparatus

Both diagnostic tools were designed using Google Forms.

Materials

Consistency Screening

The consistency screening in this study was a direct replication of that used by Simner et al. (2006), where participants were asked to report their color associations for each grapheme they were shown, and were subsequently given a surprise retest. Instructions for this portion of the study used the same rhetoric as Simner et al. (2006) by asking participants to select one of the given colors they believed “best fit” the letter or number they were provided. Respondents were asked to complete this task for 36 graphemes (A-Z, 0-9), and were given 13 colors (yellow, orange, pink, red, purple, dark blue, light blue, dark green, light green, brown, black, grey, white) to choose from. Furthermore, graphemes were shown individually to limit confusion or influence from other graphemes.

Questionnaire

In addition to the consistency screening, 6 questionnaire questions were included to gather more qualitative information about respondents' potential synesthetic experiences. Each item was a statement, to which participants were asked to respond using a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). While Simner et al. (2006) used a 6-point Likert scale, this study utilized a 5-point scale to avoid fence-sitting. Additionally, 2 items in the questionnaire were reverse-coded to later be able to identify acquiescence and non-differentiation in data analysis.

Procedure

First, participants were provided a consent form outlining the instructions and implications of this study; they were instructed to provide consent by entering their Prolific ID number. Once consent was acquired, instructions for how to complete the consistency screening were presented. These instructions specified that this portion of the study was not asking for the color in which each grapheme was written, but for the color that respondents associated most with each grapheme. Graphemes were individually presented in alphabetical and numerical order. After completing this task for all 36 graphemes, respondents were asked to answer 6 questionnaire items, followed by a surprise retest of the initial screening. When all items had been answered, participants were debriefed and provided with contact information, should they have any questions. Lastly, a link was provided to redirect respondents to the Prolific website to confirm that they had participated and could get compensated.

Results

Data for 9 respondents were removed on the grounds of acquiescence and insufficient data. With this, 94 responses were analyzed and compiled to generate a "consistency" score and a "questionnaire" score. The consistency score measured how consistent respondents were across the two screenings (range=0-36), whereas the questionnaire score compiled answers on the questionnaire (range=6-30). Cutoff scores for those who qualified as grapheme-color synesthetes were set at 2 standard deviations from the mean for both measures. The cutoff score for the questionnaire portion of the study was 24.59 (≈25), however, the cutoff score for synesthesia was not calculated for the screening for reasons outlined below. 100% of participants chose the color black for 100% of their responses, which means that all participants had a consistency score of 36 (out of 36). This high consistency score could lead one to erroneously come to the conclusion that all members in this sample are strongly synesthetic. However, due to the absolute lack of variability in this dataset and the low mean questionnaire response scores ($M=14$, $SD=5.32$), it can rather safely be presumed that 0% of respondents fulfilled the criteria for grapheme-color synesthesia. Furthermore, the color reported by all respondents for every grapheme was black, the color in which each grapheme was written, which could suggest instructional issues described in the following discussion. This also supports the conclusion that respondents were not selecting photism colors that a grapheme-color synesthetes would experience, but physical colors that are all that non-synesthetes would see.

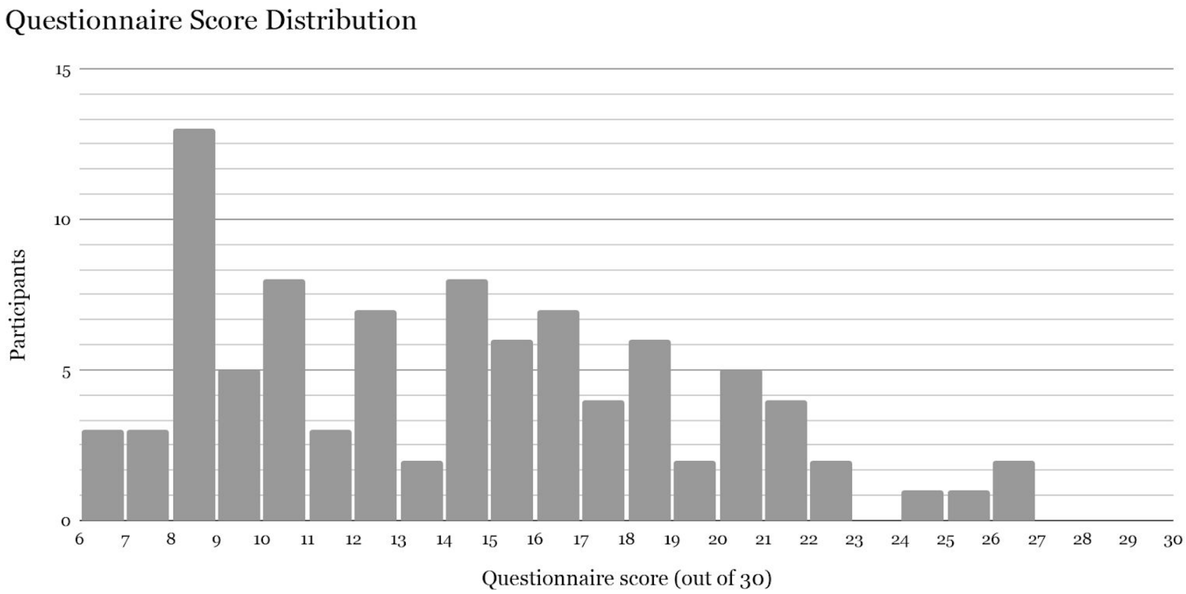

Figure 2. Distribution of questionnaire scores for 94 participants. The cutoff score for satisfying the criteria for grapheme-color synesthesia is set 2 standard deviations from the mean (cutoff=25).

With this cutoff score, 3 individuals technically qualified as grapheme-color synesthetes, but this was not reflected in their consistency screenings.

Discussion

Data collected in this pilot study reveal that none of the respondents fulfilled the consistency criteria designed by Simner et al. (2006) for grapheme-color synesthesia, however 3 individuals did score within the known synesthetic range in their respective questionnaires. There are several explanations for this, the first being that these individuals did not understand the instructions for the screening portion, and thus reported the color black for all questions. The other potential explanation could be that these individuals have synesthetic *tendencies,* which is entirely possible, considering that questionnaire responses for all three individuals were consistently coherent, such that responses on reverse-coded questions were in line with responses on the rest of the questionnaire. If the former is true, instructions will need to be altered so as not to confuse participants.

The questionnaire was designed to reveal more qualitative information about one's synesthetic experiences; this being said, questionnaire scores alone are not enough to determine whether someone has synesthesia. The consistency test is far more valuable in measuring synesthesia, as it collects data that is difficult to sway or falsify without being aware of the upcoming retest. Considering the absolute lack of variability in responses on the consistency test, as well as the low questionnaire score mean, it can be concluded that no one tested in this sample has grapheme-color synesthesia. Taken at face value, these findings could be interpreted in three ways. Firstly, they could indicate that the prevalence of grapheme-color synesthesia is lower than what was previously believed, and a sample size of 94 individuals is not enough to detect potential grapheme-color synesthetes. However, we have already determined that studies conducted on a much larger scale (Simner et al., 2006, Carmichael et al., 2015) have detected grapheme-color synesthetes and have yielded an estimated prevalence of 1.4%. A conclusion that can also be made is that synesthesia is not a real condition, however for the same reason outlined above, this is likely not the case. Lastly, and most likely, these findings could indicate that the diagnostic measures used in this screening are not sensitive enough to detect grapheme-color synesthesia.

If this is indeed the case, it is pertinent that shortcomings of the pilot study are identified and modified for future screenings. The first limitation of this pilot study is the fact that it was conducted online. Online data collection does not hold individuals accountable for their participation and can, thus, lead to passive responses and skipped instructions. If instructions had been read, however, it could be inferred that they were not clear enough, even though a significant effort had been made to make these instructions as clear as possible by, for instance, offering a brief framework comparing “what to do” with “what not to do” (i.e. “This task is NOT asking you to select the color in which the letter/number is written, but rather the color you associate most with each letter/number.”). While these limitations could explain these results, the most compelling explanation for this finding is the small sample size from which data was collected. Prolific has a minimum compensation rate of $6.50/hour, which, due to budgetary constraints, limited the number of participants to 103. As such, the sample size for this pilot study may not have been large enough to identify one of the estimated 1.4% of individuals who have grapheme-color synesthesia.

Taking these limitations into account, a future screening would need to be conducted on a much larger sample size of at least 500 individuals. A screening of this size would likely identify at least one synesthete, and would provide more statistical power for prevalence estimates. Moreover, this screening would need to be conducted in person, when it is eventually possible to do so. Conducting this screening in person will allow respondents to ask any clarifying questions about the instructions and would keep materials standardized. In other words, only one computer would be used across all participants, so software/hardware characteristics such as brightness and display size will not vary across respondents, as they plausibly did in the pilot screening. Additionally, it may be constructive to conduct this screening at a college or university, which would likely be Bard College - college campuses have the added benefit of pooling individuals with widely varying skill sets and interests. It has been theorized that grapheme-color synesthesia is far more prevalent in samples of art students[9] than in the general population. If this is the case, conducting this study at Bard would provide the unique opportunity to obtain data from a group of individuals - art students - who have been shown to have a higher chance of being synesthetic. Presumably, this would increase the chances of identifying a grapheme-color synesthete so that differences in performance between synesthetes and non-synesthetes in future perceptual and behavioral tasks can be examined. Plans for future experimental research on grapheme-color synesthetes are detailed below.

