Color-grapheme synesthesia: A study of population prevalence

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Color-Grapheme Synesthesia: A Study of Population Prevalence

Christopher Hill

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JAMES MADISON UNIVERSITY

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Doctor of Psychology

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Abstract

Given the current state of the literature and weaknesses of many previous prevalence studies, the primary purpose of this research study was to gather base-rate data of color-grapheme synesthesia in a general population sample. Over a period of seven months, 502 participants enrolled in the study on Mechanical Turk and completed the online Synesthesia Battery. The primary data collected was the participant’s score on the synesthesia test, whereby a score of a one or below is deemed by the battery to be indicative of someone with a color-grapheme synesthetic ability. Of the 502 participants, eight percent (0.082) of the population sampled had scores below one, the cutoff suggestive of synesthesia on the Synesthesia Battery. This is a much higher percentage of the population than previously reported by previous studies. Exploratory analyses of demographic variables revealed some significant findings for handedness and education, such that left-handed people may have a greater representation among synesthetes than right-handed people and participants meeting the one score cutoff suggestive of synesthesia were more likely to have a graduate education.
Chapter 1

Introduction and Overview

The word synesthesia originates from the Greek as a combination of the suffix syn, meaning together, and the root, aesthesia, meaning to feel sensation. It describes the phenomena by which individuals experience uncommon sensory inputs associated with certain stimuli, such as seeing letters as being of a particular color. Synesthesia is conceptualized as an involuntary neurological ability deriving from the brain’s intermingling of senses or the experience of senses in a simultaneous manner (Sagiv, 2005).

Color-grapheme synesthesia, specifically, is an ability to perceive a specific letter and/or number as a certain color. For example, an individual might experience the letter A as being red. This simple description conceals some additional complexity. For instance, is color-grapheme synesthesia the ability to see a letter in color on the page, floating in front of the eye, or seen in the mind’s eye? To differentiate, Tyler (2005) puts color-grapheme synesthesia into two different categories. One group consists of individuals who have a genuine synesthetic experience going back to childhood. This concept would suggest that the synesthetic experience is genetically based and not better explained by associative learning. In the other group, color-grapheme synesthesia is a learned ability starting in childhood when the primary language function makes associations between letter and color. Associations of letters and colors begin at an early age, enabling children to make connections (Barnett, Feeney, Gormley, & Newell, 2009).

Along with these conceptual issues, much debate continues regarding the prevalence of color-grapheme synesthesia, and many studies using different data collection methods point to a variety of prevalence rates. Subsequent to reviewing the
literature, a number of color-grapheme synesthesia prevalence studies are discussed and critiqued for their study design, including for their use of a confounding variable and data collection strategies.

Given the current state of the literature and weaknesses of many previous prevalence studies, the primary purpose of this research study was to gather base-rate data of color-grapheme synesthesia in a general population sample. A secondary research question was to explore the rates of projector and associator subtypes of synesthesia.

The data sample was obtained via Mechanical Turk. Mechanical Turk (also known as MTurk online market) is an Amazon product that gathers data from internet participants (see Appendix B). Mechanical Turk crowd-sources (a term meaning information collection from people via the internet) tasks for internet users to complete (Overview / Requester / Amazon Mechanical Turk, n. d.).

The primary measure used to analyze the presence of color-grapheme synesthesia was the assessment at Synesthete.org, a uniform online protocol called the Synesthesia Battery. Found at http://www.synesthete.org/, the battery is open to the general public encouraging synesthesia researchers and synesthetes to utilize the assessment tool (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). According to Baron-Cohen et al. (1993), the ability to test for color-grapheme synesthesia is based on synesthetic consistency of the same letter over multiple trials. Meaning, if a letter is consistently endorsed as the same color in a reliable manner, then the measure is accurately testing for color-grapheme synesthesia. Studies utilizing a battery rather than self-report have shown to have higher validity and reliability (Simner et al., 2006).

Over a period of seven months, 502 participants enrolled in the study on
Mechanical Turk and completed the online Synesthesia Battery. The primary data collected was the participant’s score on the synesthesia test, whereby a score of a one or below is deemed by the battery to be indicative of someone with a color-grapheme synesthetic ability. Of the 502 participants, eight percent (0.082) of the population sampled had scores below one, the cutoff suggestive of synesthesia on the Synesthesia Battery. This is a much higher percentage of the population than previously reported by any other study. Exploratory analyses of demographic variables revealed some significant findings for handedness and education, such that left-handed people may have a greater representation among synesthetes than right-handed people and participants meeting the one score cutoff suggestive of synesthesia were more likely to have a graduate education.

The second question the current study attempted to address regarded the prevalence rates between projector and associator subtypes. Participants were asked about how they experience the color to letter association. Of participants who were below the one score cutoff suggestive of synesthesia (n = 28), 48% (n = 14) reported an associator subtype, 22% (n = 6) reported a projector subtype, and 30% (n = 8) reported no subtype. This finding may show that more people are of the associator subtype or that the associator subtype is more readily understood allowing for participants to choose it at a higher rate. One limitation is the participants may not have understood the differences in subtypes from the question asked in the study.

Although this study used a specific test for the purpose of assessing the presence of synesthesia, there were other limitations. These limitations include a large number of missing values in the demographic variable data. While the study collected data from over 500 participants and their color-grapheme synesthesia scores, much of the variable
data (up to 209 participants did not answer some of the variable questions) was left incomplete. Future studies should include the following best practices: gathering participants from a wide geographic area, having a large N with generalizable variables, ensuring that additional variables are kept out of research, utilization of a crowd-sourcing tool, and embedding the researcher’s questions directly into the battery.
Chapter 2

Literature Review

Synesthesia is described in the literature as a phenomenon whereby individuals experience uncommon sensory interactions associated with specific stimuli (Sagiv, 2005). According to Ferrine & Maurer (2009), there are over 54 different kinds of synesthesia, with a wide spectrum of elements and abilities. More common abilities reported by synesthetes are the association of words, letters, or numerals with color. Less common, a synesthete may have the ability to see a musical tone or have a taste sensation represented by a color. Finally, there appear to be those with rarer types of synesthesia, able to taste the tactile such as a table or a wall, or those with multiple synesthetic perceptions all at once: touching, tasting, and seeing an object with an overlap of sensation (Day, 2005).

The basic elements of synesthesia were first characterized by Georg Tobias Ludwig Sachs in 1812 (Jewanski, Day, & Ward, 2009; Simner, 2012). Later, Francis Galton, famous as the founder of psychometrics and statistical correlation, described the concept of numbers as having an almost hallucinatory state. Galton reportedly could see numbers appear before his eyes, almost as if by magic (Galton, 1881), suggesting that he may have been a synesthete. Historically, synesthesia had been dismissed by some as a fraudulent phenomenon with little to no research directed towards its elements. This conception lasted until approximately 25 years ago when the first prevalence studies were completed and basic etiological factors were investigated (Spector & Maurer, 2009).

Currently, few doubt the reality of synesthesia, as it has now been well-documented some individuals do experience uncommon sensory inputs associated with
certain stimuli, such as seeing letters as being of a particular color. Nevertheless, much remains unclear about this phenomenon, not the least of which pertain to questions about commonality. The current project seeks to add to the existing database by exploring the prevalence and nature of one particular type of synesthesia, color-grapheme synesthesia.

**Color-Grapheme Synesthesia**

Color-grapheme synesthesia is defined as an ability to perceive a specific letter as a certain color (Spector & Maurer, 2009). According to Ramachandran and Hubbard (2001), a synesthete is able to see a letter printed on a page as a certain color. In fact, the shape of the letters seems correlated with the associative color. Therefore, changes to the shape of the character, in turn, change the color experienced by the synesthete. Moreover, similarly shaped letters appear to have the same or closely related colors in synesthesia. In fact, differently shaped letters have been used to determine specific color in several well-known studies (Brang, Rouw, Ramachandran, & Coulson, 2011).

The etiological factors underlying synesthesia are an important area of research in the field. A main line of investigation concerns the extent to which the abilities are largely rooted in biology (often defined as “projectors” as described below) or arise as a learned, associative ability. One hypothesis of how synesthesia develops promotes the view that all children have neuroanatomical cross-sensory wiring and that the ability is lost due to the pruning of neurons during the maturation process. In this hypothesis, children make associations between symbols and colors much more quickly than adults. For instance, a child hears his mother’s voice, associates it with safety, and stops crying. The theory postulates that children have a synesthetic experience due to an associative learning process. As children advance into adulthood, they have a more external
experience from which to draw knowledge, and the neurons involved in this process are pruned away. In this view, the associative connections become disabled as the child ages (Simner, 2012; Spector & Maurer, 2009).

From this perspective, which has been termed the associator model of color-grapheme synesthesia, experience with commonly encountered objects, such as the alphabet that runs across the top of the blackboard (now the whiteboard) in a prototypical school classroom and ordinary flashcards, create associations between objects, colors, and letters. For example, flashcards may cause the child to learn a letter quickly, and do so by emphasizing a link between a color and a corresponding object (e.g. “A” is for apple, the apple is red). More often than not, the colors paired with the letter start with the same letter, like the letter “B” is blue, causing a learned association. For children, learning a color and an object along with the letter may create associations. Every time the child sees the object, she or he may know that the object starts with that letter. Conversely, when the color is seen then the object and letter may also be pictured (Day, 2005).

To illustrate, the letter “Y” corresponds to the color yellow for most people with synesthesia in the United States (Day, 2005). The idea here is that there is a process whereby the letter “Y” is paired with the color yellow because the word yellow starts with that same letter. An object paired with the letter “Y” could be an animal that starts with a “Y,” a yak, or a yellow dog. Despite the object being more obscure than the “A” object, an apple, the letter “Y” is almost always associated with yellow for synesthetes. The following is an example of color and letter pairings from Day (2005):

With 11 colors, if things were evenly distributed, that means that any particular
Color-Grapheme Synesthesia

letter (A, for example) would have one of these colors (red, for example) about 9.1% of the time. In my study, of 172 “colored letter” synesthetes, 43% perceive the letter A as red ($\chi^2 = 134.93$); of 123 synesthetes, 57% perceive the letter O as white ($\chi^2 = 277.37$). The letter I holds interest: of 119, 38% perceive this letter as white, 28% as black, and 12% as gray; that is, 78% perceive it as non-hued; likewise, 75% perceive the letter O as non-hued. Of 93 synesthetes, 44% perceive Y as yellow. Actually, working with the assumption of even distribution across all 11 colors, only one letter, Q, falls within parameters ($\chi^2 = 14.38$), and this might just be serendipitous (p.14).

