Using an Individualized Implicit Association Test to Measure Synesthesia Strength

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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Synesthesia is a neurological phenomenon in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway. The most common form is grapheme-color. This involves an individual experiencing or seeing a specific color consistently when seeing a letter. Currently, the standardized method of confirming synesthesia is the online synesthesia battery. However, the synesthesia battery tests for the consistency of synesthetic associations but does not give information about the strength of these associations. This study utilized an individualized version of an implicit association test (IAT) to measure strength of synesthetic associations. The study focused on grapheme-color synesthesia to reduce inconsistencies and because of grapheme-color synesthesia's particularly high prevalence. An implicit association test uses difference in reaction times to measure how strongly a person associates items. 9 synesthetes and 8 controls were tested on the IAT where controls were matched to synesthetes for age and gender. One control is yet to be tested. The same IAT based on the synesthete's associations was given to matched pairs. We found that congruency effect was significantly higher for synesthetes when compared to non-synesthetes. This indicates that an IAT may be an effective way of differentiating synesthetes and measuring strength of associations. Preliminary data also showed that synesthetic strength might not be correlated with strength of associations.

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Introduction and Background

Defining Synesthesia

Synesthesia is a phenomenon in which a person experiences a secondary, unrelated perception (referred to as the 'concurrent') in one modality in response to a stimulus in a separate modality (referred to as the 'inducer': Eagleman et al., 2007). For example, a synesthete might hear music (auditory) and experience a color perception (visual). This phenomenon can alternatively occur in just one modality such as when visually perceived graphemes induce color experiences. Such synesthetic associations are idiosyncratic and arbitrary (Deroy and Spence, 2013). They are idiosyncratic in the sense that each synesthete's associations are unique to themselves and arbitrary in the sense that the relations are random. However, there are anecdotal cases where a synesthete's synesthetic colors are linked to specific memories from their childhood (e.g. Witthoft, 2006). These associations are also automatic in that synesthetes are unable to repress their associations (Ward, 2003).

Cases of synesthesia have been reported for over 200 years (Sachs, 1812), but it took decades before synesthesia became a part of mainstream science. Currently, there are records of as many as 61 types of synesthesia with color being the most common secondary experience (Day, 2005). This allows for a wide range of experiences between synesthetes. For example, the most common type of synesthesia, estimated to occur in 1-2% of the population (Simner et al., 2006), is grapheme-color synesthesia in which an individual might experience the color "green" in response to the letter "A" and "orange" in response to the letter "B" and so on. One taste-shape synesthete describes the taste of spiced chicken as pointy (Cytowic, 1993) while another synesthete experiences color while listening to music (Myers, 1911). For some synesthetes, ordinal linguistic sequences, such as numbers, give strong automatic perceptions of personality (ordinal linguistic personification: Simner and Holenstein, 2007).

Synesthetes are often divided into two subcategories: associators and projectors (Dixon et al., 2004). For a majority of synesthetes, the secondary experience is in their "mind's eye." For example, they might just feel strongly that blue is associated with "A" without any physical perception, and the color automatically comes to mind. However, for some synesthetes, they project the associated color onto the grapheme itself almost as if a transparency of their synesthetic color was placed on top of the grapheme. These projected photisms are a perceptual reality for these synesthetes (Palmeri et al., 2002) and affect perceptions in other tasks. For example, projected photisms can enhance the McCullough effect (Ramachandran and Marcus, 2017) in which priming a participant with colored gratings makes colorless gratings appear colored depending on their orientation. For example, if primed with red horizontal gratings, a participant will perceive colorless horizontal, but not vertical, gratings as red. Synesthetic photisms can also enable perceptual grouping (Ramachandran and Hubbard, 2001). For example, distinguishing a shape made out of "5"s embedded in a matrix of "2"s may be difficult because these numbers are visually similar, but is easier for a projector synesthete because their colored photisms make the "5s" stand out.

The rate of synesthesia overall in the population varies widely with some reporting it as common as 4% of the population (Simner et al., 2006) while other reports suggest a lower rate of 1-2% (Simner, 2012) or even 0.05% (Baron-Cohen et al., 1996). Synesthesia appears to have some genetic basis since there are studies showing the tendency of multiple synesthetes to exist in the same family line (Galton, 1880; Baron-Cohen et al., 1996). It has also been reported that those who are synesthetic are more likely to be involved in the arts (Rich et al., 2005). Early reports (Cytowic, 1996) claimed that synesthesia is more common among left-handed people, but more recent studies have found contradicting evidence stating that prevalence is not correlated to handedness (Rich et al., 2005).

Popular Theories

There are two general categories of theories regarding the basis of synesthesia. The first category of theories posits that synesthesia occurs through activation-through-connectivity mechanisms (Leeuwen et al, 2015; Dovern et al, 2012; Newell et al, 2016; Bargary and Mitchell, 2008). These theories assert that neural connections cause activation that produces concurrent sensory experiences. One of the more prominent theories in this category, entitled cross-activation theory, argues that the intersensory experience is backed by direct neural connections between, for example, the respective brain areas processing graphemes and colors (Ramachandran and Hubbard, 2001; Brang et al., 2010; Leeuwen et al, 2011; Sinke et al, 2012). This is supported by reports of increased white matter connection in the inferior temporal cortex for grapheme-color synesthetes (Rouw and Schoulte, 2007). It is additionally supported by a study finding genetic correlates for synesthesia. These genes were seen to be related to axonogenesis and are expressed during early childhood at a similar time to when synesthetic associations are formed (Tilot et al., 2018). The shortfalls of this interpretation include the inability to explain higher-level, conceptual forms of synesthesia such as time-unit synesthesia (Smilek et al., 2007), where months or days are linked to color. Because the inducer is a concept, there is no direct sensory input to induce activation in a secondary area.