Experiment Proposal

Permitting that another screening can be conducted in-person and on a larger scale, the experiment in this study will have two parts. The first part will attempt to replicate the findings of Palmeri et al. (2002), where synesthetes are shown to be more efficient in visual search than non-synesthetes, due to the attentional capture of their photisms. If stimuli and photisms are being processed pre-attentively, it would imply that the inner mechanisms of synesthesia are not visual, but cognitive. This replication experiment will be a 2 (Diagnosis: Synesthete, Non-Synesthete) x 2 (Condition: Congruent, Incongruent) x 3 (Set Size: 16, 25, 36) mixed-factorial design, where Diagnosis is a between-groups factor, and Condition and Set Size are within-groups factors. The visual search task will have two conditions, congruent and incongruent, which are characterized as follows: in congruent trials, participants will be presented with achromatic stimuli, where neither the target, nor the distractor elicit synesthetic photisms; incongruent trials will use an achromatic target stimulus that does elicit photisms, presented among achromatic distractors that do not. The hypotheses for this first experiment are:

[9]Rothen and Meier (2010) have estimated a prevalence of 7.2%.

H1: For incongruent and congruent trials, response times will decrease as set size increases for both groups. This is represented as a main effect of set size.

H2: Synesthetes and non-synesthetes will not differ in response time for congruent trials.

H3: Synesthetes will have faster response times than non-synesthetes in incongruent trials. Response times for synesthetes in these trials will be faster than those of congruent trials.

As such, this experiment is predicted to yield a two-way interaction for synesthetes between condition and set size. This interaction is not expected to be replicated for non-synesthetes and, as such, a three-way interaction between diagnosis, condition, and set size is anticipated, given the predicted difference between the interaction found for synesthetes and that not found for non-synesthetes.

To understand the extent to which these hypothesized effects occur in one's visual field, the second part of this experiment will ask participants to complete a covert, circular visual search task, the results of which will highlight any differences in attentional gradients that grapheme-color synesthetes and non-synesthetes may have. This particular experiment will address how far into the periphery of one's visual field that synesthetes and non-synesthetes effectively process graphemes such that they can report their presence or absence. A covert visual search task is designed so that eye movements are limited, which holds the center of each participant's visual field constant: because one's eyes do not move, neither does the center of one's visual field. By keeping the location of the center of each participant's visual field constant and presenting targets at a visual angle in the periphery of their visual field, one can isolate the extent to which weaker cognitive resources are allocated. This characteristic of this particular iteration of visual search is also important because it tells us more about what these exogenous resources are actually responsible for. For example, if synesthetes are shown to be more successful in visual search tasks in their periphery than non-synesthetes, it could be hypothesized that color processing occurs through the engagement of exogenous cognitive resources. Furthermore, because overt, endogenous attentional resources cannot be deployed without eye movements, potential differences in performance between synesthetes and non-synesthetes highlighted in this experiment would suggest that photism processing is occurring pre-attentively.

Given that attentional gradients can change across people (Brefczynski-Lewis et al., 2009; Robertson et al., 2013), and visual search performance varies across trial types (Palmeri et al., 2002), this study proposes that the attentional gradients will differ between synesthetes and non-synesthetes across trial types. For the purposes of this study, the attentional gradient of an individual will refer to the extent to which one's cognitive resources reach across one's visual field. Using the rubric employed by Robertson et al. (2013), performance (% correct) will be assessed, but will be compared across eccentricities as opposed to target location. An individual will be considered to have a "sharp" gradient of attention if the slope of their performance is steep when plotted against eccentricity. Furthermore, an individual will have a "flat" gradient of attention if the slope of their performance is flat when plotted against eccentricity. In addition to the slope of one's performance, this study will also analyze the height of participants' performance curve - individuals with a curve that is located higher than other curves will be observed as having superior performance in this task than others.

This covert visual search task would be a 2 (Diagnosis: Synesthete, Non-Synesthete) x 3 (Condition: Congruent, Synesthetically Incongruent, Physically Incongruent) x 4 (Eccentricity: 2.29°, 4.58°, 6.87°, 9.15°) mixed-factorial experiment, whereby Diagnosis is the between-subjects factor, and Condition and Eccentricity are the within-subjects factors. The hypotheses for the second part of this experiment are as follows:

H1: Across all conditions and groups, accuracy will decline as eccentricity increases. This main effect of eccentricity will be referred to as the eccentricity effect.

H2: In synesthetically incongruent trials, synesthetes will be more accurate as eccentricity increases, than non-synesthetes. In these trials, synesthetes will, thus, have a flatter gradient of attention than non-synesthetes.

H3: In physically incongruent trials, synesthetes and non-synesthetes will have no difference in accuracy. Performance slopes for this condition will not be completely flat, but they will have the flattest slopes of all three conditions.

H4: Synesthetes and non-synesthetes will not differ in accuracy for congruent trials.

When combined, H2, H3, and H4 represent an anticipated main effect of condition for each group (synesthetes and non-synesthetes). Moreover, all four hypotheses describe a two-way interaction between condition and eccentricity for both groups. Because synesthetes are expected to perform significantly differently from non-synesthetes in synesthetically incongruent trials, it is anticipated that this will differentiate the 2 two-way interactions between condition and eccentricity identified for each group, such that a three-way interaction will also be found.

Method

Participants

Participants will be recruited through various on-campus flyers and emails distributed to the student body at Bard College. Once each participant completes the diagnostic screening and questionnaire, their emails will be collected and they will be asked to return to the lab to complete the two perceptual experiments described in this section.

Presuming that at least one synesthete is identified in the in-person screening and questionnaire, this experiment will test both grapheme-color synesthetes and non-synesthetes. Each identified synesthete will have their own control sample of 30 individuals; while most larger-scale synesthesia studies use an equal number of controls to synesthetes, in this case, a larger number of controls will ensure statistical power and will be more representative of the population. Ideally, at least 6 grapheme-synesthetes would be identified through the diagnostic screening, half of which would be male and and the other half of which would be female[10]. As such, these experiments will be administered to 150 individuals (permitting that 5 synesthetes are identified). Only participants with normal or corrected-to-normal vision will be considered for this study.

Apparatus

Both experiments will be designed using Psytoolkit and will be presented on a PC with a 17-inch color monitor at full brightness.

[10]It is important that future research - here, and in general - also addresses and examines individuals who are non-binary or trans.

Materials

Traditional visual search

In replication of the visual search task administered by Palmeri et al. (2002), participants will be presented with an 18x18cm display with a black background; this display will present an array of either 16, 25, or 36 stimuli in a given trial. Each stimulus will be 2x2cm in size and will be presented against a black background.

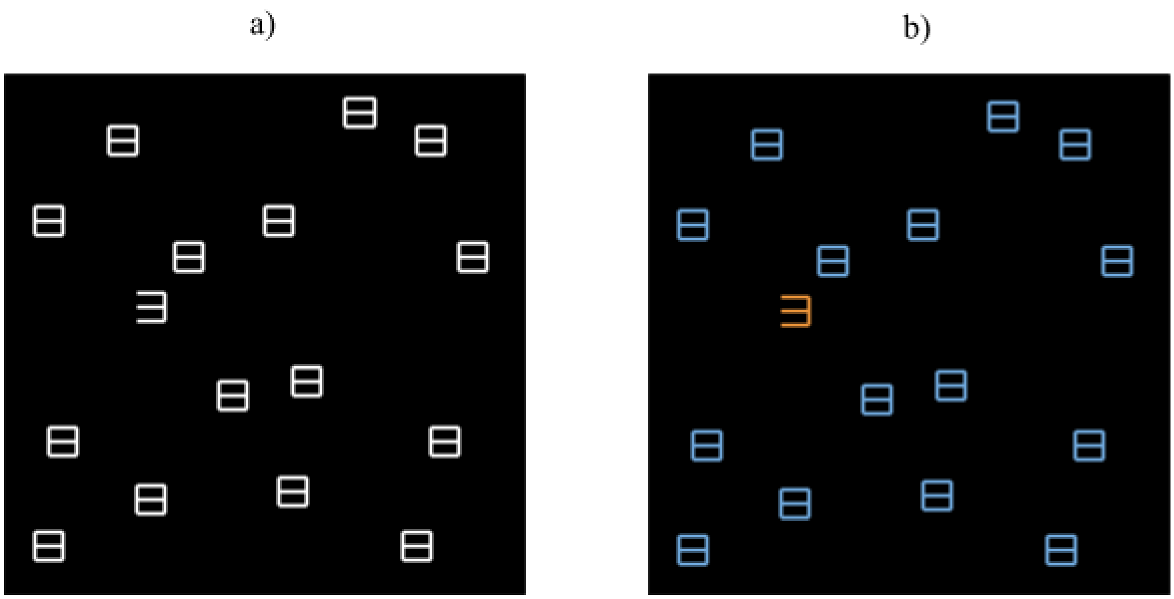

Figure 3. a) Sample incongruent trial, presented achromatically. Participants are tasked with identifying whether or not the 3 is present. In this example, the synesthete perceives the number 3 as orange, and the number 8 as blue, making this an incongruent trial. b) Example of what this synesthete would perceive in such an incongruent trial.