Research suggests that most adults, synesthetes and non-synesthetes, follow the schema that A is red, B is blue, and Y is yellow, for the reasons previously stated. Yet, researchers have also uncovered regular associations that do not make clear sense from an association perspective. For example, the letter C is also often experienced as yellow, but the underlying cause of the association is not well understood (Spector & Maurer, 2009). Similarly, X and Z have been found to be associated with black and O and I white. These findings are not readily explained by the associator mode and most color-grapheme synesthetes cannot point to why colors are associated with specific letters, simply that they are associated (Spector & Maurer, 2009).

In addition, if color-grapheme synesthesia is learned via association, why would some individuals be more likely to learn it than others? Birkener, Greenlee, Karmann, and Volberg (2013) offer one idea in terms of reduced inhibition, which they claim may be “an important factor for the emergence of synesthetic colors” (p.1148). Inhibition of extraneous stimuli takes concentration. Reduction of inhibitions puts one into a relaxed
and less taxing state (Mattingly, 2009). As we reduce our inhibitions, we are more likely to see letters as colors. Intuitively speaking, as our inhibitions are low during our formative years, preschool through kindergarten, the period when letters are being learned, it is possible that children make more effortless color- to-letter associations at this developmental stage (Birkener, Greenlee, Karmann, & Volberg, 2013). This concept raises the questions about how many individuals make associations between letters and colors. In this regard, it is worth noting that Tyler (2005) was trying to understand the variety and frequency of synesthesia when he canvassed a small group of people at a conference on vision. Tyler’s questioning, which found that 8 people, representing 50% of the group, seemed to have synesthesia, and led to the speculation that possibly a large portion of the population make associations between color and letters, but is unaware of the modality unless focal attention is applied (e.g. actively thinking about their associative ability) (Tyler, 2005).

Although many researchers believe associations play a key role, it is important to note that not all researchers view synesthesia as a learned ability (Brang, Edwards, Ramachandran, & Coulson, 2008; Spector & Maurer, 2009). These researchers postulate that synesthesia begins at birth/childhood and continues into adulthood. According to this conception, synesthesia is constant throughout the lifespan and there are no developmental features to the ability. Synesthetes do not intensify nor do they gradually lose the ability as they age or mature. Furthermore, the ability seems to be utilized in work and play as it is accepted as part of the individual’s everyday life. Such an individual may believe it is a typical ability and live their life without questioning their synesthesia as it is as intrinsic to themselves as other perceptions (Brang, Edwards,
Ramachandran, & Coulson, 2008; Spector & Maurer, 2009).

Still, there are other researchers, Kadosh, Henik, and Walsh (2009) for example, who believe that both formulations are correct. Their theory, called the Interactive Specialization Approach, postulates that the underlying mechanisms come from an integrative developmental viewpoint that features a lack specialized cortical functioning. Therefore, non-synesthetes have barriers in their brains preventing cross-talk between areas of specialization and synesthetes are without such barriers (Kadosh, Henik, & Walsh, 2009).

Yet, another theory reports that many normal, healthy individuals may have a synesthetic experience a few times over the course of their lives. These experiences may be acquired from a pharmacological origin, meaning that synesthesia can be drug induced (Day, 2005). Tyler (2005) agrees, saying that a small amount of hallucinogen can make almost anyone have a synesthetic experience. The following from Day (2005) reports on the discrepancies between what is understood about synesthesia:

Although synesthesia is now generally considered to have genetic-based, biological causes, these are influenced by cultural factors. Synesthesia is, to some extent, also learned; or, rather, we might say that one learns how to be a synesthete. My research strongly suggests to me that most if not all correspondences which a given synesthete experiences are not via learned associations; however, I have encountered rare cases in which a handful of the correspondences (particularly the first four or five items in a sequence, such as the alphabet) are very evidently through childhood association (p. 17).

Ultimately, the field has yet to settle on specific terminology and has not
definitely confirmed whether synesthesia originates developmentally or congenitally. As research continues on letter to color synesthesia, subtypes of the ability are also being researched.

**Projector and Associator Types of Color-Grapheme Synesthesia**

Paralleling the etiological debate of synesthesia, the color-grapheme synesthetic experience appears to take two forms. The projector type of synesthesia may appear visually in front of the individual’s eye, superimposed upon a background and conforming to the biological or congenital theory of color-grapheme synesthesia. This experience can be described as an almost hallucinatory experience, with a color infused letter appearing visually in front of the synesthete. Another type of color-grapheme synesthesia is called the associator type, also discussed earlier, and corresponding to the associatively learned or developmental theory of color-grapheme synesthesia. In this type, the synesthete may see the colored letter in the mind’s eye (Spector & Maurer, 2009; Van Leeuwen, den Ouden, & Hagoort, 2011). To understand the differences between the subtypes, exploration of how perception emerges via the workings of the visual cortex is useful.

The visual cortex is located in the occipital lobe with six separate components. One component, the V1 area, is the primary visual cortex and is believed to have developed in evolutionary history as the first component of the entire visual system. Closely related, the V4 area of the visual cortex is employed for orientation, spatial frequency, and color, including the analysis of color. The V4 area is used for simple shapes like letters or numbers, but not for more complex shapes like faces or highly detailed art (Kolb & Whishaw, 2009; Moran & Desimone, 1985).
According to neuroscientific research, the V4 area on the left and right sides of the brain is split for synesthetes. The left V4 area seems to be utilized to sense color from wavelength, while the right V4 area is the mechanism for the synesthetic color capability, as determined by Magnetic Resonance Imaging (MRI) (Robertson & Sagiv, 2005). The right V4 area may have cross communication with other parts of the brain, specifically the Superior Parietal Lobe (SPL) involved in spatial orientation, and the Letter Space Area (LSA) a part of verbal production (Van Leeuwen, den Ouden, & Hagoort, 2011).

In line with this description of synesthetic perception, a Van Leeuwen, den Ouden, and Hagoort (2011) study, comprised of 19 synesthetes (projectors n = 14, associators n = 5), performed functional magnetic resonance imaging (fMRI) to understand the relationship between synesthesia functioning and the V4 area. After the participant’s fMRI, they were given nine distinct questions with Likert scales attached to determine the shape and location of their color-grapheme experience and whether they endorsed either a bottom-up or a top-down approach to their synesthesia. For example, questions were used to succinctly define the subtype terminology: if the “percept is really ‘out there’” (i.e. externally localized, bottom-up, projector) “or it is located ‘in the mind's eye’” (i.e. internal percept of color, top-down, associator) (Van Leeuwen, den Ouden, & Hagoort, 2011, p. 9783).

The following diagram by Van Leeuwen, den Ouden, and Hagoort (2011) illustrates the subtype concepts. The diagram portrays the synesthetic bottom-up approach, projector-type, with the LSA, located in the left fusiform gyrus (Thesen et al., 2012) activating the V4 area and the SPL activating in turn. In contrast, the associators of synesthesia have both the LSA and the V4 acting on the SPL. The following figure
delineates the proposed neural mechanism for projector and associator synesthesia (Van Leeuwen, den Ouden, & Hagoort, 2011):

As displayed in the diagram, the synesthetic associators are on the right, while the projectors are exhibited on the left. Distinction between associators and projectors is important as they delineate between etiological factors and broaden our understanding of the ability.

According to Van Leeuwen, den Ouden, and Hagoort, (2011), the model represents a bottom-up (BU) (A, red) versus top-down (TD) (B, blue) modulation by the SPL. The letter G on the model represents grapheme stimuli as input to the LSA. The D model portrays the probability of one model being better than the other model as demonstrated in the equation “r_{TD} = 1 − r_{BU}.” In this case, r signifies the likelihood of
the generated experimental information. The C and E diagrams represent the synesthesia inducing graphemes as “all parameters are larger than zero with 100.0% confidence (shaded area) across participants, within each group.” The participant views the color wavelength as a unit of the frequency measured as hertz (Van Leeuwen, den Ouden, & Hagoort, 2011, p. 9782). In detail, the approach of the “re-entrant and disinhibited feedback models propose that synesthetic sensations are caused by disinhibited feedback from higher cortical areas (e.g., in parietal lobe) failing to suppress non-relevant activation from lower cortical areas” (Carmichael & Simner, 2013, p. 563).

**Prevalence Rate of Synesthesia**

What percentage of people have color-grapheme synesthesia? To answer this prevalence question, a base rate needs to be defined. The term ‘base rate’ is defined as a set of probabilities or percentages that are referenced against the general population. For instance, if it is desirable to compare how many people have a certain habit to the general population, a base rate would be determined, which would give a percentage of people with that habit for the entire population. The base rate is a critical percentage for comparing variables within a group (Bar-Hillel, 1980; Kahneman & Tversky, 1973; Kahneman & Tversky, 1985).

The first reported color-grapheme study was completed in 1917 (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). This study required participants to report on their synesthesia and the colors they associated with each grapheme. Five years later, these same participants were asked to repeat their performance in a follow up study to determine consistency of synesthesia overtime. The researchers at the time found that the participant’s performance was consistent over time. Unfortunately, due to the more
rigorous scientific standards of today in comparison to methods in 1917, this study presents lingering questions as data on the test materials used were not recorded. For instance, did the colors used for the first and second performances of the test correspond or were they different? More questions linger regarding how this consistency test was performed. This earliest study set the stage for later problematic testing replication, including an inability to test consistency between color and graphemes, an over-reliance on self-report, and poorly constructed test batteries (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

The first modern study was completed by Domino (1989), which found a color-grapheme synesthesia prevalence rate of 23% amongst art students. This study began the accepted use of data gathering amongst art students, a seemingly popular cohort for color-grapheme synesthesia studies. One rationale for why this population may be so popular in the literature is due to art students seemingly having a higher base rate of synesthesia than the general population as synesthetes may be attracted to the arts (Domino, 1989).

While a note-worthy and groundbreaking study, the data collected may not be of much value as a prevalence study. The data was collected via self-report and not through the use of an empirical test. Moreover, a study that uses a standardized test needs to show that specific letters correspond to specific colors multiple times within the test battery.

Another prevalence study by Baron-Cohen et al. (1996), found that .05% of the population (one in two thousand people) had synesthesia from 55,000 participants who responded to a newspaper advertisement. The geographic parameters which limited the study to Cambridge, England along with this study being unfocused on color-grapheme
Color-Grapheme Synesthesia

synesthesia are problematic as it used both letters and numbers in its data collection (Baron-Cohen et al., 1996). In addition, the study used self-report methods, which has been criticized as inadequate.