The second category of theories involves the brain's learning process and a higher level of cognition than the more simplistic perceptual theory described above. It implies that the brain makes computational, learning-like changes, and that these changes are reflected in a synesthete's secondary experience. It argues for a higher-level view of synesthesia controlled by semantic mechanisms (Mroczko-Wasowicz and Nikolić, 2014). This is supported by the fact that context can affect synesthetic associations (Dixon et al., 2006; Miozzo and Laeng, 2016). For example, "V" can have a different synesthetic color when interpreted as a letter than when interpreted as the Roman numeral for "5." It also supported by the fact that different visual representations of the same concept can still induce the same synesthetic response (Ramachadran and Hubbard, 2001). For example, the concept of "4" can elicit the same secondary experience whether written as "4", "IV" or "four." Synesthetes also have greater sensitivity than non-synesthetes to high-level cross-modal correspondences, such as word-shape in which auditory pseudowords such as 'keekay' and 'lohmoh' are associated with pointed and rounded shapes respectively (Lacey et al., 2016). However, this does not hold true for low-level sensory cross-modal correspondences such as pitch-size or pitch-elevation in which high and low pitched auditory tones are associated with small/large size or high/low spatial elevation respectively (Lacey et al, 2016). These findings suggest that synesthesia might be related to cross-modal correspondences that include complex linguistic associations.

Stability of Synesthetic Associations over Time

Synesthesia typically develops throughout childhood except for some rare, anecdotal cases of one-shot synesthesia, a phenomenon where a synesthetic association is created in response to a specific life event (Kirschner and Nikolic, 2017). For synesthetic children, associations mature over time from disordered pairings into long-term consistent associations. On average, synesthetic colors for graphemes are 34% fixed at 6-7 years old, 48% fixed at 7-8 years old and 71% fixed at 10-11 years old (Simner and Bain, 2013). However, there are several cases that varied significantly from this typical pattern either developing slower than the typical synesthete or dying out completely as children aged.

Once a synesthete enters adulthood, their synesthetic associations typically do not change (Simner and Logie, 2007). However, there are some circumstances that can affect synesthetic color associations. For example, colors can fluctuate in the presence of clinical mood disorders; anxiety has been seen to decrease luminance in induced colors while depression may inversely correlate with color saturation (Kay et al., 2015). Head trauma and medication can also have reduction effects on synesthetic associations. A music-color synesthete, AB, experienced reduced synesthetic abilities after head trauma while another music color synesthete, CD, experienced a loss of synesthetic associations due to anxiolytic medication (Farina et al., 2016). Both synesthetes showed a return of their synesthetic associations virtually unchanged later, which was suggested to reflect an element of 'hard-wiring' of these associations (Farina et al., 2016).

Older individuals are less likely to report having synesthesia and less likely to pass the synesthesia battery (Simner, 2017). A number of cognitive processes that have the ability to affect a person's synesthetic associations decline with age. For example, an age-related decline in the ability to differentiate between different colors (Kinnear and Sahraie, 2002) can lead to problems for synesthetes with color-related synesthesia. Older synesthetes tend to experience a desaturation of their synesthetic colors, and low-saturation colors have been linked to a higher rate of synesthesia test failure. Some researchers have suggested that a higher threshold may be necessary to prevent older synesthetes with desaturated synesthetic colors from being classed as non-synesthetes (Simner et al., 2017). There have also been a number of reports of adults who feel they had synesthesia as a child but no longer retained these abilities as adults (Simner et al., 2009).

Tests of Consistency of Synesthetic Associations

The traditional determinant of synesthesia is internal consistency over time. An early test of this was the Test of Genuineness (TOG-R: Baron-Cohen et al., 1987) in which synesthetes were asked to report their synesthetic response (be it color, taste, sound, etc.) to a set of inducing stimuli and then some significant time later (e.g., after 6 months; Ward and Simner, 2003) were asked to recall the associations they had previously reported. Controls have been asked to do the same task inventing analogous associations and using their memory to recall them later. In some cases, the controls are given monetary incentive to perform well on the recall task (Ward and Simner, 2003). In order to be considered a synesthete, the subject must significantly outperform controls.

This procedure was considered the gold standard method for determining synesthesia. Among studies, however, there was some variability in methodology. When asking subjects to indicate synesthetic colors associated with graphemes, researchers have used verbal descriptions (Ward et al., 2005), written descriptions (Simner et al., 2006), Pantone© swatch color wheels (Asher et al., 2006), online color wheels (Simner et al., 2009), or computerized color pickers with a selection of over 16 million shades (Simner and Ludwig, 2012). This difference in methods has the potential to create difficulty in comparing results from various studies. However, regardless, the main criterion of outperforming controls is what all methods ultimately rely on.