Grapheme combinations for each condition will be hand selected for each identified grapheme-color synesthetes and their respective control samples. Congruent grapheme sets will consist of two achromatic graphemes[11], both of which elicit similar photisms for the synesthete to which they are assigned. Incongruent grapheme sets will contain two achromatic graphemes

[11]Graphemes presented in a non-color (i.e. black, grey, white)

that each elicit significantly different colors from one another, as will be determined using a 12-color, color wheel. Colors will be considered to be significantly different from one another if there are at least three degrees[12] of separation between them on the color wheel. Moreover, in line with Palmeri et al.'s methodology, locations of stimuli will be randomized for every trial. Participants will be asked to respond to whether the target was present or absent using two keys on the keyboard (P=present, A=absent).

Covert visual search

In the covert visual search task, participants will be presented with a 24x24cm display, which will display a fixation point surrounded by 8 stimuli arranged in a circular array. This task will use 4 different circular array sizes, all of which are centered by a fixation point. Set size will remain the same simply so as not to make trials on larger circles more difficult, both as a function of distance and set size. By keeping set size constant, one can more easily isolate the potential effects of increasing eccentricity, which is also more relevant for measuring visuospatial attentional distribution. Circle sizes will be measured in terms of distance from the central fixation point, which will be referred to as the eccentricity of each circle. Each increase in eccentricity will be reflected by a 2.2915° (2.4cm) increase in distance from the center at every point on the perimeter, such that the perimeter of the smallest circle will be 2.4 cm from the center, and that of the largest circle will be located 9.6cm from the center. The reasoning behind this choice of increments was to use a spacing consistent with a 1998 study conducted by Wolfe, O'Neill, and Bennett[13], while maintaining proportional increases in distance from the center.

[12]Degrees of separation are defined as individual color segments on a 12-color wheel.
[13]Increases in distance used in this study were 2.3° (Wolfe, O'Neill, and Bennett, 1998).

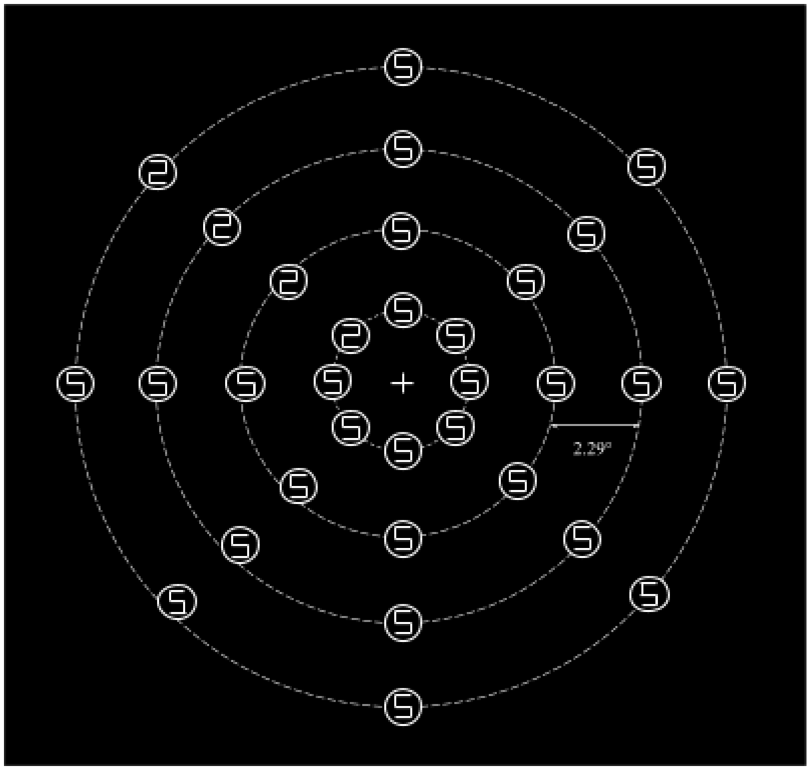

Figure 4. The four circle sizes. The increase in distance from the center will be 2.29° for each increase in the number of stimuli. (Dotted lines are only included to represent the circular array; participants will not see these)

Each stimulus will be a "disc" composed of a grapheme framed by a circle. Discs will each cover 1.6° of visual angle[14] and will be presented against a black background. Stimuli for this covert visual search task will be identical to those in the traditional visual search task administered in the first part of this experiment. Congruent trials will present a pair of graphemes that elicit the same or similar photisms, one of which will be the target and the other of which is used as distractors, where synesthetically incongruent trials will present a pair of achromatic graphemes which elicit significantly[15] different photisms from one another. To understand if the pop-out effect is true for all set sizes in a covert visual search task, physically incongruent trials will employ the same stimuli as congruent trials, with the notable difference that the target would

[14]With a viewing distance of 60cm, this translates to 1.6756cm.
[15]Determined using the same criteria as in Part 1.

be presented chromatically in red. Sample stimuli for these three conditions are provided in Figure 5.

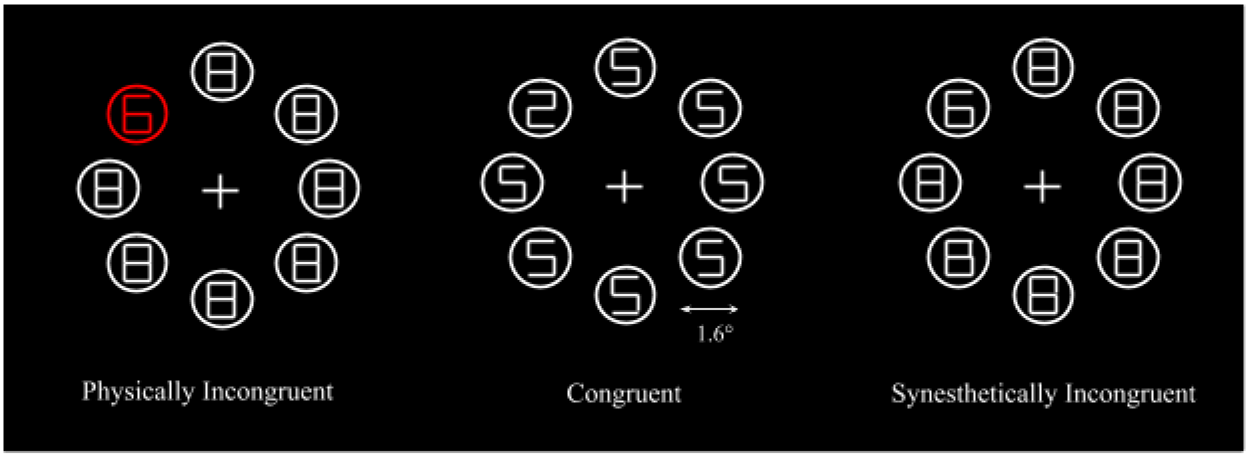

Figure 5. Examples of physically incongruent, congruent, and synesthetically incongruent stimuli sets. This example assumes the assigned synesthete associates similar colors for the number 2 and the number 5, and associates significantly different colors for the number 6 and the number 8.

Again, locations of stimuli would be randomized for every trial. Participants will be asked to respond to whether the target was present or absent using two keys on the keyboard (P=present, A=absent).

Procedure

Traditional visual search

Once participants complete the diagnostic synesthesia screening and questionnaire, they will be asked to come back to the lab approximately 2 weeks later to complete the experiment portion of the study. Another consent form will be provided and subjects will be asked to voice any questions or concerns they have before giving their consent. After signing this form, participants will be asked to read over the instructions indicated on the screen, which will explain the procedure of the experiment and will indicate which buttons to press to indicate presence or absence of the target stimulus. Before the experiment begins, participants will be shown the list of graphemes that will be presented in this task, and will be asked to state what each grapheme is. Because the graphemes used in both tasks are stylized, it is important to obtain confirmation that these graphemes are interpreted exactly as they are intended to (e.g. a stylized 3 being interpreted as the number 3), as photisms may not be experienced otherwise. At this point, participants will begin the experiment, which will be divided into four blocks of 120 trials, with an opportunity to rest between each block; subjects will complete a total of 480 trials. This portion of the experiment should not take more than 35 minutes, including breaks.

Conditions (congruent and incongruent) will each be randomly presented in 50% of trials, and the target will be present in half of the trials. Set sizes will also vary randomly throughout the experiment. As such, each combination of condition, set size, and target status (present or absent) will be presented in 40 trials. Participants will be asked to respond as quickly and accurately as possible as to whether the target was present or absent. Performance will be measured by response time in correct trials.

Covert visual search

When the first part of the experiment has been completed, subjects will be given a chance to rest their eyes before continuing. Instructions will then be shown on the screen, which will describe the task they are about to complete; once they have read the instructions, they will be asked if they have understood what is expected of them. Participants will be asked to respond to each trial as quickly and accurately as possible. Additionally, to ensure that stimuli consistently represent the same portion of each subject's visual field, participants will be positioned so that the distance between their eyes and the screen is about 60cm for the duration of the experiment. Once the participant has confirmed that they have understood the instructions, they will be asked to begin the practice block of 12 trials. After the practice block, participants will be given a chance to ask any final questions and rest their eyes before the experiment begins.