A study by Simner et al. (2006), utilized a large group of participants to research multiple types of synesthesia. This study was the first to utilize a computerized method for collecting data and report that synesthesia is not likely to be correlated to sex. Their study found that one percent of the population had color-grapheme synesthesia from a sample of 1690 participants who were “opportunistically recruited” from two Scottish universities and a museum in London (Simner et al., 2006, p.1025). Furthermore, this study changed the field of synesthesia research with the use of a standardized battery becoming conventional. Despite collecting data for just letters to color, this study did not report a clear percentage. A percentage on total amount of color to letter and/or numerals was reported, rendering the figure meaningless for the current study’s purposes (Simner et al., 2006).

Another study that attempted to answer the prevalence question by Rothen and Meier (2010), found a seven percent prevalence rate amongst art students, while two percent of students in the general population (n = 96) had test scores correlated to the ability. However, due to a low sample size, these estimates are not deemed reliable (Bridges & Holler, 2007; Niles, 2006). In addition, this study incorporated numbers not just letters, allowing for a possible skew away from a synesthetic letter to color ability (Bar-Hillel, 1980; Kahneman & Tversky, 1973; Kahneman & Tversky, 1985; Rothen & Meier, 2010). In later research, the visualization process for numbers was confirmed to be different for numbers than for letters (Shum et al., 2013).
A study completed by Simner and Bain (2013) sampled 615 children not as a prevalence study, but to understand the development of color-grapheme synesthesia. The Simner and Bain computer test used, “26 letters and the digits 0–9 (i.e., 36 graphemes) alongside an electronic palette of 13 colors (black, dark blue, brown, dark green, gray, pink, purple, orange, red, white, light blue, light green and yellow)” (p. 605). Amongst developing youth, 1.3% were determined to be “genuine synesthetes” (eight synesthetes out of 615 total participants) (Simner & Bain, 2013).

Another recent study, Carmichael et al. (2015), utilized the Synesthesia Battery, the same test used in the current study. This study reviewed the validity and reliability of the battery using college students as stakeholders to collect participants. While their data was collected from the snowball recruitment of participants, they found similar percentages as previous studies as 1.2% of their participants had synesthesia for numbers or letters. Furthermore, they collected data only from self-reported synesthetes and ensured that non-self-reported synesthetes were disallowed from the study’s percentage. While their study was not a formal prevalence study, their data can still be reviewed along with other prevalence studies due to their similar methods (Carmichael et al., 2015).

In order to understand these factors in a clear and meaningful way, the following table was developed to summarize previous prevalence studies:
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Age Range</th>
<th>Methodology Used</th>
<th>Variables Used</th>
<th>Base Rate</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baron Cohen et al. (1996)</td>
<td>55,000 approx.</td>
<td>None reported.</td>
<td>Self-reported measure. No objective test.</td>
<td>Letters &amp; numbers.</td>
<td>.05%</td>
<td>Sex: Females 6:1 ratio of synesthesia.</td>
</tr>
<tr>
<td>Simner et al. (2006)</td>
<td>500 1st study; 1190 2nd study.</td>
<td>2nd study included children age 6-11 &amp; Undergrads. 2nd study 12+.</td>
<td>Computerized Test; 1st study was from self-report. No rate for letter to color synesthetes.</td>
<td>1st study Letters or numbers or other types; 2nd study Letters &amp; numbers.</td>
<td>1st Study 1.4%; 2nd Study 1.1%</td>
<td>Sex: Lack of sex bias. All Scottish Undergrads; Museum attendees.</td>
</tr>
<tr>
<td>Rothen &amp; Meier (2010)</td>
<td>99</td>
<td>No age range. Students mean age: 24.1; Controls mean age: 35.5.</td>
<td>Computerized Test.</td>
<td>Letters &amp; numbers.</td>
<td>7% in art students; 2% in controls.</td>
<td>Sex. All Swiss art students. Swiss controls from University event.</td>
</tr>
<tr>
<td>Simner &amp; Bain (2013)</td>
<td>615, then 80 child synesthetes</td>
<td>6-7; then 7/8; then 10-11.</td>
<td>Longitudinal with computer test.</td>
<td>Letters or numbers.</td>
<td>1.3%</td>
<td>Sex, age. All synesthetes.</td>
</tr>
<tr>
<td>Carmichael et al. (2015)</td>
<td>2847</td>
<td>16-90</td>
<td>Copy of Synesthetec.org and self-report of letters or numbers only.</td>
<td>Letters &amp; numbers; Letters or numbers.</td>
<td>Letters &amp; numbers .5%; Either letters or numbers 1.2%.</td>
<td>Age, sex, handedness, language. Snowball sampling. Participants without self-reported synesthesia not included in %.</td>
</tr>
</tbody>
</table>
Inadequacy of the Previous Base Rate Studies and the Purpose of the Current Study

In summary, previously described prevalence research does not define the prevalence rate of color-grapheme synesthesia due to a confounding variable, they may not be formal prevalence studies, and may focus of specific non-generalizable geography such as Baron Cohen et al. (1996), Day (2005), Simner et al. (2006), Rothen and Meier (2010), Simner and Bain (2013), and Carmichael et al. (2016) (see Chapter 5 Discussion and Recommendations for specifics), nor do the data collection techniques and utilized measures employ best practices. Best practices include using a standardized battery, including a wide geographic distribution of participants, having a large N with generalizable variables, allowing all participants to complete the battery without restricting use by self-reported lack of synesthesia, and using a crowd-sourcing method of data collection.

The Color-Grapheme Synesthesia Battery

According to Baron-Cohen et al. (1993), the valid method to test for color-grapheme synesthesia is based on synesthetic consistency of the same color to letter association over multiple trials. This means that if a letter is consistently endorsed as the same color in a reliable manner, then the measure is an accurate test for color-grapheme synesthesia. Simner et al. (2006) concluded that self-report measures are inaccurate in testing for color-grapheme synesthesia. Self-report measures share limitations including social desirability bias, poor detail recollection, and participant mood states. What is needed is an objective test that includes a measure of consistency, identifies a color-grapheme synesthesia percipient, and to measure color to letter synesthesia without confounding variables (Simner et al., 2006; Simner and Bain, 2013).
Toward that end, the battery at Synesthete.org was developed. The test is simple and direct, allowing for use by almost anyone. The battery employs a computer layout with a color-oriented test screen used multiple times to determine reliability. The Synesthete Battery uses an “extensive color palette (256 x 256 x 256 colors)” (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007, p. 104). Thus, synesthetes are able to review colors and letters with a precision not seen in other tests. A total of 16.7 million colors can be chosen to match any single letter. In detail, “the color variation for each letter ($v_j$) is measured by $v_j = \sum |x_{C1} - x_{C2}| + |x_{C2} - x_{C3}| + |x_{C3} - x_{C1}|$, $c = \{R, G, B\}$, which represents the geometric distance in RGB (red, green, blue) color space. R, G, and B values are all normalized to lie between 0 and 1. The total color variation score for a participant is $V = \sum_{j=A-Z,0-9} v_j / N$, where $N$ is the total number of graphemes for which the participant experiences synesthetic colors” (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007, p. 141).

The online protocol has been developed so that the final data form has a score that is comparable to other participant’s scores, but remains individualized to the particular participant. Scores on the battery can range from zero to five. As the study reports, these numbers are guidelines and correlate highly to synesthetic or non-synesthetic abilities, respectively. According to the creators of the battery, the cut-off score of one is a threshold and is not fool-proof. Yet, due to the battery’s test-re-test reliably, and its ability to identify “faking good” participants, the one threshold is a good estimate of synesthetic ability (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

Test objectivity is ensured through the independent use of each online protocol. That is, participants do not have the opportunity to study terminology or understand the
outcome of their answers until after the test. Moreover, each test presents colors and letters randomly, so that participants cannot share answers about which colors and letters matched (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

The Synesthete Battery has been found to make valid inferences regarding identifying synesthetes and non-synesthetic ability (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007; Carmichael et al., 2015). In a validity study, participants who identified as synesthetes (n = 15) took the battery and received a score reflecting their synesthetic ability, scores measuring as below a one. As a corollary, a control group (n = 15) was utilized with participants who self-identified as non-synesthetes, scoring higher than one listed on their results page. Thus, the cutoff score of 1 differentiated the two groups and this study adds to the evidence that the battery enables users to make valid inferences regarding individuals’ synesthetic ability (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

In addition, test-retest reliability has been substantiated. When participants were asked to rematch colors to graphemes during a retest stage set after the initial test, their matches were shown to be consistent. According to Eagleman, Kagan, Nelson, Sagaram, and Sarma (2007), “synesthetes score very well on this speeded congruency test, scoring an average of 94% correct responses with an average reaction time of 0.64 ± 0.78 s[seconds]. By contrast, non-synesthetic control participants score an average of 67% with an average reaction time of 0.91 ± 0.87 s[conds]” (p. 143). Furthermore, the Synesthesia Battery borrows heavily from previous tests constructed by Drs. Edward Hubbard and Vilayanur Ramamchandran, with reworked material to make the computer test viable and user-friendly. These scientists also showed that the battery has test-re-test reliability due
to the previous testing with the separate forms (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007; Carmichael et al., 2015).

The Development of the Current Prevalence Study

In order to understand the battery further, the author, while instructing students in his psychology class about neuropsychology and synesthesia, offered students the opportunity to complete the Synesthesia Battery. It was noted that out of approximately 40 students who took the test, about a quarter (25%) of the class reported scoring in the

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1 “The speeded congruency test. (a) After taking the consistency test (Fig. 1), participants are presented a series of trials in which a letter appears on the screen for 1 s. The letter’s color is either congruent with the synesthetic color chosen in the previous test, or incongruent. Participants answer as quickly as they can whether the color ‘matched’ or ‘did not match’ their synesthetic perception. (b) Screenshot of the test on http://www.synesthete.org. (c) Synesthetes perform at a much higher accuracy rate than controls (left panel), and do so with faster reaction times (right panel). In combination with the color consistency test, this test provides a clear distinction between synesthetes and controls, and therefore a second level of verification for synesthetic genuineness.”
range suggestive of color-grapheme synesthesia. These numbers suggested a much higher prevalence level of color-grapheme synesthesia amongst the general population than previous studies and pointed to the need for a larger, more comprehensive collection of data.