Since the TOG-R was devised, a more modern and less complex synesthesia diagnostic measure, the Synesthesia Battery (SB: Eagleman et al, 2007) has been developed. This battery reduced the consistency measure to a short interval only lasting minutes. The SB works by assessing how consistently an individual can identify the exact synesthetic perception they experience in response to a stimulus. It tests for a wide variety of synesthesia varieties that are testable via computer, i.e., it cannot verify synesthesia types that include senses such as taste, touch, and smell. For the example of grapheme-color, the SB would require an individual to select the exact color from a color wheel 3 times for each grapheme in randomized order. Presence of synesthesia would be determined on the consistency of color selection. The battery also reports whether a synesthete is a projector or associator based on a questionnaire.

A number of studies have focused on verifying the reliability of SB for correctly identifying synesthetes. Two studies using a self-reported population both showed a bimodal distribution that separated the self-reported synesthetes from controls (Eagleman et al., 2007; Rothen et al., 2013). Synesthetes and non-synesthetes showed distinctly different performance on the SB and were, thus, differentiable by this testing method. These results have also been repeated with a random sample and the overall prevalence of synesthetes seen using the synesthesia battery matched with the prevalence reported with the traditional testing method (Carmichael et al., 2015). The SB has since become the new gold standard for determining the presence of synesthesia in research.

Tests of the Strength of Synesthetic Associations

Another way to measure synesthetic association is a modified version of The Stroop test (Stroop, 1935). In a traditional Stroop test, names of colors (e.g. "yellow", "red", "green") are presented either congruently ('yellow' printed in yellow) or incongruently ('yellow' printed in red). In each trial, the participant would be asked to read the words (while ignoring the color the word is printed in). The mismatch between the color name and the print color in incongruent trials produces an interference effect such that participants are both slower and less accurate than in congruent trials. The modified version functions similarly. The Stroop test is tailored to each grapheme-color synesthete's specific color associations. In congruent trials, letters are presented in the synesthete's synesthetic colors for those letters, while in incongruent trials letters are presented in unassociated colors. During testing, synesthetes would be asked to list either the actual color of the grapheme shown or the color they associate with the grapheme shown. This test has been used to measure interference patterns of synesthetic associations. It has also been used to differentiate projectors and associators as projectors show a larger interference pattern during the task (Dixon et al., 2004). During an incongruent trials, a projector will see both the color the grapheme is written in and their projected color making it more difficult to perform the task. Unlike the synesthesia battery, the main measure of the Stroop test is strength of associations and not consistency.

The Implicit Association Test

The implicit association test (IAT: Greenwald et al, 1998) can be used to test the strength of various types of associations. It is meant to measure the strength of automatic associations between mental concepts in memory and was first used to measure implicit biases and attitudes regarding topics like race and gender (Greenwald et al., 1998). Its other uses include testing for valence, stereotype, and self-esteem (Nosek et al., 2002; Bossom et al., 2000). The IAT relies on the principle that response times will be quicker if associated stimuli are assigned to the same response key (congruent trial) than when unassociated stimuli are assigned to the same response key (incongruent trial). It is an advantageous testing method because the presentation of stimuli individually rules out the possibility of selective attention effects driving the results (Parise and Spence, 2012). A variation on the combined trials of the IAT has also been successfully used to compare synesthetes' and non-synesthetes' responses to cross-modal correspondences (Parise and Spence, 2012; Lacey et al, 2016).

Rationale and Hypothesis

Synesthesia is a growing field of research. However, current studies are limited in their testing methods for synesthesia. The current diagnostic method, the SB, only measures for consistency of association but does little to tell us about how strong these associations are (Eagleman et al., 2007). While the Stroop test gives us more of a sense of the strength of the association through effects of interference, it is heavily affected by whether a synesthete is a associator or projector as the projected color association will affect the ability to discern the color of non-black graphemes (Dixon et al., 2004). The IAT, on the other hand, focuses on the mental concepts of associations and graphemes can be presented in black as they would in normal reading situations (Greenwald et al., 1998). Thus, the IAT may be a better test of the strength of synesthetic associations than the Stroop test. This study aims to be the first to use the IAT as a means of measuring the strength of synesthetic associations by creating trial runs customized to a particular synesthete's SB results. We expect that synesthetes will have larger congruency effects and greater accuracy in the IAT than their non-synesthetic counterparts. To the extent that strong associations should also be consistent, we expect scores from the current SB to be positively correlated with the magnitude of the IAT congruency effect. This would be an entirely new way of testing for synesthesia.

Methods

Participants

Participants were recruited via flyers placed around Emory University and, with permission, Georgia Institute of Technology, Savannah College of Design, Agnes Scott College, Gwinnett Technical College, and Georgia State University. Participants primarily consisted of Emory University undergraduate and graduate students. 9 synesthetes (9 female, average age=21.9) and 8 controls (8 female, average age=20.6) were recruited for this study. Non-synesthete control subjects were matched directly to a synesthete for age and gender (NB one control subject is yet to be tested). All participants provided written informed consent and were given $10 per hour compensation for taking part. Procedures were approved by the Emory University Institutional Review Board (IRB protocol 45974).