The covert visual search task will consist of 3 blocks of 192 trials, giving a total of 576 trials for the entire covert visual search task. Each trial should take about 3000ms in total, and between each block, subjects will be given the opportunity to rest their eyes before resuming. Participants will first be shown a fixation point for 1000ms, followed by one covert visual search trial. In order to ensure that participants are not moving their eyes, each visual search trial will be presented for 200ms, as this is the average of the two times needed for endogenous (300ms) and exogenous (100ms) attention to be deployed (Carrasco, 2018). While both endogenous and exogenous attention are being measured, exogenous attention is what will potentially set the performance of synesthetes apart from that of non-synesthetes, and because exogenous attention begins to decay after 100ms, a trial time of 200ms is needed, as opposed to a longer 300ms trial time that fully measures endogenous attention. Moreover, a similar time frame (180ms) was used by Turatto et al. (2004), where they argued that such a short trial would "render any eye movements useless". After each trial, a fixation point will be presented for 500ms, followed by a screen asking "Was the target present?", to which participants will either respond "present" or "absent" using the assigned buttons on the keyboard. The entire experiment should take no more than 35 minutes to complete, including breaks. Because this is a covert perceptual task, and trial times are predetermined, performance will solely be a function of accuracy, such that more accurate responses are indicative of superior performance.

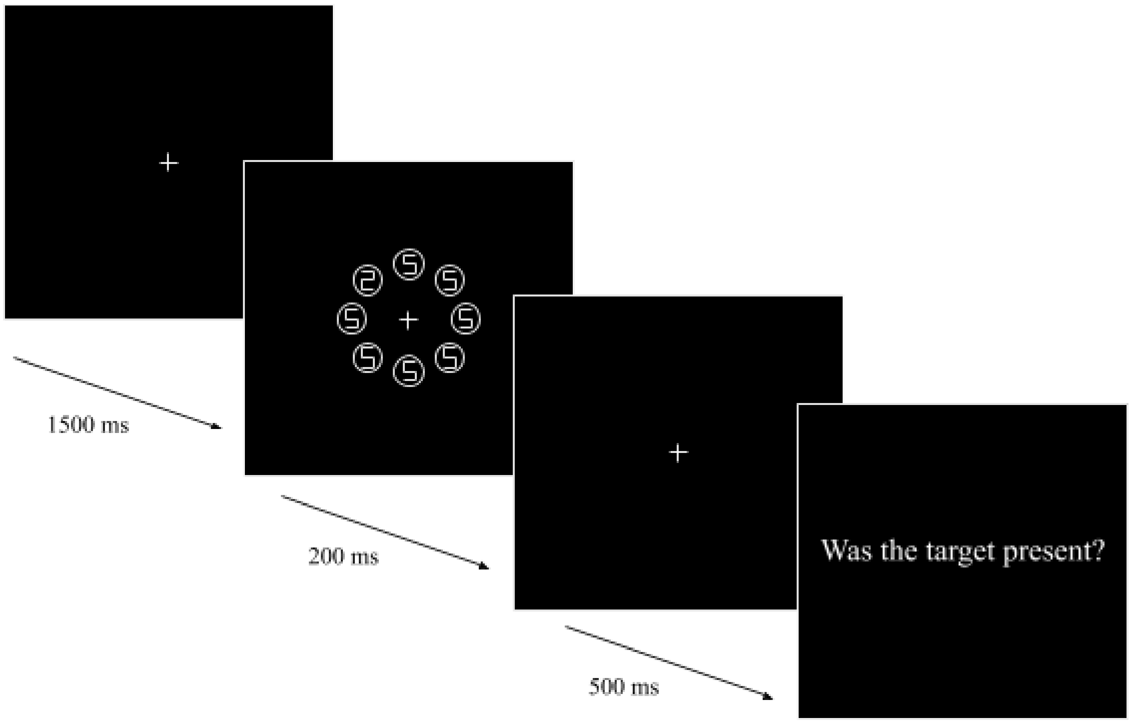

Figure 6. Procedure of the experiment. The fixation point will be presented for 1500 ms, followed by the covert visual search containing one target and 7 distractors, which will be presented for 200ms. Following the visual search, a fixation point will be displayed for 500 ms; participants will then be asked if the target was present.

After completing the experiment, participants will be given the opportunity to raise any questions and concerns, and will be debriefed. Finally, participants will be given my email address, in the event that they have any questions or concerns that arise later on.

Results

Traditional visual search

The results of this study are predicted to be the same as those found by Palmeri et al. (2002). However, taking into consideration the variation in performance found across studies examining the synesthetic “pop-out” effect, the extent to which this effect holds for each individual synesthete may vary. A main effect of set size will likely be found for this study, where there is a positive relationship between set size and response times for both synesthetes and non-synesthetes: as set size increases, response times of both synesthetes and non-synesthetes will increase.

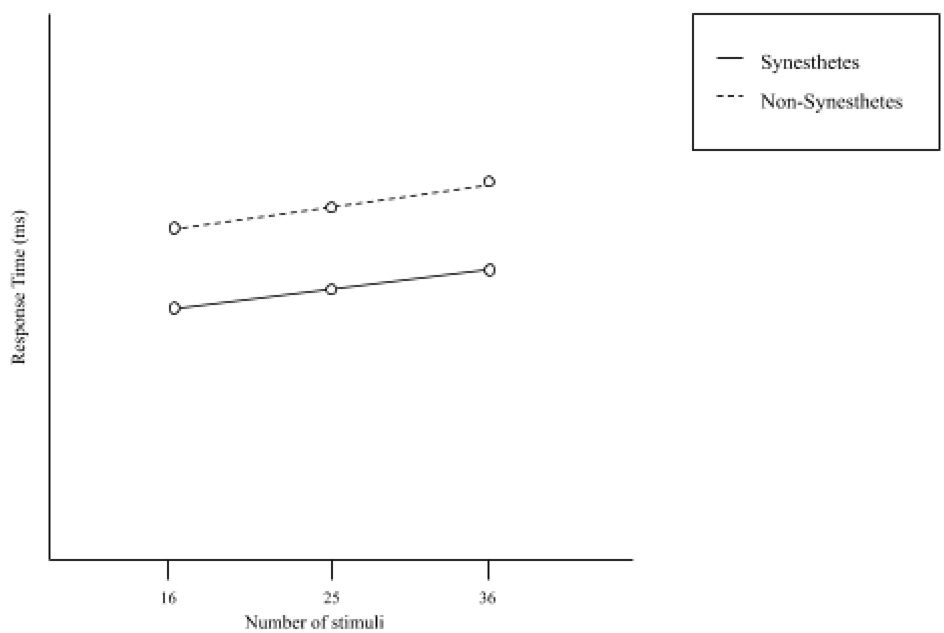

Figure 7. Predicted main effect for set size: for both groups, as set size increases, so do response times.

Response times for synesthetes are predicted to be generally higher than those of non-synesthetes. This is because when the average response times across conditions are calculated, faster response times in incongruent trials bring down the average response time for synesthetes. This is demonstrated in Figure 7.

In addition, this experiment is predicted to highlight a two-way interaction between condition and set size for synesthetes, such that response times in incongruent trials will be higher than response times in congruent trials. The shape of the curve representing response times in incongruent trials is modelled after that which was reported by Palmeri et al. (2002) for the grapheme-color synesthete, W.O. It indicates that, as set size increases, the extent to which the photisms experienced by grapheme-color synesthetes aids them in visual search decreases. This is consistent with the theory that synesthetes do not process photisms pre-attentively across their visual field, but rather in a smaller subset. Furthermore, such an interaction will likely not be found for non-synesthetes, as there is no discernable difference between congruent and incongruent trials for non-synesthetes. The only reason one would find a two-way interaction between condition and set size for non-synesthetes is if stimuli in one condition resemble each other significantly, and significantly differ in the other in such a way that would enhance their performance in only one condition. However, this would be controlled for when selecting grapheme sets, so data from non-synesthetes will most likely not show this interaction.