Regarding subtypes of color-grapheme synesthesia, the battery does not necessarily differentiate associators and projectors. Instead, that information would have to be gathered in a questionnaire associated with the battery from an outside source. Participants with valid scores for color-grapheme synesthesia could submit subtype designations to ensure validity as part of a variable screening (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). A formal measure was not developed to determine associators from projectors. Some past studies have used self-report and have asked multiple questions to get to this answer. While many previous studies report that asking multiple questions is better, there is no standardized questionnaire to identify and differentiate subtypes. This study employed the Synesthete Battery to address the base rate/prevalence question because it has not been adequately answered in previous studies.
Chapter 3

Method

Design Overview

The primary goal of this study was to obtain a reasonable estimate of the prevalence of color-grapheme synesthesia, specifically letters to color, as measured by the Synesthesia Battery. To achieve this goal, the researcher set out to have at least 500 individuals take the Synesthesia Battery via the Amazon product Mechanical Turk (described below). The number of participants was limited from a monetary basis. An incentive of $0.50 from the primary researcher’s personal fund was offered to the participants to complete the battery. Data was collected from April 2015 to December 2015 when the goal of 500 participants was reached.

This research study was non-experimental. All data was collected following Institutional Review Board approval from the James Madison University Internal Review Board. Data was collected utilizing Mechanical Turk, as it was more generalizable than other modes of data collection and captured a large number of participants quickly. The Synesthesia Battery was utilized because it was deemed to be the most reliable and sound assessment of color-grapheme synesthesia available, continues to be used in synesthesia research, due to its internet accessibility, and thus, could be completed by Mechanical Turk workers in an efficient manner.

Participants

A total of 502 individuals participated in the study. Unfortunately, complete variable data was not collected on all participants. While 293 participants provided complete information, the variable questions were not embedded on the Synesthete.org
site. Therefore, a participant could finish the Synesthete Battery without fully completing the variable data section of the study. Hence, the participant could view their score, believe from the reported score listed on the site that they had fully completed the HIT, and not provide the necessary variable data. Despite the missing data being, all collected data was analyzed and reported.

**Procedure**

**Amazon’s Mechanical Turk**

The study utilized Mechanical Turk, also known as MTurk online market, an Amazon product to gather data from internet participants (see Appendix B). Mechanical Turk crowd-sources tasks, known more simply as internet user data collection. The individuals who create a task are called requesters (in this case the requester is the primary researcher) who post a Human Intelligence Task (HIT), like “choosing the best among several photographs of a storefront, writing product descriptions, or identifying performers on music CDs” (Overview /Requester /Amazon Mechanical Turk, n.d.).

For our task, the worker (the Mechanical Turk term for the participant carrying out the task) completed the color-grapheme section of the Synesthete Battery and answered specific variable questions as described in the cover sheet on the HIT including age, gender, country of origin, primary language, education level, handedness, and subtype of synesthesia consisting of projector, associator, or neither.

The primary researcher placed the HIT on Mechanical Turk once the project was approved by the IRB Committee. A monetary reward was added to encourage workers to perform the task that came from the primary researcher’s personal funds. The primary researcher paid a $0.50 reward for each completed task to ensure that 500 +/-
participants’ data was captured (Overview /Requester /Amazon Mechanical Turk, n.d.). Not all participants received the incentive. Only the participants who completed the battery and answered the variable information in full received the $0.50 reward.

The Measure

The Synesthesia Battery, located at Synesthesia.org, is an online protocol. The data collected quantitative information as the participant’s score on the synesthesia test was either below or above a one. These scores correlate to the participant’s synesthetic ability (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

The Synesthesia Battery, found at http://www.synesthete.org/, is open to the general public with synesthesia researchers and synesthetes encouraged to utilize the assessment tool. The following is an explanation on the website for use of the test:

This battery of tests provides a standard battery of questions, tests and scoring. This test is available to the whole community of researchers and synesthetes for their use in making scientific progress. Your data will be kept entirely private, for use only by yourself, and by a researcher (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

In total, the synesthesia test utilizes 80 questions and takes about 10 minutes to complete. Each question requires a quick, one tap response allowing for brevity of utilization. While the test screens for as many as 20 different types of synesthesia, the proposal question is designed so that the worker will take the color-grapheme synesthesia battery and exclude the other available batteries. The color-grapheme synesthesia battery presents a letter on the computer screen and the participant identifies it as a specific color.

The following picture from Eagleman, Kagan, Nelson, Sagaram, and Sarma
Color-Grapheme Synesthesia (2007, p. 141), is a representation of the test:

The top left picture is an exact representation of the color-grapheme test with the letter “T” presented and colors ready for accurate matching. The possible synesthetic response is compared with controls. Finally, a printable copy of the scores is ready for access by the researcher once the test has been completed (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

The final score, based on how reliably a participant identifies a particular color with a letter, is compared to one with any number under one, .82 for instance, indicating that the participant’s score is positively correlated to synesthesia. A number over one

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2 “Fig. 2. Color match consistency testing. (a) Participants are presented with randomly ordered graphemes a total of three times each (108 trials). Using a color palette, participants choose the color that best matches their synesthetic space between their three answers. Controls were asked to fake synesthesia, which allowed for strategies like free association and associative memory. Controls (right) are much less consistent in their matching than self-reported synesthetes (left). (c) On http://www.synesthete.org, each subject’s report is accompanied with a graphical layout of the results and autoFMRIc scoring. Shown are screenshots from a representative synesthete and a non-synesthetic control. (d) Summary data from 15 self-reported synesthetes and 15 control participants. All synesthetes scored below 1.0 in their consistency score, while controls had more variance in their color choices” (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007, p.141).
indicates that the participant does not have a score that positively correlates to synesthetic ability (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

The test rates the user from zero to five as a consistency score. The consistency score is determined through the matching of colors to grapheme (Carmichael et al., 2015). The battery's score is calculated by “the geometric distance in RGB (red, green, blue) colour (sic) space, where R, G, and B values are all normalised (sic) to lie between 0 and 1” and the participant’s consistency with that geometric distance over the tests (Carmichael et al., 2015, p. 378). As previously stated, “the color variation for each letter \(v_j\) is measured by \(v_j = \Sigma |x_{C1} - x_{C2}| + |x_{C2} - x_{C3}| + |x_{C3} - x_{C1}|, c = \{R, G, B\}\), which represents the geometric distance in RGB (red, green, blue) color space. R, G, and B values are all normalized to lie between zero and one. The total color variation score for a participant is \(V = \Sigma_{j=\{A-Z,0-9\}} v_j / N\), where \(N\) is the total number of graphemes for which the participant experiences synesthetic colors" (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007, p. 141). Therefore, the geometric distance is measured through the test scores and then averaged out to create an overall score. The zero score is a 100% match between all graphemes and color. Each number higher than zero portrays a lower synesthesia score with a score over one indicating a probable lack of synesthesia. Scores higher than the one cutoff are not suggestive of synesthesia (Carmichael et al., 2015).

The lower bound of the test, zero, indicates that there is no discrepancy in color choice for each letter. The value zero to one indicates that the participant is likely a synesthete, whereas values of 1.1 and above indicate that the participant is not likely a synesthete. Discrepancy is defined by how each color is assigned to each letter through the matching process. The upper bound of two to five indicates that there is complete
discrepancy in color choice for each letter on the test. Therefore, the closer a participant’s score is to zero, the higher in significance the participant’s level of synesthesia. As previously discussed, the creators of the test use the one threshold for diagnosis, which was driven by data collected in pilot use of the battery (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007).

**Ethical Standards**

Our study was submitted to the JMU IRB and approved in April 2015. All research was conducted through Mechanical Turk as it was the most efficient method of collecting data from a large number of diverse participants. All answers to the test were password protected. Only the participant and the primary researcher had access to the results. In order to preserve confidentiality and ensure anonymity, no names or identifying information were used. Participation in the research study was voluntary.

**Database Management**

All data was gathered through the use of the synesthesia test utilized by the primary researcher and recorded in an excel spreadsheet without identifying information. The battery was a data collection tool used by the primary researcher analyzing data from synesthetes. Moreover, the test was constructed by the aforementioned creators of the battery as a valid and reliable data-gathering tool available for use by outside researchers.
Chapter 4

Results

The primary research question of interest for this study was on the prevalence of color-grapheme synesthesia in the general population. According to studies of the Synesthesia Battery, a score of less than one on the battery is indicative of color-grapheme synesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Of the 502 participants who contributed to the study, eight percent (n = 41) scored below a one. This is a higher percentage of the population than reported in previous prevalence studies (0.05% to 2%), raising a number of questions (Simner et al., 2006; Carmichael, & Simner, 2013).

A histogram created from the data portrays the distribution of participants’ scores on the Synesthesia Battery (see Figure One). The distribution of Synesthesia Battery scores (n = 502, M = 2.25, SD = .74) for the sample appears to be univariate and normally distributed. The skewness value (-.473) did not exceed an absolute value of two and the kurtosis value (.415) did not exceed an absolute value of seven (Curran, West, & Finch, 1996; Finney & DiStefano, 2006). It is worth noting that the distribution is not definitively bimodal. If synesthesia is a unique capacity that only some individuals have in full, whereas others do not have at all, then the distribution of the scores would have a more bimodal shape. The scores as given are more suggestive of a continuum, at least as it is measured by this test. However, any test of a complex variable can have multiple determined factors, which will give rise to a bell-shaped curve. The remainder of the research questions pertained to whether or not any personal or demographic variables were associated with scores on the Synesthesia Battery.
Age

As noted previously, demographic and personal variable data were missing for some participants. For the 293 participants who provided age data, the range was from 18-67, with two 18 year olds representing the youngest participants and one 67-year-old being the oldest. The mean age was 31.34 (SD = 13.14). A correlational analysis was computed to examine the relationship between synesthesia score and age for those who provided age information. The results show a non-significant relationship between score and age, \( r(291) = .059, p = .316 \), two-tailed.

Gender

For participants reporting gender (58 %), the sample had more female participants (n = 214) than male (n = 79) participants. Nearly three-quarters of the sample self-reported as female while approximately a quarter of the participants who self-reported on gender identified as male. No subject reported outside the gender binary, despite the variable question simply asking for gender and without framing it within a male and female dyad. MTurk does not report gender percentages of their workers (Overview / Requester / Amazon Mechanical Turk, n. d.), so there is no basis for comparison.

An independent t-test (see Table One) failed to reveal a statistically significant difference between the mean scores of males (\( M = 2.24, SD = .78 \)) and females (\( M = 2.19, SD = .72 \)), \( t(291) = .476, p = .63 \), suggesting males and females did not differ significantly on their synesthesia scores. Levene’s test indicated equal variances, \( F = .919, p = .34 \).
**Country of Origin**

Participants from the United States made up 85% of the sample (n = 250). Participants from India followed with nine percent (n = 27). Canada, Germany, and the United Kingdom respectively had two participants complete the battery, each contributing one percent of the total sample. Beyond these nations, 13 more countries had one participant complete the battery. Sixteen countries in total were represented in the study with as few as one subject coming from countries as geographically distant as Albania and the Philippines. In total, 15% of participants came from countries other than the United States.