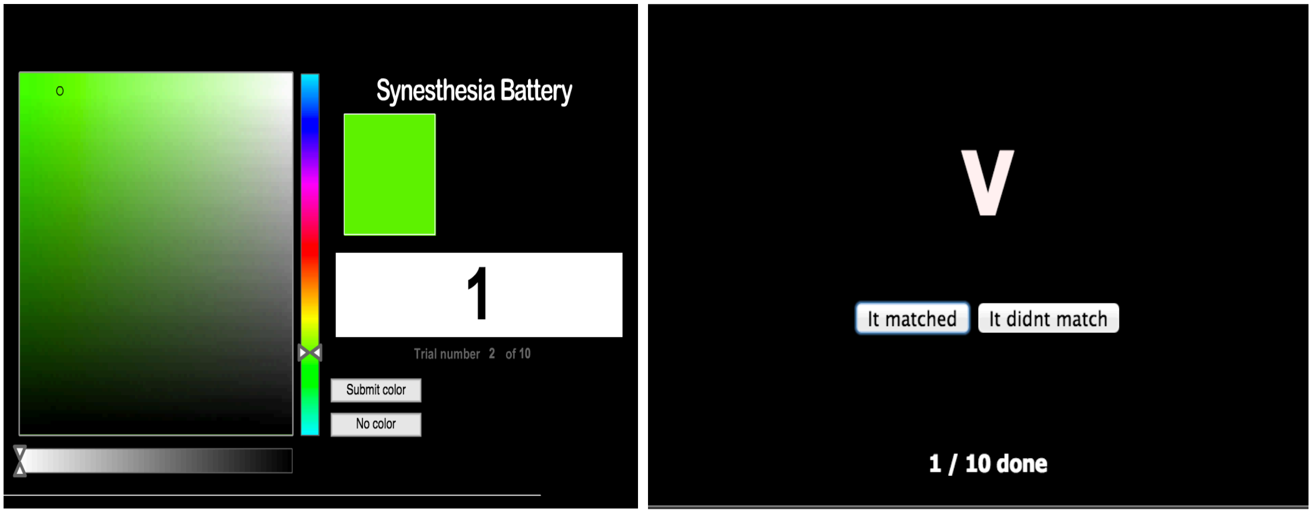

Figure 1. Synesthesia Battery

An example of the color-picking section of the synesthesia battery (left) and an example of the speed-congruency section of the synesthesia battery (right).

Synesthesia Battery

Synesthesia was confirmed via the SB. The primary interest for this paper was grapheme-color synesthesia, the high prevalence of which made it easier to recruit participants and also ensured consistency of synesthesia type across participants. The SB tests for consistency of an individual's synesthetic associations to the extent that is testable on a computer. For grapheme color, this was determined via the color wheel test referred to in the introduction above (Figure 1). The order in which graphemes were presented was randomized and there was a shift in the color wheel for each new grapheme in order to prevent any spatial cuing. A lower score on the SB indicates greater consistency, with 0 indicating exact color matches between three trials for all graphemes. A synesthetic score of less than 1 indicates the participant is synesthetic while a score above 2 indicates the absence of synesthesia. Scores between 1 and 2 are considered inconclusive and were not included in either group for this study (Figure 2). Additionally, Euclidean distance was calculated between the RGB values for the three of each grapheme. This was averaged to find a mean Euclidean distance. The battery also includes a speeded congruency task that records accuracy and reaction time (RT) for each participant to identify whether or not a grapheme was presented in its synesthetic color. Accuracy of less than 90% ruled out synesthesia and excluded a subject from study participation. There was no required threshold for reaction time, but mean RTs provide a check on task compliance, i.e., whether responses were made quickly or not.