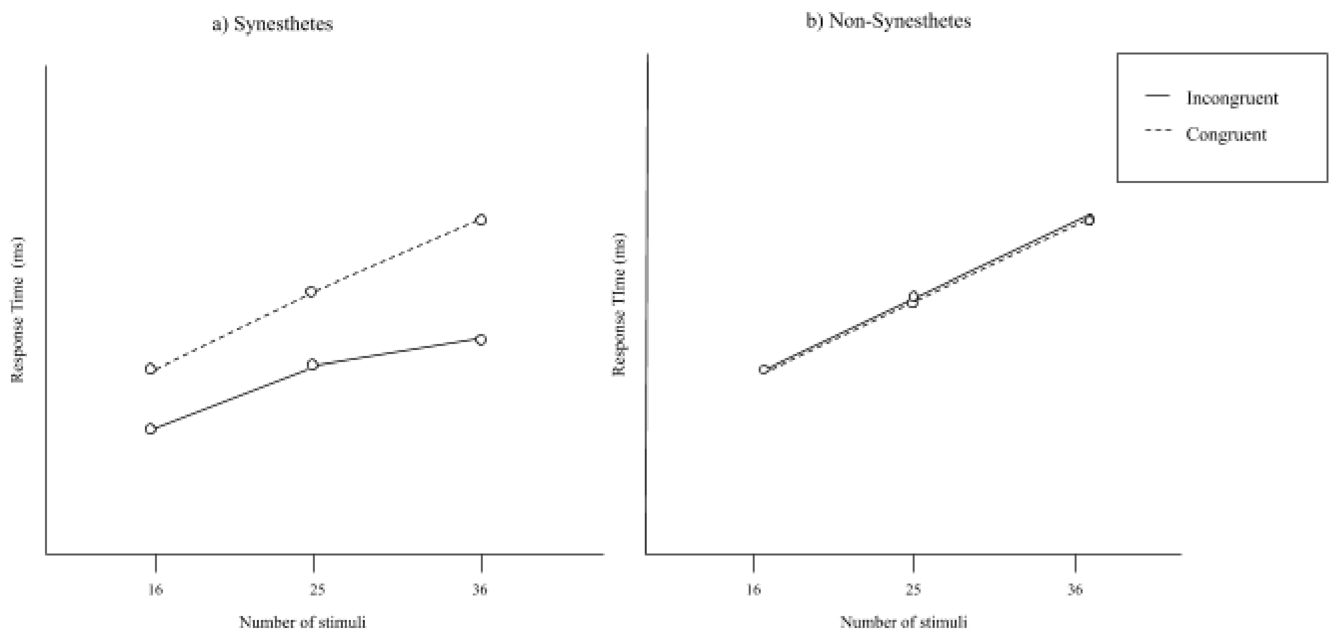

Figure 8. Predicted response times for each set size. a) Synesthetes will have high response times with a steep slope in congruent trials, and will perform better in incongruent trials, with a flatter slope and lower response times. There will be a main effect of condition and a two-way interaction between set size and condition. b) In both conditions, non-synesthetes will perform the same as synesthetes do in congruent trials. There will be no main effect of condition or two-way interaction between condition and set size for non-synesthetes.

Among other things, Figure 8 illustrates a three-way interaction between diagnosis, condition, and set size such that response times of synesthetes in incongruent trials will be lower and less affected by set size than congruent trials, and response times of non-synesthetes will increase as set size increases, but will not differ across conditions. Lastly, data collected from this experiment are expected to reveal a two-way interaction between diagnosis and condition, which is presented in Figure 8.

Covert visual search

Based on the statistics reported by Wolfe, O'Neill, and Bennett (1998) for a similar visual search task addressing the eccentricity of stimuli, a main effect of distance is predicted to be found, such that, as eccentricity increases, proportion of correct responses decreases; this prediction is consistent with the eccentricity effect and is represented visually in Figure 9. Moreover, this main effect is hypothesized to be true for both groups, though synesthetes will likely have a higher proportion of correct answers, in general, due to the same averaging of performance in each condition mentioned in the previous subsection.

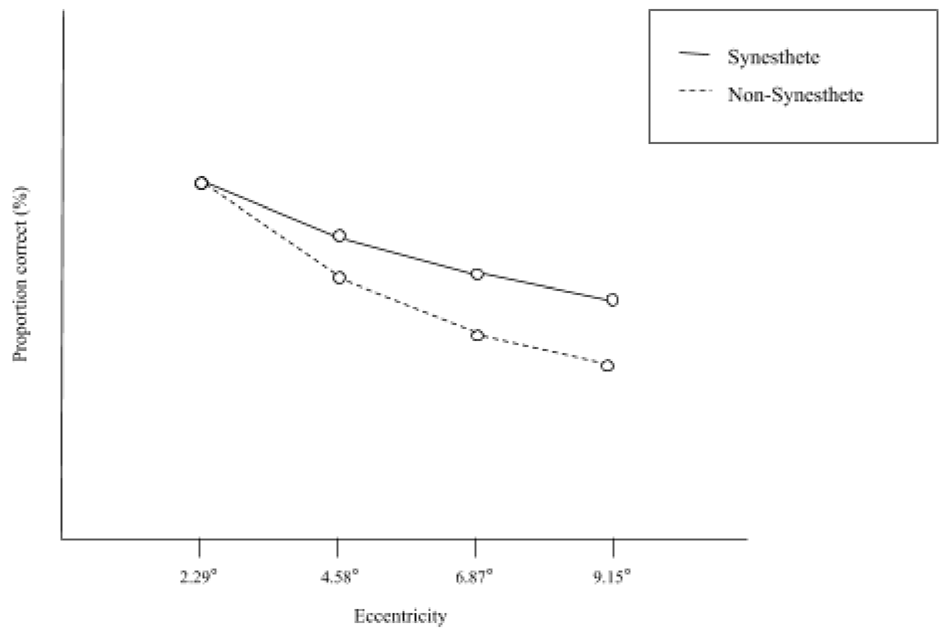

Figure 9. Predicted main effect for eccentricity: for both groups, as eccentricity increases, accuracy (proportion correct) decreases. This figure also illustrates that non-synesthetes will have a sharper gradient of attention than synesthetes.

The particular shape of the two curves in Figure 9 are predicated upon slopes reported by Turatto et al. (2004). As eccentricity increases, the proportion of correct responses falls, as does the rate at which it falls. In other words, differences in accuracy of responses between the smallest and second-smallest circle arrays will be greater than differences in the accuracy of responses between the largest and the second-largest circles.

A main effect of condition is also expected to be found in this study for both groups, as well as a two-way interaction between diagnosis and condition (Figure 10).

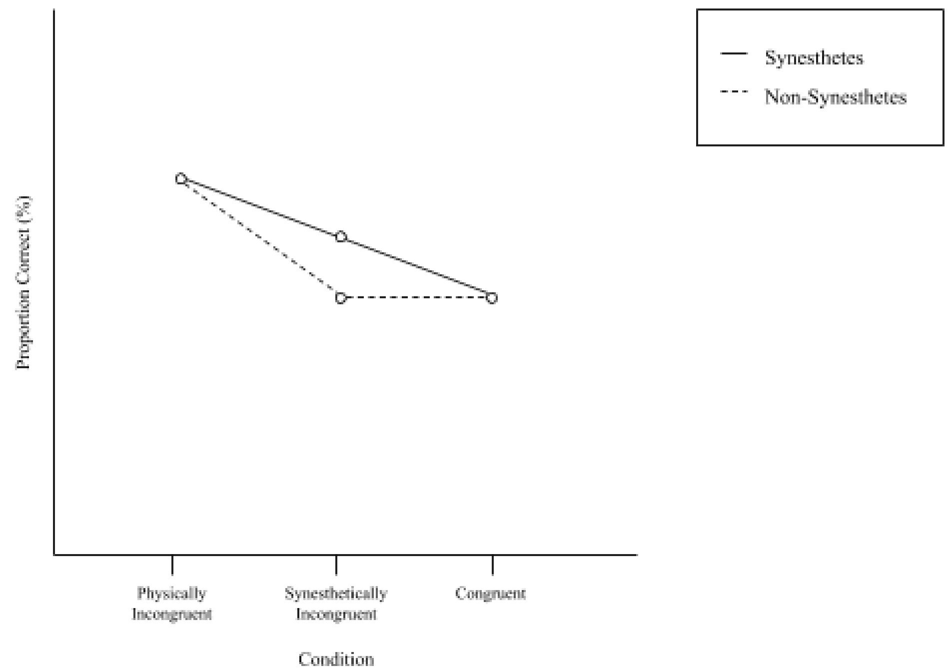

Figure 10. Predicted main effect of condition for both groups, and two-way interaction between condition and diagnosis. Performance in synesthetically congruent trials is higher for synesthetes than non-synesthetes, where performance on congruent and physically incongruent trials is the same for both groups.

Non-synesthetes will perform the same as synesthetes in congruent trials because targets and distractors will be equally difficult to differentiate for both groups. The same would be true for physically incongruent trials, because both synesthetes and non-synesthetes experience the same advantage of being shown a chromatic target. In synesthetically incongruent trials, however, synesthetes are expected to respond more correctly than non-synesthetes. This is explained by the fact that in synesthetically incongruent trials, synesthetes process photisms, which help identify target stimuli in the periphery of their visual field. Non-synesthetes will likely experience no such advantage, and thus, will have the same proportion of correct responses for congruent and synesthetically incongruent trials.