For participants reporting scores below the one score cutoff suggestive of synesthesia, only two came from outside of North America. One participant was from Iran and the second from India. Twenty-five individuals from the United States of America (89%) and one Canadian reported scores below the one score cutoff suggestive of synesthesia. No additional comparisons were made do to the dramatically unequal sample sizes across the countries.

**Level of Education**

Participants with bachelor’s degrees made up the greatest proportion (35%) of those self-reporting their highest level of education. Seven percent of participants reported having a high school diploma, 35% reported having attended some college, 19% had a master’s degree, and three percent had a doctoral degree. These data are largely consistent with general census data collected in the US, although there were more participants with master’s degrees than found in the general population (approximately 12%).
An analysis of the Synesthesia Battery scores was completed based on level of education
(n = 293) (see Table Two) for high school graduate (M = 2.39, SD = .63), some college (M = 2.24,
SD = .69), bachelor’s degree (M = 2.22, SD = .75), master’s degree (M = 2.05, SD = .79), and
doctoral degree (M = 2.03, SD = .75). An ANOVA (see Table Three) was conducted too
compare mean scores based on the differing levels of participant education. No
significant differences were found, $F(5, 287) = 1.02, p = .406$.

Of the 29 participants that reported data on their highest level of education and
scored below the cutoff suggestive of synesthesia, those with bachelor’s degrees again
had the highest proportion of the sample, with 35% (n = 10). Furthermore, high school
graduates accounted for four percent (n = 1), some college reported as 24% (n = 7),
master’s degrees counted as 31% (n = 9), and doctoral degrees accounted for seven
percent (n = 2).

Because higher degrees seemed more prominent in those who reported scores
below the one score cutoff suggestive of synesthesia than those who did not (see Figures
Three and Four), an ANOVA (see Table Four) was conducted that compared differing
levels of education on reported scores below the one score cutoff suggestive of
synesthesia. The data analysis did not reveal a statistically significant difference, $F(5, 23)$
$= .97, p = .456$.

However, because this is an exploratory study, another analysis was conducted.
Individuals were dichotomized on the presence (or not) of graduate education and the
presence (or not) of synesthesia as defined as scoring below the 1 cutoff score. This time,
A 2 x 2 Chi-square analysis was run and a significant interaction was found, $\chi^2 (1) =$
4.62, \( p = .032 \), the odds ratio is 2.38. This analysis is suggestive of the possibility that those with higher education are more likely to exhibit synesthesia.

**Handedness**

For handedness, of the 440 participants who reported on this variable, 84% (n = 369) reported as being right-handed while 11 percent (n = 47) reported being left-handed and five percent (n = 24) reported being ambidextrous. This distribution is consistent with the general population (Holder, 1997). For participants who scored under a one on the battery and reported data for handedness (n = 37), 70% were right-handed, 24% were left-handed, and about five percent were ambidextrous.

An analysis of mean scores was conducted based on handedness (see Table Six). As displayed in the table, the participants’ mean scores were clustered around a score of two (Right \( M = 2.25, SD = .71 \); Left \( M = 1.99, SD = .84 \); Ambidextrous \( M = 2.37, SD = .64 \)). An ANOVA (see Table Seven) was conducted that examined the effect of handedness on synesthesia score and found statistical significance, but with a small effect size, \( F(2, 437) = 3.12, \ p = .045, \eta^2 = .014 \). A Bonferroni’s post-hoc test was conducted for all pairwise contrasts and no findings emerged that were statistically significant.

Because this is an exploratory study, additional analyses were done on this variable to determine where the effect may lie. A Chi-square analysis was run with handedness placed as a dichotomous variable (right-handedness and left-handedness), along with the presence of synesthesia (again defined by the 1 or below cutoff score). A significant effect was found, \( \chi^2 (1) = 7.925, p = .005 \), the odds ratio is 0.32 (see Table Eight). The results are suggestive that individuals who are left handed are more likely to score as having synesthesia.
Synesthesia Subtypes

In addition to exploring scores on the Synesthesia Battery, this study sought to investigate self-reported projector or associator subtypes. Data was gathered on the following question: “Do you have associator or projector subtype of color-grapheme synesthesia (or neither)? These groups are defined by the following: the projector subtype means a letter is superimposed upon a background in an almost hallucinatory manner; the associator subtype may only see a letter in their mind’s eye.” For participants who were below the one score cutoff suggestive of synesthesia (n = 28), 48% (n = 14) reported an associator subtype, 22% (n = 6) reported a projector subtype, and 30% (n = 8) reported no subtype. For the variables of subtype and scores below the one cutoff suggestive of synesthesia (See Table Nine), the means were clustered around .7 as reported by the following subtypes: associator (M = .79, SD = .17), projector (M = .71, SD = .16), and neither (M = .79, SD = .27).
Chapter 5
Discussion

The primary purpose of this study was to gather base-rate data of color-grapheme synesthesia in a general population sample. As reviewed, a variety of different prevalence rates have been reported by previous synesthesia studies. This current study made design changes unmatched in the previous literature leading to a new set of results.

In order to determine the general prevalence of color-grapheme synesthesia, the decision was made to use Mechanical Turk, which is an Amazon product that gathers crowd-sourced data and directs participants to the uniform online assessment measure (Overview / Requester / Amazon Mechanical Turk, n. d.). This online tool was deemed to have advantages, which included the ability to canvass a wide geographic area with a diverse group of people in a simple and direct manner.

As discussed in the literature review, self-report of synesthesia abilities is not as widely accepted in the field as other data collection methods. As such, the current study employed as its primary assessment, the Synesthesia Battery. This assessment was chosen because of its ability to be accessed from instructions embedded onto Mechanical Turk, ease of use, and capacity to provide the primary researcher with data from which to determine a population percentage.

Five hundred and two participants enrolled in the study and completed the Synesthesia Battery via the MTurk interface. As noted, according to the Synesthesia Battery protocol, a score of one or less is suggestive of synesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Of the 502 participants who contributed to the study, eight percent (0.082) scored below a one on the battery. If a cutoff score of one is
genuinely indicative of synesthesia, then the conclusion from the present study is that there is a much higher percentage of synesthetes than found in the previous prevalence studies.

The incongruity between previously reported prevalence rates and the study’s figure of eight percent raises questions regarding the source of the discrepancy. The study’s limitations (See Limitations section) along with three differences this current study had from previous research may account for the discrepancy. Those three factors are: 1) a confounding variable, specifically the combination of letters and numbers in previous studies’ prevalence data that may have led to an overall lower percentage; 2) the data collection methods; and 3) allowance versus disallowance of participants in the study to complete the Synesthesia Battery due to a self-report of a lack of synesthesia (described in detail below).

The current study focused only on letters. However, unlike the current study, several other studies such as Domino (1989), Baron Cohen et al. (1996), Day (2005), and Rothen and Meier (2010), used both numbers and letters data to calculate their prevalence percentages. Although there are some justifications for the use of both numbers and letters, the argument here is that there is no particular reason as to why an individual must have a synesthetic experience with numbers to classify as having color-grapheme synesthesia. As such, the current study only used letters, which may have been a factor in why this study’s prevalence rate was higher.

A second factor that might account for the difference in prevalence rates is data collection. One major challenge of several previous studies was how they accrued participants as snowball sampling and canvassing a group of students seems to have been
the norm for previous studies (Domino, 1989; Simner et al., 2006; Rothen & Meier, 2010; Carmichael et al., 2015). In particular to this issue, the Carmichael et al. (2015) study is worthy of detailed analysis as it is essentially a base rate study using some of the same methodology as this study, includes the use of the Synesthesia Battery, and does not use a confounding variable (e.g. numbers) for their prevalence scores. Furthermore, the Carmichael et al. (2015) used a much higher N as they collected data from 2,847 participants, while the current study only included 502. Also, their study collected a wider range of ages from 16 to 90 as opposed to this study’s 18 to 67 years old. Far and away, the Carmichael et al. (2015) study is the most rigorous to report data on synesthesia prevalence.

Carmichael et al. (2015) pre-selected participants from a localized area around the University of Edinburgh by undergraduate students, which might raise questions regarding the generalizability of their results beyond a similar localized sample. The present study’s sample came from a crowd-sourcing mechanism, which may have allowed for greater generalizability across a larger geographic scope. Unlike the present study, the Carmichael et al. (2015) study utilized snowball sampling to collect data in that they used undergraduates at the University of Edinburgh as stakeholders to pre-select participants. The snowball sampling technique may have been biased due to attraction of like participants and could have caused a lack of variation from the data pool (Salganik & Heckathorn, 2004). As undergraduates were to pre-select people, it may be likely that they choose friends and relatives, which may have limited the genetic scope of their study, i.e. possibly collecting similar people without the genetic structure to allow for the presence of synesthesia. Moreover, the more limited geographic area in the Carmichael et
al. (2015) study may cause challenges for generalizing out beyond education, nationality, and culture.

Finally, another challenge for the Carmichael et al. (2015) study is the following: “If participants indicated that they saw neither letters nor numbers in colour (sic), they advanced to an early-exit page thanking them for their participation. The rest of the test was completed by participants who answered in the affirmative to having coloured (sic) letters/digits.” Meaning, the Carmichael et al. (2015) study disallowed 2707 participants and only allowed 140 to complete the Synesthesia Battery, creating a lower number of overall participants who completed the Synesthesia Battery than this study. By limiting the study, Carmichael et al. (2015) may have reduced the number of participants who could still have color-grapheme synesthesia and may not have known it. The argument here is that by disallowing participants in the Carmichael et al. (2015) study from completing the full battery, a lower percentage of color-grapheme synesthetes may have been reported than if the full complement of participants was assessed. The reasoning is such that the current study avoids the Carmichael et al. (2015) study’s false negatives.

Data Analysis

In addition to gathering general prevalence data, this study examined a number of demographic variables to determine if any statistically significant differences were observed. The variables reported by the participants included age, language, gender, level of education, country of origin, handedness, and subtype of synesthesia including associator or projector subtypes. An analysis of the variables was completed, yet only handedness and level of education had significant results.