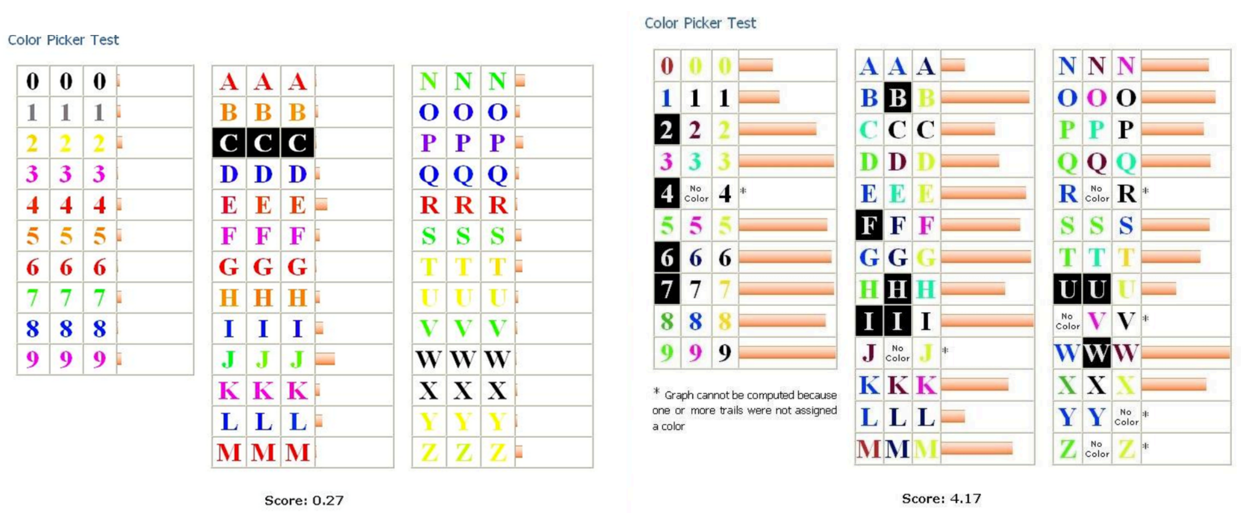

Figure 2. Synesthesia Battery Results Typical synesthete (left) and non-synesthete (right) color picker battery results. A score of below 1.0 indicates synesthesia; scores between 1.0 and 2.0 are considered indeterminate; scores over 2.0 indicate non-synesthesia.

For 4 participants, a manual synesthesia battery (manual SB) was used because the SB itself was taken offline while being transferred to a new website. In the manual version, participants were similarly asked to select their exact synesthetic color for each grapheme on a color wheel (https://www.rapidtables.com/web/color/RGB_Color.html) with the RGB values hidden from view. RGB values were recorded for each grapheme. Graphemes were presented in alphabetical order (A-Z) or reverse alphabetical order (Z-A) three times. From there, the Euclidian distance between each of the three estimates was calculated and then averaged. The two graphemes with the lowest average Euclidian distances were taken as the most consistent associations for that synesthete. It should be noted that the manual synesthesia battery does not include a threshold for determination of synesthesia and does not have the additional requirement of the speed-congruency test.

IAT Stimuli

Stimuli used in the IAT consisted of either a grapheme or a colored square presented on a white screen. The colors were displayed as a 30mm square of solid color. Graphemes were displayed in a black font and sized to fit within a notional 30mm square. Stimuli were tailored to each synesthete's associations as follows. Two graphemes with the highest consistency were selected for each synesthete. For the traditional synesthesia battery, this is indicated by the two graphemes with the shortest bar length on their results page. For the manual version of the battery, the two graphemes with the lowest average Euclidian distances were selected. In either case, if the two graphemes had color associations that were not substantially different (for example, if the graphemes are both associated with shades of yellow), the next most consistent association was selected.

Graphemes with associations to black or white are excluded because graphemes were presented in a black font on a white background, as a person would normally see them while reading. On the day of testing, synesthetes were asked to pick the exact color that they synesthetically associated with these two graphemes. The RGB values of these colors were then recorded to be used in the experiment. They were also asked to name the color and this name was used in the instruction for the IAT trials. All controls were shown the same stimuli as the synesthete they were matched to for age and gender.

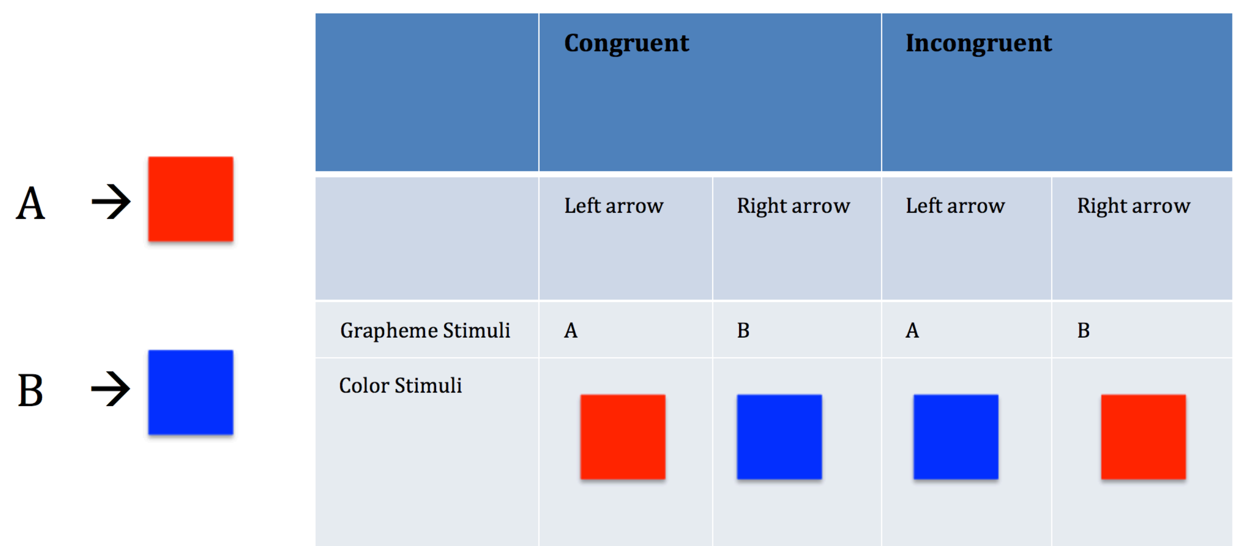

Figure 3. Congruent and Incongruent Trials An example of an association that could be used in the synesthesia IAT. The table shows one example of key responses for what a congruent and incongruent trial would look like. In the congruent trials, the paired grapheme-color (ex. A and red) were paired with the same response key.