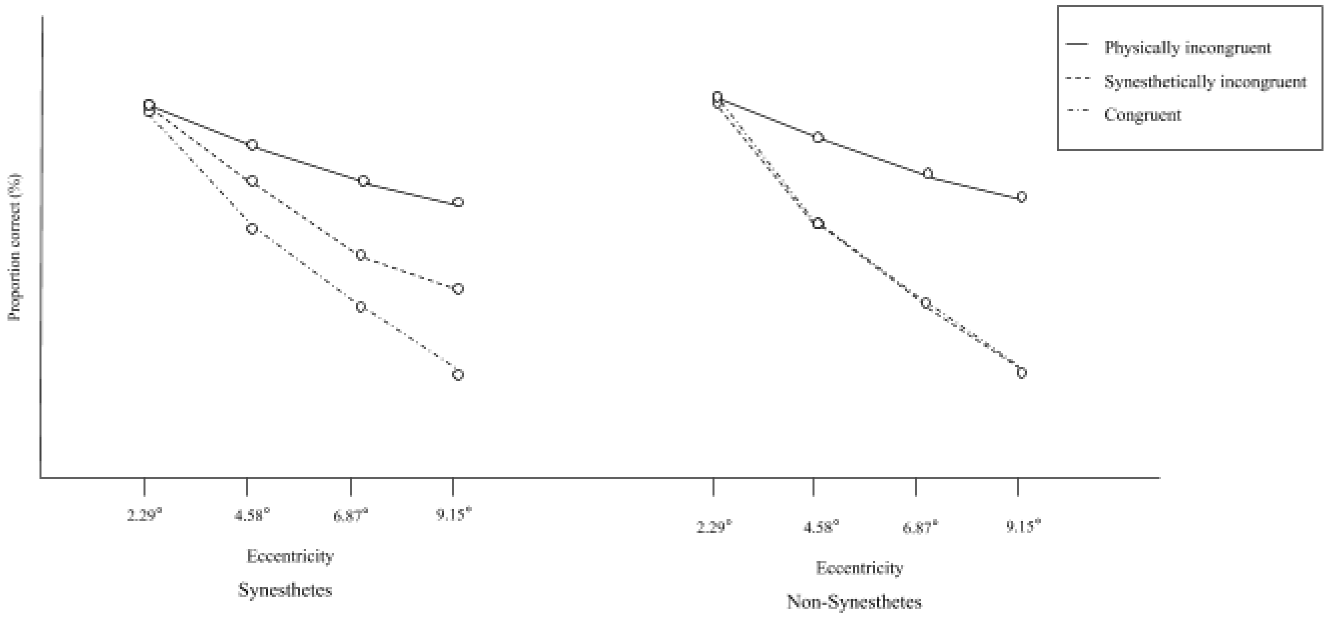

Figure 11. Two-way spreading interaction between condition and eccentricity for both groups, and three-way interaction between diagnosis, condition, and eccentricity. Performance slopes are flatter for synesthetes than for non-synesthetes in synesthetically incongruent trials, indicating a flatter gradient of attention.

A two-way interaction between condition and eccentricity is anticipated for both groups, such that performance on congruent and physically incongruent trials differ significantly as eccentricity increases. For synesthetes, as per Hypothesis 2 for this experiment, it is expected that their performance will be better on synesthetically incongruent trials than on congruent trials due to the photism processing that occurs through exogenous attention. This effect is not expected to be found for non-synesthetes, so, assuming this difference in performance on synesthetically incongruent trials, a three-way interaction between diagnosis, condition, and eccentricity is predicted to be found as well. In other words, synesthetes and non-synesthetes will be more correct on physically incongruent trials than congruent trials, as eccentricity increases, but will differ significantly in their performance on synesthetically incongruent trials as eccentricity increases.

Discussion

Presuming that these results hold true when data is collected, these two experiments will have several implications. In the traditional visual search task, participants will be asked to identify a target among distractors that are either synesthetically congruent or incongruent with the target. If this experiment can replicate the effect found by Palmeri et al. (2002), Ramachandran and Hubbard (2001), and Smilek et al. (2003), whereby synesthetes are more efficient in trials where the target and distractors are synesthetically incongruent, it would suggest that synesthetes experience a more mild form of the “pop-out effect”. Moreover, this finding would support the claim that when attention is deployed to a specific part of the visual field, synesthetes bind colors to their graphemes prior to the full processing of these graphemes (Palmeri et al., 2002). These two implications combined would suggest that synesthetes have a type of “spotlight” or area of focus in which synesthetic colors are bound pre-attentively, as opposed to the entire visual field.

Assuming that the study conducted by Palmeri et al. (2002) can be replicated, the proposed results for the second experiment should hold true as well. Firstly, the anticipated findings - that the accuracy of both synesthetes and non-synesthetes declines as eccentricity increases - would support the gradient model of attention, where cognitive resources are concentrated in the center of one’s visual field and diffuse as they are located further from the center. Secondly, if synesthetes and non-synesthetes perform the same on congruent and physically incongruent trials, it would suggest that both groups generally have the same size of attentional gradient. Supposing the theory that synesthetes would be more accurate than non-synesthetes on synesthetically incongruent trials applies, it would imply that synesthetes are processing their synesthetic color associations pre-attentively. However, if in a covert circular visual search task, synesthetes are significantly more accurate on synesthetically incongruent trials with greater eccentricities than non-synesthetes, it would imply that not only are photisms being processed pre-attentively, but that synesthetes have a flatter and larger gradient of attention. That is to say, in such trials, synesthetes process their photisms at a greater distance from the center of their visual field than non-synesthetes can process graphemes. This would support the aforementioned claim that grapheme-color synesthetes have a “spotlight” through which photisms are processed and can capture their endogenous attention. With this, it could be also interpreted that exogenous resources located in the periphery of one’s attentional field are responsible for color processing while not being strong enough to process forms.

This interpretation would be confirmed by the expected improved performance of both synesthetes and non-synesthetes on physically incongruent trials. If synesthetes and non-synesthetes exhibit superior performance in trials where the target is presented chromatically, presumably the color of the target is being processed prior to the processing of the target, further supporting the claim that exogenous resources process color, both synesthetic and physical.

As is the case with many multiple case-study experiments, it is difficult to make conclusions about an entire population of individuals when the sample size is so small. Given that synesthetes have a low estimated prevalence *and* are difficult to diagnose, it would be challenging to address this limitation without more resources and funding. Moreover, it has been shown that individual differences between synesthetes also exist, so any sweeping conclusions about synesthetes should generally be taken with a grain of salt. As such, the purpose of this study is rather to contribute to the communal knowledge of synesthesia and perhaps shed light on some differences synesthetes may have from non-synesthetes or from other synesthetes.

Because this line of study can reveal cognitive and behavioral characteristics of both synesthetes and non-synesthetes, it is particularly important that further studies are conducted to enrich our understanding of these characteristics. Retinotopic mapping using an fMRI, for example, could highlight which parts of the brain are responsible both for exogenous attentional deployment, and for photism processing. This type of testing could also pinpoint whether exogenous attentional resources are responsible for color processing, or if this is located in another area of the brain. In addition, eye tracking could be applied to both experiments and could address any minor eye movements that might occur in a covert visual search. In fact, if the traditional visual search task described in this study can employ eye tracking, one could map the extent to which synesthetes search serially or are “drawn” to the target. Both of these tests require significant funding and resources that are not currently available, but would certainly improve our understanding of this cognitive phenomenon.

Conclusion

While the study of synesthesia is a complex and mysterious one, it continues to surprise and reveal information about how we process information. The pilot screening revealed just how difficult grapheme-color synesthetes are to diagnose, especially using self-report measures. In not identifying any synesthetes, the results of this study suggest that grapheme-color synesthesia has a prevalence of 0%, and thus does not exist. This conclusion is not being made here, however, because perceptual tasks and other diagnostic tools have demonstrated that synesthesia is indeed a real condition. Additionally, it is extremely unlikely that a certain subset of individuals are pretending to have this specific condition or that they have such precise imaginations on a global scale.

Due to restrictions presented by the COVID-19 pandemic, the two experiments detailed in this study were not able to be conducted, and thus, no data was collected for either experiment. However, the previously outlined predicted findings suggest that grapheme-color synesthetes have additional cognitive processes occurring that can enhance their performance in tasks involving graphemes. As such, synesthetes may be able to engage and utilize weaker cognitive resources to their advantage to an extent that non-synesthetes cannot.

As more research on synesthesia emerges, hopefully we can gain a better understanding of this condition so that it can both be formally defined and normalized in society. As awareness of this condition is increased over time, negative experiences had in childhood, or even adulthood, can potentially be averted and synesthetes may at least be able to avoid ridicule or misdiagnosis (e.g. hallucinations or delirium). Our enhanced comprehension of synesthesia and its underlying workings will ultimately help us to understand why “V is a kind of pale, transparent pink”, in the mind of Vladimir Nabokov.

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Appendix A

IRB Proposal

IRB New Proposal Form 2020

Project Title: The Difference in Attentional Gradients Between Synesthetes and Non-Synesthetes, Identified Through Visual Search

Start date: Sep. 1 2020

Describe your research question:

Synesthesia is a condition whereby sensory stimuli evoke unusual additional sensory perceptions and experiences; this condition can be identified with visual search. Visual search has also been used to measure the distribution of visual spatial attention, where several findings have supported the gradient model of attention. This model proposes that cognitive resources are the most concentrated centrally in our visual field, and taper off in a gradient, such that the perimeters of our visual field deploy fewer cognitive resources. The goal of this study is to identify potential size differences in attentional gradients between synesthetes and non-synesthetes. This will be done using a covert, circular version of visual search that is often used in the study of attentional gradients.