As noted in the literature review, there are reasons to believe that handedness is
connected to the presence of synesthesia as it is related to the location of language function and its effect on memory (Noroozian, Minagar, & Khalaj, 2014). Because of this research, we explored the issue and found some evidence for a higher rate of synesthesia in left handed individuals, but the strength of the effect was tenuous. Primarily, the data collected aligned with Holder’s (1997) general population percentages for handedness and had the following results: 84% of study participants reported being right-handed, 11% left-handed, and six percent ambidextrous. While the handedness data was found to be statically significant, it had a low effect size and the post-hoc test did not detect significance.

Further data analysis revealed that triple the number of left-handed than right-handed participants met the cutoff score suggestive of synesthesia. This analysis leads to the possibility of left-handed people having a greater representation among synesthetes than right-handed people. Of course, the analysis could be effected by low participant turnout as left-handed people accounted for 47 out of 416 participants reporting on handedness.

Education was another demographic variable examined by the study. For education, those participants who met the one score cutoff suggestive of synesthesia were more likely to have a graduate education than those who did not. The odds of having a graduate education, according to the data, are 2.38 times greater in synesthetes compared to non-synesthetes, again pointing to a possible link between advanced education (perhaps as a proxy for intelligence) and synesthesia. Data on graduate education versus non-graduate education has not been observed previously in the empirical synesthesia literature. Furthermore, a low number of participants (n = 29) reported on this
demographic variable and had below the one score cutoff suggestive of synesthesia. Graduate education may be associated with higher rates of synesthesia, but more research is needed as the evidence gathered does not point to why this association may exist.

Data were also collected regarding prevalence rates between projector and associator types. To obtain these data, participants were asked a question that directly assessed their experience regarding the color to letter association. Of participants who were below the one score cutoff suggestive of synesthesia (n = 28), 48% (n = 14) reported an associator subtype, 22% (n = 6) reported a projector subtype, and 30% (n = 8) reported no subtype. This finding may show that more people are of the associator subtype or that the associator subtype is more readily understood allowing for participants to choose it at a higher rate. However, it must be acknowledged that the participants may not have understood the differences in subtypes from the question asked in the study as it was shortened for brevity’s sake, ultimately leading to a weak variable.

Beyond the aforementioned demographic variable data, there remain challenges for how to conceptualize synesthesia. According to the previously discussed histogram (see Figure One), which reports on the cutoff score, the distribution does not appear to be bimodal. In other words, the distribution does not to appear to have two different means. If synesthesia is a unique capacity that only some individuals have, it could well be argued that the distribution of scores should be bimodal. In contrast, if synesthesia is viewed as perception in that some people have a greater ability than others, much like some people have better hearing than others, then synesthesia would fall along a continuum. Synesthesia is currently characterized in the literature mostly as a dichotomous ability. It is worth noting that the data from this study appeared as more of a
continuum than a bimodal distribution. This could well stem from how the test measures the phenomena, and the extent to which multiple factors might contribute to the score, which will yield more of a smooth data curve. Additional discussion and research into whether or not the phenomena is considered as a continuum or a categorical ability may be warranted.

**Limitations**

This study encountered a number of challenges that make the interpretation of the findings difficult. With regards to data collection, 502 participants contributed data. This figure was limited due to monetary constraints. Of course, more participants would have been optimum and may have allowed for a larger amount of data to be collected. Furthermore, as synesthesia prevalence studies are now using more participants, this study should have aligned with those best practices, as described later in the limitations section.

As with all samples there were selection biases in this study. For instance, the study’s monetary reward changed from no reward (zero participants), to a $0.10 reward (four participants), to a $0.50 reward (all other participants who received the monetary reward). This increase in funds was offered as participants were not taking the battery in a timely manner. Once the monetary reward was increased to the full $0.50, the number of participants began to flow at a more adequate pace. None of the data collected from the participants with the $0.10 reward were used in the study.

Another challenge to the study’s data collection may have been the primary researcher’s misunderstanding of Mechanical Turk. Mechanical Turk believed that the fake email addresses used by the participants to access the Synesthesia Battery could be
utilized as identifying information. As a result, Mechanical Turk shutdown the study’s data collection for two weeks. None of Mechanical Turk’s rules on personal information were violated and the study’s IRB approved cover page, which was affixed to the HIT, ensured protection of identifiable data. After a two-week break, the study was allowed to continue utilizing Mechanical Turk.

Demographic variable data was limited, as only a subset of our total population reported this information. Additionally, age range was limited as individuals under the age of 18 were not permitted to use the Mechanical Turk site. Furthermore, a participant would need to be computer savvy to complete the HIT, meaning that those without the proper computing backgrounds may have been unable to complete the battery. These limitations raise questions about the extent to which the sample generalizes to the broad population.

Another study limitation included the subtype question put to the participants. In retrospect, the question could have been worded in a more informative and user-friendly way. Many of the participants may not have had any previous experience with synesthesia. In fact, this battery may have been their first exposure to this construct that they had come to understand in their own terms and, therefore, may have had challenges interpreting the subtype question.

Due to the aforementioned issues with the study, further research is needed to understand the meaning and relevance of the eight percent prevalence rate.

**Future Directions**

The main question raised by this study pertains to why eight percent of the population was found to be under the cutoff score. Given that the Carmichael study
eliminated everyone who did not self-report any synesthetic tendencies, an important question is raised about the potential of participants that would answer “no” to the self-report question, but would score beneath the cutoff. The findings here suggest there are quite a few of those participants, which raises the question of exactly what this means. Is it the case that the battery can yield false positives? Or are those who do not identify actually false negatives? Future research should explore this issue.

In addition, this study only tested for color-grapheme synesthesia, which begs the question: What about the prevalence of all other types of synesthesia? For that reason, further research should be completed to determine the prevalence rate of other types of synesthesia.

This study yielded weak suggestions that maybe handedness and graduate education were associated with color grapheme synesthesia. Additional research focused on demographic variables, including a possible measure of intelligence as correlated to synesthesia, may prove enlightening.

Towards this similar end, more data may need to be gathered to ensure that synesthesia subtypes are more meaningfully and completely understood. As some participants reported having projector or associator subtype synesthesia, but did not report scores below the one score cutoff suggestive of synesthesia, they may have misunderstood the question or interpreted the question differently than intended, leading to self-report error. The participants may have been unable to interpret the question as they did not have experience with synesthesia previously. In contrast, they may have falsely believed they had synesthesia. Therefore, proper definitions of associator and projector types of synesthesia should have been made available for the participants. In
addition, multiple questions may have been helpful in yielding more complete data as that system of questioning was used in previous studies in determining participant subtype.

Further research into subtypes of color-grapheme synesthesia may be helpful to comprehend how subtypes work, how the synesthete understands their subtype, and the possibility of switching between subtypes. Data on subtypes may assist synesthetes to understand their abilities. Canvassing a group of color-grapheme synesthetes to understand how they would describe their subtype would be helpful.

Furthermore, evidence of the differentiation between subtypes may allow for a clearer understanding of Tyler’s (2005) two etiological categories. One group is theorized to consist of individuals who had a genetic synesthetic experience (the projector subtype), while the other group purported that color-grapheme synesthesia is a learned ability (the associator subtype). More research into the etiological factors that establish subtypes and how they interact with environmental factors may be a useful goal for scientific research.

As previously mentioned, another challenge for this study was the one score cutoff suggestive of synesthesia on the Synesthesia Battery. Ultimately, this study calls into question whether the one score cutoff is meaningful due to a mix of data pointing toward a potential continuum of ability or a possible binary, i.e. synesthesia or lack of synesthesia. Perspective of the ability may reinforce either position. Further analysis of the Synesthesia Battery and development of batteries to test synesthesia is encouraged as this study cannot point to either position with complete assurance. A third possibility, that synesthesia is both a continuum and binary, depending on perspective, may also be explored in further research.

In addition, the best practices for prevalence research into color-grapheme
synesthesia is encouraged. As reported by Simner et al. (2006), prevalence studies should not use self-report, but instead utilize standardized test batteries (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007; Carmichael et al., 2015). Further best practices include gathering variable information from a wide geographic area, and having a large N with a representative population. Moreover, allowing all participants to complete a battery despite self-report of absence of synesthesia may be optimum.

These best practices could employ a crowd-sourced data collection tool as an efficiency standard instead of snowball sampling. In the future, the researchers should be aware of challenges with their crowd-sourcing tool, communicating with Mechanical Turk, and other relevant players before events become problematic. Furthermore, clear communication with the HITs on how to complete the study and the variable questions would be optimal.

Finally, another best practice could include imbedding variable questions directly into the Synesthesia Battery for the participants to complete. A further constraint on the participant’s completion of the study is that data would be input directly into the battery or a score would not be calculated. In this case, the participants would not be able to ignore the query for variable data and would be compelled to complete the variable information. In sum, these aforementioned best practices could allow for more stringent, yet more thorough, demographic variables and prevalence data to be collected in the future, filling in the gaps in the field’s understanding of synesthesia.

**Conclusion**

As previously noted, the primary research question was on the prevalence of color-grapheme synesthesia in the general population. Of the 502 participants who
contributed to the study, eight percent (n = 41) scored below a one on the Synesthesia Battery. These data raise some interesting questions about the true prevalence, as it is important for the field to move forward with precision and accuracy in further study of this exciting phenomenon.
References


Baron-Cohen, S., Johnson, D., Asher, J., Wheelwright, S., Fisher, S. E., Gregersen, P. K.,


Methods, 159(1), 139-145.


97. doi:10.1037/h0043158


doi:10.1080/10673220902979896


doi:10.1038/nrn2022


Table 1

*Means and Standard Deviation on the Measure of Synesthesia Score as a Function of Gender*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2.24</td>
<td>79</td>
<td>.78</td>
</tr>
<tr>
<td>Female</td>
<td>2.19</td>
<td>214</td>
<td>.72</td>
</tr>
<tr>
<td>Total</td>
<td>2.20</td>
<td>293</td>
<td>.73</td>
</tr>
</tbody>
</table>

*Note.* For missing variables N = 209. Total participants N = 293.

Table 2

*Means and Standard Deviations on the Measure of Synesthesia Score as a Function of Education Level*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School Graduate</td>
<td>2.39</td>
<td>20</td>
<td>.63</td>
</tr>
<tr>
<td>Some College</td>
<td>2.24</td>
<td>105</td>
<td>.69</td>
</tr>
<tr>
<td>Bachelor’s</td>
<td>2.22</td>
<td>103</td>
<td>.75</td>
</tr>
<tr>
<td>Master’s</td>
<td>2.05</td>
<td>55</td>
<td>.79</td>
</tr>
<tr>
<td>Doctorate</td>
<td>2.03</td>
<td>10</td>
<td>.75</td>
</tr>
<tr>
<td>Total</td>
<td>2.20</td>
<td>293</td>
<td>.73</td>
</tr>
</tbody>
</table>

*Note.* For missing variables N = 209. Total participants N = 293.
Table 3

*One-Way Analysis of Variance of Education Level by Synesthesia Score*

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>2.73</td>
<td>5</td>
<td>.55</td>
<td>1.02</td>
<td>.41</td>
<td>.02</td>
</tr>
<tr>
<td>Error</td>
<td>153.66</td>
<td>282</td>
<td>.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>156.39</td>
<td>287</td>
<td></td>
<td>.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* For missing variables N = 209. Total participants N = 293.