Procedure

An implicit association test (IAT) was used to measure the strength of synesthesia. IATs consist of two trial types: congruent and incongruent (Figure 3). During a congruent trial, the participant responded with the same response key for a displayed grapheme and the corresponding synesthetic color. Response keys were the right and left arrow keys on a standard US-QWERTY keyboard. During an incongruent trial, the response key was paired with a grapheme and a color synesthetically associated with another grapheme. For example, if a synesthete associated "A" with red and "B" with blue, a congruent trial would tell the participant to press the left arrow key in response to "A" or red and an incongruent trial would pair a left key response to "A" or "blue." The main IAT experiment was presented via Presentation software (Neurobehavioral Systems Inc., Albany, CA, USA), which also recorded RTs.

Preceding testing, instructions were displayed on screen identifying the appropriate response keys for each stimulus presented. Participants were given as much time as they needed to read over the instructions before pressing any key to continue. 12 practice trials were included to ensure the participant properly learned the task before the test phase. Each trial during this practice period was followed by on screen feedback. Once the participant was ready, they could enter the testing session that consisted of 48 trials where feedback was no longer provided. One stimulus appeared at a time and the participants were asked to press the corresponding arrow key as quickly as possible while maintaining accuracy. Trials consisted of 1000ms of blank screen followed by stimulus presentation for 1000ms and were terminated when a response key was pressed. If the participant failed to respond within 3500ms, the trial ended automatically and proceeded to the next trial. RTs were recorded from stimulus onset. Stimuli were presented in a random order split equally between graphemes and colors. At any time during testing, participants could hit "p" on the QWERTY keyboard to pause the testing session and "r" to resume.

The implicit association task was given in two runs consisting of 96 trials each. The 96 trial blocks were broken down into a block of 48 congruent trials followed by 48 incongruent trials or vice versa, counterbalanced across participants.

Analysis

The main measures being studied were congruency effect (IAT) and consistency (SB). The congruency effect is a measure of a person's sensitivity to their synesthetic associations, or how much faster a person is in the congruent trials compared to the incongruent trials of the IAT. The magnitude of the congruency effect was calculated separately for response times to graphemes and colors. The data were trimmed to remove any response times ± 3 standard deviations away from the mean. Incorrect answers and practice trials were also excluded.

$$\text{Magnitude of Congruency effect} = ((\text{incongruent RT} - \text{congruent RT})/(\text{incongruent RT} + \text{congruency RT})) \times 100$$

Consistency was measured via the three responses given for each grapheme in the synesthesia battery or manual battery. In order to quantify the color consistency, the Euclidean distance between RGB values was calculated using the following formula:

$$\text{Euclidean distance} = \sqrt{[(r_1-r_2)^2 + (g_1-g_2)^2 + (b_1-b_2)^2]}$$

The average of all Euclidian distance scores for each grapheme was calculated and served as a universal measure of consistency across both forms of testing. A lower score indicates higher consistency of synesthetic associations.

Data was analyzed via a repeated-measure ANOVA (RM-ANOVA) with the congruency effect and accuracy as the dependent variables. Between-group factor was the presence/absence of synesthesia (synesthetes, controls) and within-group factor was the stimulus type (grapheme, color). Only p-levels of less than 0.05 were considered to be significant.

Results

Among the synesthetes, a synesthesia battery score obtained within the past year was available for 5 of the subjects. For these 5 subjects, the mean SB-score for grapheme-color for synesthetes was 0.548 with a minimum of 0.39 and maximum of 0.85. 4 of these synesthetes were associators and 1 was a projector. SB scores for the other 4 synesthetes will be collected when the SB is online again. The average Euclidean distance across graphemes for all synesthetes was 32.1 with a minimum of 17.7 and maximum of 51.8.