Describe the population(s) you plan to recruit and how you plan to recruit participants. Please submit all recruitment material, emails and scripts to IRB@bard.edu:

I plan to recruit psychology students at Bard College by email (See Appendix G). Additionally, the greater undergraduate population will also be given the chance to participate in this study and will be recruited with flyers posted across campus (See Appendix G). These flyers will list my email and will ask interested students to write to me for more information. To compensate them for their time, participants will be given the opportunity to enter a raffle to win a $150 Bard Bookstore gift card.

Approximately how many individuals do you expect to participate in your study?
50

Describe the procedures you will be using to conduct your research. Include descriptions of what tasks your participants will be asked to do, and about how much time will be expected of each individual. NOTE: If you have supporting materials (printed surveys, questionnaires, interview questions, etc.), email these documents separately as attachments to IRB@bard.edu. Name your attachments with your last name and a brief description (e.g., "WatsonSurvey.doc").

Participants arrive in the testing room (Preston Hall) and will be asked to sign an informed consent form that explains the basics of the experiment and participant rights (See

Appendix H). If participants have any questions, I will answer them. Once they have signed the consent form, participants will be given instructions for Part One of the study.

Part One: Synesthesia Screening and Questionnaire

Participants will be shown a series of graphemes (numbers and letters) one at a time, accompanied by a palette of colours, all of which will be displayed on a computer. For each grapheme, participants will be asked to select the colour that they feel best represents the grapheme being shown by clicking on a colour shown in the colour palette. Once all 36 graphemes have been shown, participants will be given a surprise retest of the exact same procedure. The test and retest should take about 8 minutes in total to complete. After the retest is complete, participants will be asked to complete a general questionnaire (See Appendix E) about their experiences in this test and with reading graphemes in general - this questionnaire will be Likert-scored from 0 (strongly disagree) to 5 (strongly agree) (this should take approx. 7 minutes).

If a participant has rated the statement “There were not enough colours on screen for me to choose from” with a Likert score of 3 or higher, they will be given a sheet with all 36 graphemes and will be asked to report the corresponding perceived colours using a colour wheel on Google Docs. Colours will be noted down on the sheet according to their Hex Codes. Once this process has been completed (approximately 8 minutes) they may leave. If a participant has rated this statement with a Likert score of 2 or lower, they may leave after the general questionnaire.

The purpose of this screening is to a) identify synesthetes through their consistency across the two tests and their questionnaires and b) understand the specific grapheme-colour associations of potential synesthetes. By identifying specific grapheme-colour associations, unique visual search tasks can be designed for each identified synesthete in Part Two of the experiment.

Part Two: Covert Visual Search

Participants will be individually emailed to set up a time for them to come to the lab for the second part of this experiment. Participants will be asked to sit in front of a computer and read the instructions for the task at hand. This experiment will be using a covert, circular visual search task, where stimuli are presented in a ring surrounding a fixation point. There will be 4 sizes in which these rings can be presented where accurate performance on larger rings indicates a larger attentional gradient. Response time and accuracy data will be collected.

Participants will be asked to complete four blocks of this task, where each block contains 200 trials and takes approx. 15-20 minutes to complete. Between blocks, participants will have the opportunity to take a break. And proceed when they feel comfortable. In the visual search task, participants will be presented with a fixation point, followed by a brief (200ms) display of the visual search task to render any eye movements useless. Attention must be covert (no eye movement) in order for the size of one’s attentional gradient to be measured. They will then be presented with another fixation point, and subsequently, will be asked to report whether or not the target was present by pressing one of two designated buttons. The entire experiment should take a little over an hour to complete.

Depending on the results of the synesthesia screening, participants will be administered either a synesthetic visual search set or a non-synesthetic visual search set.

- Synesthetes will be given the synesthetic visual search set, which will consist of two conditions: synesthetically homogeneous and synesthetically heterogeneous. Based on their individual responses in the synesthesia screening, this group will be presented stimuli that reflect their responses. Synesthetically homogeneous visuals search trials will consist of a target and distractors that elicit similar synesthetic colours. Synesthetically heterogeneous visual search trials will consist of a target and distractors that evoke significantly different synesthetic colours. Across all trials, however, all stimuli will be presented in black on a white background.
- Non-synesthetes will be given the non-synesthetic visual search set and will experience two conditions: physically homogeneous or physically heterogeneous. Physically homogeneous trials will consist of a target and distractors that are presented in the same physical colour: black on a white background. Physically heterogeneous stimuli will consist of a target presented in a different physical colour than the distractors, such as a red target among black distractors.

Following the completion of the final block, participants will be given a debriefing statement (See Appendix I) and the opportunity to ask any questions they have about the study. Participants will also be reminded that they will be entered in a raffle to win a $150 Bard Bookstore gift card. The winner will be contacted by email.

Describe any risks and/or benefits your research may have for your participants.

This study will pose minimal risks to participants. Given that Part Two of the experiment should take an hour to complete on the computer, participants may experience eye strain.

Describe how you plan to mitigate (if possible) any risks the participants may encounter.

Over the course of the visual search task, participants will be given 3 chances to rest their eyes. They will also be told in the informed consent form that they may stop or end their participation at any time. This applies both to Part One and Part Two of the experiment.

Describe the consent process (i.e., how you will explain the consent form and the consent process to your participants):

Prior to the experiment, participants will be provided a consent form and will be asked to read it. Once they have finished reading the consent form, I will ask if they have any questions, and will answer accordingly. Participants will be reminded that they may leave at any time over the course of the experiment. As soon as any questions are answered, I will ask them to sign the consent form and provide them with their own copy. The experiment will begin once the consent form is signed.

Have you prepared a consent form(s) and emailed it as an attachment to IRB@bard.edu? Note: You must submit all necessary consent forms before your proposal is considered complete. *

- **Yes**
- No

What procedures will you use to ensure that the information your participants provide will remain confidential and safeguarded against improper access or dissemination? *

All procedures in this study will keep information confidential. Data and forms will be identifiable only by the participant's Bard email address and will be stored in a password-protected file. Physical copies of the general questionnaire and colour association form will be stored in a locked file cabinet. Only myself and my faculty advisor will have access to these records.

For all projects, please include your debriefing statement. (This is information you provide to the participant at the end of your study to explain your research question more fully than you may have been able to do at the beginning of the study.) All studies must include a debriefing statement. Be sure to give participants the opportunity to ask any additional questions they may have about the study. *

See Appendix I.

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certifies that

Kirsten Helena Ostbirk

has completed the

RESEARCH ETHICS TRAINING CURRICULUM

February 28, 2019

Correction: Details (such as the number of blocks) of this study have slightly changed - all changes are outlined in the method section of the Experiment Proposal.

Appendix B

IRB Approval Confirmation

Bard College Institutional Review Board

Date: June 18, 2020

To: Kirstin Ostbirk
Cc: Thomas Hutcheon, Deborah Treadway
From: Laura Kunreuther, IRB Chair

Re: The Difference in Attentional Gradients Between Synesthetes and Non-Synesthetes, Identified Through Visual Search

DECISION: APPROVED

Dear Kirstin,

The Bard Institutional Review Board reviewed the revisions to your proposal. Your proposal is approved through June 18, 2021. Your case number is 2020JUN18-OST.

Please notify the IRB if your methodology changes or unexpected events arise.

We wish you the best of luck with your research.

Laura Kunreuther
IRB Chair

PO Box 5000, Annandale-on-Hudson, New York 12504-5000 Phone 845-758-6822

Appendix C

Informed Consent Form for Pilot Study

Synesthesia

I am a student at Bard College and I am conducting an experiment for my Senior Project. More specifically, I'm studying the differences in the distribution of visual attention between synesthetes and non-synesthetes.

In this study, you will be shown a series of letters and numbers, and will be asked to select one color that you associate most with the given letter or number. You will also be asked a series of questions about your experience with this procedure and the general experiences you have when reading letters and numbers.

All the information you provide will be confidential. All of your information, including your data, will be kept in a password-protected computer.

Participant's Agreement:

I understand the purpose of this research and my participation in this study is voluntary. I may skip any questions or tasks that I am not comfortable with. If I want to stop participating for any reason, I may do so at any time without providing an explanation.

To the extent there are any risks, the researcher has reviewed any risks and benefits that may be associated with this study. I am aware that the information and data I provide will be used in a Senior Project that will be publicly accessible online and at Bard College's Stevenson Library in Annandale-on-Hudson, New York.

The information collected in this study is confidential and will not reveal any details about my personal identity.

If I have questions about the study, I can contact the researcher at ko8306@bard.edu. If I have questions about my rights as a research participant, I can contact the Chair of Bard's Institutional Review Board at irb@bard.edu.

I am at least 18 years of age and I consent to participate in this study.

Please insert your Prolific ID below to give your consent to participating in this study.

Also please note that you will not be compensated unless you click the link at the end of this study.

By entering your Prolific ID, you are consenting to participating in this experiment.

Short answer text

Appendix D

Screening Instructions and Contents

Choose the most appropriate color

Below, you are shown letters and numbers - your task is to select one of the given colors that you believe "best fits" the letter or number you are given. This task is NOT asking you to select the color in which the letter/number is written, but rather the color you associate most with each letter/number.

If you associate a given letter or number with a color not given below, please select a color that is closest to your answer. Please avoid choosing the same color repeatedly.

Sample question from the screening, asking participants to choose the color that "best fits" the letter A.