Table 4

*One-Way Analysis of Variance of Education Level with a One Score Cutoff by Synesthesia Score*

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>.18</td>
<td>5</td>
<td>.04</td>
<td>.97</td>
<td>.46</td>
<td>.17</td>
</tr>
<tr>
<td>Error</td>
<td>.85</td>
<td>23</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.03</td>
<td>28</td>
<td></td>
<td>.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* For missing variables N = 474. Total participants N = 29.
Table 5

*Crosstabulation of Education Level and One Score Cutoff Suggestive of Synesthesia*

<table>
<thead>
<tr>
<th>Education Level</th>
<th>No Graduate Education</th>
<th>Graduate Education</th>
<th>$\chi^2$</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above a 1</td>
<td>210</td>
<td>54</td>
<td>4.62*</td>
<td>2.38</td>
</tr>
<tr>
<td>Below a 1</td>
<td>18</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. *$p < .05$.*

Table 6

*Means and Standard Deviations on the Measure of Synesthesia Score as a Function of Handedness*

<table>
<thead>
<tr>
<th>Handedness</th>
<th>Mean</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>2.25</td>
<td>369</td>
<td>.71</td>
</tr>
<tr>
<td>Left</td>
<td>1.99</td>
<td>47</td>
<td>.84</td>
</tr>
<tr>
<td>Ambidextrous</td>
<td>2.37</td>
<td>24</td>
<td>.64</td>
</tr>
<tr>
<td>Total</td>
<td>2.23</td>
<td>440</td>
<td>.73</td>
</tr>
</tbody>
</table>

*Note. For missing variables N = 62. Total participants N = 440.*
### Table 7

*One-Way Analysis of Variance Handedness with a One Score Cutoff by Synesthesia Score*

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handedness</td>
<td>3.25</td>
<td>2</td>
<td>1.62</td>
<td>3.12</td>
<td>.045</td>
<td>.01</td>
</tr>
<tr>
<td>Error</td>
<td>227.69</td>
<td>437</td>
<td>.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>230.95</td>
<td>439</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. For missing variables N = 62. Total participants N = 440.

### Table 8

*Crosstabulation of Handedness and One Score Cutoff Suggestive of Synesthesia*

<table>
<thead>
<tr>
<th>Handedness</th>
<th>Left</th>
<th>Right</th>
<th>$\chi^2$</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above a 1</td>
<td>38</td>
<td>343</td>
<td>7.93*</td>
<td>3.13</td>
</tr>
<tr>
<td>Below a 1</td>
<td>9</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. * $p < .05$. 
Table 9

*Means and Standard Deviations of Score and Subtype*

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Mean</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associator</td>
<td>.79</td>
<td>14</td>
<td>.17</td>
</tr>
<tr>
<td>Neither</td>
<td>.79</td>
<td>8</td>
<td>.27</td>
</tr>
<tr>
<td>Projector</td>
<td>.71</td>
<td>6</td>
<td>.16</td>
</tr>
<tr>
<td>Total</td>
<td>.77</td>
<td>28</td>
<td>.19</td>
</tr>
</tbody>
</table>

*Note.* For missing variables N = 474. Total participants N = 28.
Figure 1.
Figure 2.

![Synesthesia Score](image)
Figure 3.
Figure 4.
Appendix A.

The following is a step-by-step user’s guide to The Synesthesia Battery at Synesthete.org for the purposes of data collection for the dissertation Synesthesia: A Study of Population Prevalence.

Numbered actions are in chronological order from the start of the test until the end where the data is emailed to the examiner:

1. The first page of the test website that the participant and the examiner will see.

2. The examiner will click on the portal to Register & Start the Battery for the participant located in the middle right side of the page.

3. Next, participants email address will be input by the participant. These procedures will be duplicated each time to protect the anonymity of the participant as well as to ensure that each participant has a numerical designation.

4. The next screen shows that the registration has been successful.

5. Next, the participant will ensure that the examiner has access to the data by inputting the examiner’s email address into the test.

6. The following screen details the data protection and what the participant may get out of the study: “You are being invited to take part in a questionnaire and some online tests for the condition of synesthesia. Your decision to take part is voluntary and you may refuse to take part, or choose to stop taking part, at any time. You may refuse to answer any questions. This research project has been reviewed by the IRB, Baylor College of Medicine, Houston, TX (protocol number: H-20366). You may receive no direct benefit from being in this study; however, this work will help us better understand the condition of synesthesia. You will not be personally identified in any reports or publications that result from this study. Any personal information gathered during this study will remain strictly confidential; our computer databases are password protected and kept on a secure server. All results will be published in a statistical manner, with no
personal identifying information. Your email address is kept private and never shared with any 
outside party. At the conclusion of the test, you will be told your score and whether that score 
indicates that you are synesthetic. Please feel free to email us prior to consenting if you have any 
questions. You may indicate your consent by clicking on the Proceed button. Checking this box 
indicates that you have read the letter of information above, that your questions have been 
answered to your satisfaction, and that you voluntarily agree to participate in this research study” 
(Eagleman et al., 2007). The participant will be asked to read this statement and clicks proceed when ready.

7. The next screen collects variable data not utilized by this study, but other variable information 
will be included for statistical analysis. Address details will be left blank to further protect the 
participant’s identity. Finally, the Letter-Color Synesthesia Test will be clicked to proceed to 
testing.

8. The next screen informs the participant that they are about to take a test and how long it will 
take. The examiner ends prompts and does not answer questions going forward in order to protect 
the validity of the data.

9. The following is the test’s first page. The participant will match color to letter on each of the 
next 78 randomized letter and color combinations. The participant can manipulate the color by 
scrolling along on the vertical dial and manipulate the shade by scrolling along the horizontal 
dial.

The following blurb at the bottom of the page reads:

“Instructions: Click and drag the triangles or circle to choose a color which most closely 
resembles the synesthetic color associated with the letter or word presented. You may also use the 
arrow keys on your keyboard to adjust the color. The test will end automatically when all trials 
are complete” (Eagleman et al., 2007).
10. The next screen appears when the participant has completed the initial test.

11. The following screen details the directions for the next part of the test:

“Thank you for completing the first of the tests we have designed for grapheme-color synesthesia. You will now begin another short test based on your responses on the previous test. Once you begin, you will see on the screen a number or a letter flash for one second and then vanish. Each grapheme will appear in a color as indicated by your color choice on the previous test or a color different from what you indicated. If the grapheme matches your synesthetic color, click ‘It Matched’ otherwise click ‘It Didn't Match’. Please respond as fast as possible for each grapheme. You will now be presented with a maximum of 72 trials and the test should take about 2 minutes to complete. Please click the button to begin” (Eagleman et al., 2007).

12. The second part of the test has a letter appear on the screen for a few seconds. The participant answers whether the letter-color representation is a match or is not a match.

13. As the testing stage is now over the participant will ensure several questions are completed. These questions include mother tongue/language of origin and handedness. Not every question on the questionnaire is relevant for the study. Hence, unnecessary or participant identifying information will be skipped.

14. The next screens include the Vividness of Visual Imagery questionnaire and the Projector Associator Test and will have to be clicked through, but will not be answered. While these screens will be left blank, they must be clicked through to get the data from the current testing.

16. Once the test is complete, the next screen appears reporting that the test has been completed. The examiner will assist the participant to opening up their data, emailing it to the examiner, explaining the data to the participant and answering any questions they may have.

17. A examiner receives an email once the test has been completed. The examiner can go to the
battery and review the individual score on the data sheet.

18. The synesthesia data is included in a data sheet. Further down the data sheet is the synesthesia score and explanation of the score. As this was a randomly answered test, the score shows that the individual is not synesthetic.
Appendix B.

The following is from the privacy notice for Mechanical Turk at
https://www.mturk.com/mturk/privacynotice

Amazon Mechanical Turk Privacy Notice

Last updated: August 5, 2009

Amazon Mechanical Turk knows that you care how information about you is used and
shared, and we appreciate your trust that we will do so carefully and sensibly. This
notice describes our privacy policy. **By visiting the Amazon Mechanical Turk site,
you are accepting the practices described in this Privacy Notice.**

PLEASE NOTE THAT Amazon Mechanical Turk, Inc. IS A WHOLLY OWNED
SUBSIDIARY OF AMAZON.COM, INC. IF YOU HAVE AN ACCOUNT ON AMAZON.COM
AND AN AMAZON.COM COOKIE, INFORMATION GATHERED BY AMAZON
MECHANICAL TURK, AS DESCRIBED IN THIS PRIVACY NOTICE, MAY BE
CORRELATED WITH ANY PERSONALLY IDENTIFIABLE INFORMATION THAT
AMAZON.COM HAS AND USED BY AMAZON MECHANICAL TURK AND AMAZON.COM
TO IMPROVE THE SERVICES WE OFFER.

What Personal Information About Users Does Amazon Mechanical Turk
Gather?

The information we learn from users helps us personalize and continually improve
your experience at the Amazon Mechanical Turk site. Here are the types of
information we gather.

- **Information You Give Us:** We receive and store any information you enter
  on our Web site or give us in any other way. Specifically, to register with the
  Amazon Mechanical Turk site, you must provide us your name, email and
  physical address. [Click here](#) to see examples of what other information we
  collect. You can choose not to provide certain information, but then you might
  not be able to take advantage of many of our features. We use the
  information that you provide for such purposes as responding to your
  requests, customizing the site for you, improving our site, and communicating
  with you.