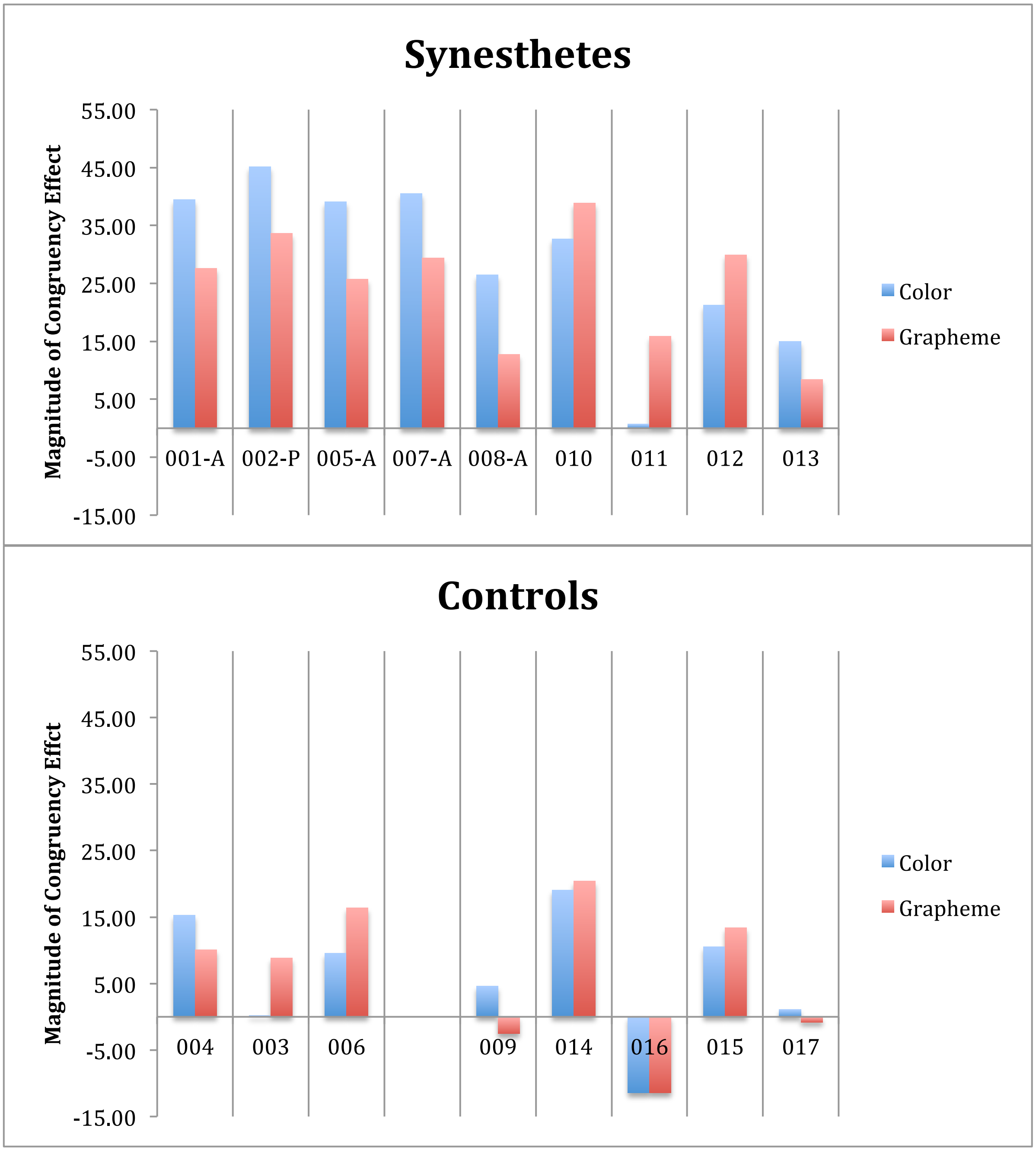

Figure 4. Individual Results The congruency effect of participants was graphed individually. An "A" next to a participant number indicates a synesthetic associator and "P" indicates a projector. Synesthetes who did not take the official SB are not marked in either category. The appropriate age- and gender-matched controls are shown directly below their related synesthete.