Appendix E

Questionnaire Questions for Pilot Study

Questionnaire

Please select the degree to which you agree or disagree with the following statements.

When performing the experiment, I felt that I knew for certain what the color for a letter or number should be.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

When performing the experiment, I felt as if I was guessing what the color for a letter or number should be.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Whenever I see or think about letters or numbers (printed black on white), I automatically experience the letter or number as having another color (e.g. red).

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Whenever I see or think about letters or numbers (printed black on white), I would never naturally experience the letter or number as having another color (e.g. red).

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Letters and numbers always evoke very precise colors (other than the color they are

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I have always associated the same particular colors with letters and numbers, and they never seem to change.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Appendix F

Debriefing Form for Pilot Study

Thank you for participating!

Debriefing Form

Thank you for your participation, it is greatly appreciated!

Purpose of the Study:

The purpose of this study is to identify the prevalence of synesthesia, and eventually, to identify the differences in the distribution of visual attention between synesthetes and non-synesthetes. Synesthesia is a benign, non-harmful condition where certain stimuli - such as letters, numbers, or sounds - evoke additional sensory experiences to those traditionally experienced. An individual with synesthesia may taste ice cream when hearing a car horn, or may strongly perceive a particular color in their mind's eye when reading the number 6. The latter example is a form of synesthesia known as grapheme-color synesthesia, which is what this research aims to address. Synesthesia is thought to affect about 1% of the population, but data from this study could indicate otherwise.

Based on your performance in this study, you may show synesthetic tendencies and fall within a particular threshold that qualifies you to be considered a grapheme-color synesthete for the purposes of this study. To be clear, this is not to say that you do or do not have synesthesia, but rather that your performance on these tasks fulfills predetermined criteria. Because I am not certified to diagnose anyone with synesthesia, I cannot definitively tell you if you have this condition.

Confidentiality:

You have the right to decide whether or not you want your data to be used in this research. If you would like to have your data removed from this study and permanently deleted, please email me at ko8306@bard.edu.

Whether you agree or do not agree to have your data used in this study, you will still receive compensation for your participation.

Final Paper:

If you would like to know the results of this study and would like a copy of this research paper, please feel free to contact me using the details listed below.

Contact Information:

If you have any questions or concerns relating to this study, please feel free to contact me by email at ko8306@bard.edu. If you have any other concerns regarding this study or if you would like to speak with someone not directly involved in this study, please contact the Chair of the Psychology Program, Sarah Dunphy-Lelii at sdl@bard.edu.

Please keep this information for future reference. Once again, thank you for your participation!

To receive compensation, please click the link below, which will take you back to Prolific.

https://app.prolific.co/submissions/complete?cc=434D2230

Appendix G

Recruitment Materials for Proposed Experiment

To: Psychology students
Subject: Participate in a study for a chance to win a $150 Bard Bookstore gift card!!!!!

Hi everyone!

My name is Kirsten Ostbirk and I am currently studying the distribution of visual attention for my senior project. I'm looking for people to participate in my experiment, which requires us to have 2 sessions a week apart: the first session will take about 20 minutes, and the second session will require a little over an hour of your time. I totally understand that everyone is super busy, so to make it worth your while, participation will enter you in a raffle to win a $150 Bard bookstore gift card!!!

Please note that people who have taken psychedelic drugs two weeks prior will not be allowed to participate.

If you are interested, please just reply to this email!

Wishing you all the best,

Kirsten

ATTENTION!

WANT A CHANCE TO WIN A $150 BARD BOOKSTORE GIFT CARD?

INTERESTED IN CONTRIBUTING TO PSYCHOLOGICAL RESEARCH?

MY NAME IS KIRSTEN AND I'M RUNNING A TWO-PART EXPERIMENT ON ATTENTION FOR MY SENIOR PROJECT.

THE FIRST PART OF THIS EXPERIMENT WILL REQUIRE ABOUT 20 MINUTES OF YOUR TIME, AND THE SECOND PART WILL REQUIRE A LITTLE OVER 1 HOUR. **YOUR PARTICIPATION WOULD BE GREATLY APPRECIATED!***

TO COMPENSATE YOU FOR YOUR TIME, YOU WILL BE ENTERED IN A RAFFLE TO WIN A **$150 GIFT CARD TO THE BARD BOOKSTORE**!

INTERESTED? PLEASE EMAIL ME:

KO8306@BARD.EDU

I LOOK FORWARD TO SEEING YOU IN THE LAB!

*People who have taken psychedelic drugs two weeks prior will not be allowed to participate.

Appendix H

Informed Consent Form for Proposed Experiment

Consent to Participate in This Experiment

Project Title: The Differences in Attentional Gradients Between Synesthetes and Non-Synesthetes, Identified Through Visual Search
Researcher: Kirsten Ostbirk
Faculty Advisor: Professor Thomas Hutcheon

I am a student at Bard College and I am conducting an experiment for my Senior Project. I am studying the differences in the distribution of visual attention between synesthetes and non-synesthetes.

In the first part of this study, I will ask you to indicate on a colour palette the colour you associate most with various numbers and letters. This procedure is designed to last about 8 minutes. After finishing this, you will be asked a series of questions about your experience with this procedure and the general experiences you have when reading letters and numbers. These series of questions should take about 7-15 minutes.

Within one week, you will then be emailed by me and asked to come back to complete the second part of this experiment at an agreed upon time. In the second part of this experiment, you will be asked to complete a visual search task on a computer for the duration of approximately one hour. In this task, you will be shown an array of letters and/or numbers and asked to report whether the target letter/number is present or absent. There will be 4 blocks of this task, and you will be given a break between each block.

Potential risks of participation are limited to visual fatigue from looking at a screen. If you feel any physical strain when participating, please tell me and we can take a break.

You are unlikely to receive any benefits from this experiment, though participants may gain indirectly from learning about this research once they are debriefed.

All the information you provide will be confidential. All of your information, including your data, will be kept in a password-protected computer. Your data will be identifiable only by your email, so that I can get in contact with you after part one of the study. Only my faculty advisor and I will have access to this information. When I write about this research, I will use pseudonyms and will withhold any information that could be used to identify you.

Participant's Agreement

I understand the purpose of this research and my participation in this study is voluntary. I may skip any questions or tasks that I am not comfortable with. If I want to stop participating for any reason, I may do so at any time without providing an explanation.

To the extent there are any risks, the researcher has reviewed any risks and benefits that may be associated with this study. I am aware that the information and data I provide will be used in a Senior Project that will be publicly accessible online and at Bard College's Stevenson Library in Annandale-on-Hudson, New York.

The information collected in this study is confidential and will not reveal any details about my personal identity.

If I have questions about the study, I can contact the researchers at ko8306@bard.edu. If I have questions about my rights as a research participant, I can contact the Chair of Bard's Institutional Review Board at irb@bard.edu.

I am at least 18 years of age and I consent to participate in this study.

I have been provided my own copy of this consent form.

______________________________ ____________________

Participant's Signature Date

____

Participant's Printed Name

____

Researcher's Signature

Correction: Changes to the experiment design were made after this was submitted. In practice, participants would complete 2 experiments, the first with 4 blocks, and the second with 3 blocks.

Appendix I

Debriefing Form for Proposed Experiment

Debriefing Form

Thank you for your participation, it is greatly appreciated!

Purpose of the Study:

You have previously been told that the purpose of this study is to identify the differences in the distribution of visual attention between synesthetes and non-synesthetes. Synesthesia is a benign, non-harmful condition where certain stimuli - such as letters, numbers, or sounds - evoke additional sensory experiences. An individual with synesthesia may taste ice cream when hearing a car horn, or may strongly perceive a particular colour in their mind's eye when reading the number 6. The latter example is a form of synesthesia known as grapheme-colour synesthesia, which is what I am researching. Synesthesia is thought to affect about 1% of the population, so I wanted to see if synesthetes showed any differences in how their visual attention is distributed; this is the study in which you participated.

Based on the accuracy of your responses in the task you just completed, I will try to measure the span over which your attention can be applied. In theory, the larger that span is, the larger the distribution of attention one has.

Based on your performance on Part One of the study, you may show synesthetic tendencies and fall within a particular threshold that qualifies you to be considered a synesthete for the purposes of this study. To be clear, this is not to say that you do or do not have synesthesia, but rather that your performance on these tasks fulfills predetermined criteria. Because I am not certified to diagnose anyone with synesthesia, I cannot tell you if you have this condition.

Confidentiality:

You have the right to decide whether or not you want your data to be used in this research. If you would like to have your data removed from this study and permanently deleted, please email me at ko8306@bard.edu.

Whether you agree or do not agree to have your data used in this study, you will still be entered in the raffle for a chance to win a $150 Bard Bookstore giftcard.

Final Paper:

If you would like to know the results of this study and would like a copy of this research paper, please feel free to contact me using the details listed below.

Contact Information:

If you have any questions or concerns relating to this study, please feel free to contact me by email at ko8306@bard.edu. If you have any other concerns regarding this study or if you would like to speak with someone not directly involved in this study, please contact the Chair of the Psychology Program, Sarah Dunphy-Lelii at sdl@bard.edu.

Please keep this form for future reference. Once again, thank you for your participation!