- **Automatic Information:** We receive and store certain types of information
  whenever you interact with us. For example, like many Web sites, we use
  "cookies," and we obtain certain types of information when your Web browser
  accesses the Amazon Mechanical Turk site. [Click here](#) to see examples of the
  information we receive. A number of companies offer utilities designed to help
  you visit Web sites anonymously. Although we will not be able to provide you
  with a personalized experience at Amazon Mechanical Turk if we cannot
  recognize you, we want you to be aware that these tools exist.
• **E-mail Communications:** By registering on the Amazon Mechanical Turk site, you will receive emails from Amazon Mechanical Turk and/or its Affiliates. As a Amazon Mechanical Turk site participant, it may be necessary for us to communicate with you to provide essential operational updates, status reports, transaction information, notices in connection with your account and other information relevant to your participation and use of the Web site (collectively "Essential Communications"). You may not opt out of such Essential Communications, and you agree to receipt of Essential Communications via email and/or other communication methods provided by you in your account registration. If we send newsletters and other non-essential email communications, we will give you the opportunity to unsubscribe to them. To help us make e-mails more useful and interesting, we may receive a confirmation when you open email from Amazon Mechanical Turk if your computer supports such capabilities.

• **Information from Other Sources:** We might receive information about you from other sources and add it to our account information.

**What About Cookies?**

• Cookies are alphanumeric identifiers that we transfer to your computer’s hard drive through your Web browser to enable our systems to recognize your browser and to provide features such as personalization.

• The Help portion of the toolbar on most browsers will tell you how to prevent your browser from accepting new cookies, how to have the browser notify you when you receive a new cookie, or how to disable cookies altogether. However, cookies allow you to take full advantage of the Amazon Mechanical Turk site’s features, and in order to participate, you must leave them turned on.

**Does Amazon Mechanical Turk Share the Information It Receives?**

Information about our users is an important part of our business, and we are not in the business of selling it to others. We are a subsidiary of Amazon.com, Inc., and we share user information only as described below and with subsidiaries Amazon.com, Inc. controls.

• **With Your Consent:** By accepting the Amazon Mechanical Turk Participation Agreement, you expressly consent to our use of your information as outlined in this Privacy Notice.

• **Participants:** As a requester or provider of services through the Amazon Mechanical Turk site, we may share certain information in order to facilitate the service relationship and to improve the Web site. For example, account numbers, account names, feedback, ratings and other attributes relating to use of the service may be publicly displayed on the Web site. In addition, service requesters may require prospective service providers to disclose additional information about themselves as a condition to accepting services from those service providers.

• **Agents:** We employ other companies and individuals to perform functions on our behalf. Examples include analyzing data, processing payments, and providing customer service. They have access to personal information needed to perform their functions, but may not use it for other purposes.
• **Promotional Offers:** We may send offers to selected groups of Amazon Mechanical Turk users on behalf of other businesses. When we do this, we do not give that business your personal information. If you do not want to receive such offers, we will give you the opportunity to unsubscribe to them.

• **Business Transfers:** As we continue to develop our business, we might sell or buy additional services or business units. In such transactions, user information generally is one of the transferred business assets but remains participant to the promises made in any pre-existing Privacy Notice (unless, of course, the user consents otherwise). Also, in the event that Amazon Mechanical Turk or substantially all of its assets are acquired, user information will of course be one of the transferred assets.

• **Protection of Amazon Mechanical Turk and Others:** We release account and other personal information when we believe release is appropriate to comply with the law; enforce or apply our Participation Agreement and other agreements; or protect the rights, property, or safety of Amazon Mechanical Turk, our users, or others. This includes (1) exchanging information with other companies and organizations for fraud protection and credit risk reduction; and (2) if you are a provider of a service on the Amazon Mechanical Turk site, we will release your name and address only to requesters for whom you provide services so that those requestors can comply with tax and other legal obligations they might have. Obviously, however, this does not include selling, renting, sharing, or otherwise disclosing personally identifiable information from users for commercial purposes in violation of the commitments set forth in this Privacy Notice.

**How Secure Is Information About Me?**

• We work to protect the security of your information during transmission by using Secure Socket Layer (SSL) software, which encrypts information you input.

• It is important for you to protect against unauthorized access to your password and to your computer. Be sure to sign off when finished using a shared computer.

**What Choices and Access Do I Have?**

• As discussed above, you can always choose not to provide information, even though it might be needed to take advantage of the Amazon Mechanical Turk site.

• You can add or update certain information, such as your e-mail address or account information by going to the "Your Account" feature of the Web site. When you update information, we usually keep a copy of the prior version for our records.

• The Help portion of the toolbar on most browsers will tell you how to prevent your browser from accepting new cookies, how to have the browser notify you when you receive a new cookie, or how to disable cookies altogether. However, you will not be able to use the Amazon Mechanical Turk site if you do not use cookies.

• [Click here](#) to explore products that offer anonymous browsing. In addition, the Federal Trade Commission provides useful information about online privacy on its own Web site.
Children

Use of the Amazon Mechanical Turk site is limited to persons and entities that lawfully can enter into and form contracts under applicable law. It is not intended for use by minors.

Participation Agreement, Notices, and Revisions

If you choose to visit Amazon Mechanical Turk, your visit and any dispute over privacy is participant to this Privacy Notice and our Participation Agreement, including limitations on damages, arbitration of disputes, and application of the law of the state of Washington. If you have any concern about privacy at Amazon Mechanical Turk, please contact us with a thorough description, and we will try to resolve it.

Our business changes constantly, and our Privacy Notice and the Participation Agreement will change also. We may e-mail periodic reminders of our notices and conditions, but you should check our Web site frequently to see recent changes. Unless stated otherwise, our current Privacy Notice applies to all information that we have about you and your account. We stand behind the promises we make, however, and will never materially change our policies and practices to make them less protective of user information collected in the past without the consent of affected users.

Related Practices and Information

- Participation Agreement

Information You Give Us

You provide most such information when you register, list, search, post, or communicate with us. For example, you provide information when you search for a service; provide information in our registration form; or list a service you'd like to purchase or provide. As a result of those actions, you might supply us with such information as your name, address, and phone numbers; services you request; services you provide; services you review; drivers license; social security number; bank account information and other personally identifiable information.

Automatic Information

Examples of the information we collect and analyze include the Internet protocol (IP) address used to connect your computer to the Internet; login; e-mail address; password; computer and connection information such as browser type
and version, operating system, and platform; the full Uniform Resource Locators (URL) clickstream to, through, and from our Web site, including date and time; cookie number; and pages you viewed or searched for.

Privacy Companies

www.anonymizer.com, www.IDzap.com, and www.somebody.net. We cannot vouch for the effectiveness of any of these products. In addition, the Federal Trade Commission provides useful information about online privacy on its own Website.
Appendix C.

This email chain is presented in reverse order with date and time indicated with one email per page. These emails are evidence of approval for use of MTurk as a data collection tool for this dissertation.

Use of Mechanical Turk for Data Collection

Strong, Carolyn Denise - strongcd <strongcd@jmu.edu>
Tue 2/10/2015 4:54 PM
Great news Chris! Thank you for keeping me updated. Please do reference this in the IRB so there are no concerns. I will make note of this on our end as well.

Have a wonderful evening!

Carolyn

******************************************************************************
Carolyn Strong, CIM, CRA
Director, Office of Research Integrity
601 University Boulevard
Room # 343, MSC 5738
Harrisonburg, VA 22807
Phone: (540) 568-2318
Fax: (540) 568-6409
Email: strongcd@jmu.edu
Office Email: researchintegrity@jmu.edu
******************************************************************************
Hello Ms. Strong,

Please see the emails below. Mr. Angel reports that he sees no issues with my plan.

I will include this in the IRB.

Thank you!

Chris
Thanks Chris. Based on what you’ve told me, I don’t have any issues with your plan.

Mark
Hi Mark,

I will not be seeking reimbursement. Honestly, for that amount it would be well worth it to me to get participants and collect data for my dissertation.

Best,

Chris
angelmw@jmu.edu
Tue 2/10/2015 12:04 PM
Chris:

Will you be seeking reimbursement for any of your costs associated with this?

Thanks
Mark

Mark W. Angel, Associate Controller
James Madison University
1031 S. Main St, MSC 5705
Harrisonburg, VA 22807
Phone (540)568-5590
Fax (540)568-3346
Hi Mark,

My initial offer would be for $0.00 for the work, but I would like to have the option to raise it to $0.05 if needed, to get the 500 participants I need for my prevalence study.

The money would come from my personal savings equally up to $25.00. Do you have any recommendations or concerns regarding any part of this plan?

Warm Regards,

Chris
Hi Chris:

It’s my understanding that you will fund an account and as you accept the participants work, a small fee moves from your account to theirs. Is this correct? If so, how do you plan on initially funding your account?

Thanks
Mark

Mark W. Angel, Associate Controller
James Madison University
1031 S. Main St, MSC 5705
Harrisonburg, VA 22807
Phone (540)568-5590
Fax (540)568-3346
Hello Mr. Angel,

I am working on my dissertation in psychology and would like to know if there are any pre-existing guidelines for using Mechanical Turk to collect research participants? I contacted Carolyn Strong previously and she directed me to you regarding use of Mechanical Turk.

I am at the point where I am preparing my IRB and just wanted to check in first before moving forward.

Warm Regards,

Chris Hill
JMU Doctoral Candidate
Hello Ms. Leeth,

I am working on my dissertation in psychology and would like to know if there are any pre-existing guidelines for using Mechanical Turk to collect research participants? I contacted Carolyn Strong previously and she directed me to you regarding use of Mechanical Turk.

I am at the point where I am preparing my IRB and just wanted to check in first before moving forward.

Warm Regards,

Chris Hill
JMU Doctoral Candidate
I will follow up with Mr. Angel and Ms. Leeth. Thank you!
Dear Chris,

Thank you for the email inquiry below. It has been almost two years since we were asked about the mTurk service. The last we were told was that the mTurk was not an approved JMU service. My recommendation is to contact either Mark Angel and Tish Leeth to see if they have gained any new information and whether or not this service can be used with your study. If they approve, please provide their approval in your IRB.

Wish I could be of more assistance.

Best,
Carolyn

******************************************
Carolyn Strong, CIM, CRA
Director, Office of Research Integrity
601 University Boulevard
Room # 343, MSC 5738
Harrisonburg, VA 22807
Phone: (540) 568-2318
Fax: (540) 568-6409
Email: strongcd@jmu.edu
Office Email: researchintegrity@jmu.edu
******************************************
Hill, Christopher B K - hillcb
Mon 2/9/2015 6:26 PM
Sent Items
To:
Strong, Carolyn Denise - strongcd <strongcd@jmu.edu>;
You forwarded this message on 2/10/2015 10:55 AM.
Hello Dr. Strong,

I am working on my dissertation in psychology and would like to know if there are any pre-existing guidelines for using Mechanical Turk to collect research participants? I am at the point where I am preparing my IRB and just wanted to check in first before moving forward.

Warm Regards,

Chris Hill
JMU Doctoral Candidate