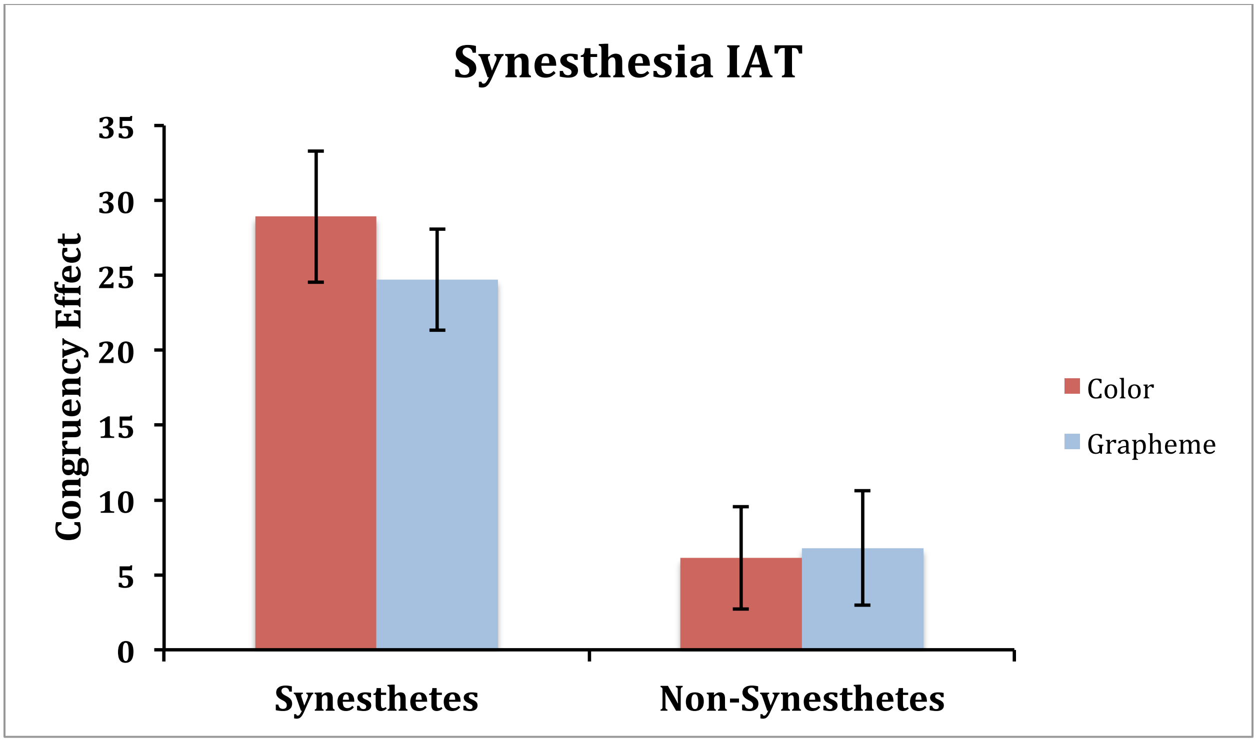

Figure 5. Difference in Congruency Effect Synesthetes had significantly larger congruency effects than non-synesthetes. Error bars represent standard error.

A global repeated-measures ANOVA (RM-ANOVA) showed that synesthetes had larger congruency effects than non-synesthetes ($F_{1,15}$= 15.59, p = .001, η^2=0.51, Figure 4). This shows that synesthetes and non-synesthetes scored significantly differently on the synesthesia IAT and thus, it may be effective in differentiating synesthetes. A notable example of this differentiation can be seen in the pairing of participant 010 and 014. Participant 010's strongest associations were "R" with the color red and "Y" with the color yellow. The matched control, participant 014, did have a notable congruency effect with magnitudes of 19.5 (color) and 20.4 (grapheme). However, participant 010 had even larger congruency effects with magnitudes of 32.65 for color and 38.89 for grapheme.

Congruency effect for stimulus type, grapheme or color, did not differ significantly ($F_{1,15}$=0.663, p=0.428, η^2=0.04). There was no significant interaction between group and stimulus type ($F_{1,15}$= 1.266, p = 0.278, η^2=0.08).

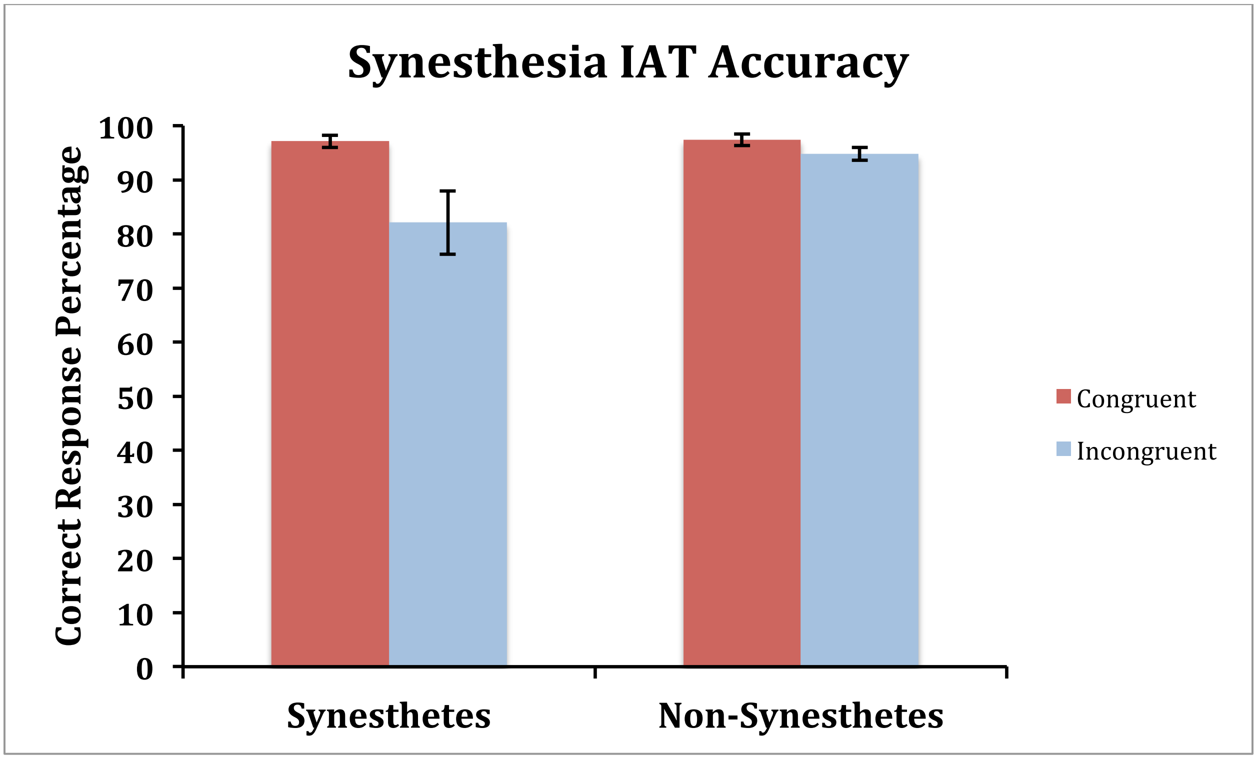

Figure 6. Difference in Accuracy Synesthetes and non-synesthetes were equally accurate in their IAT responses. Participants overall had higher accuracy during congruent trials than during incongruent trials. Error bars represent standard error.

A global RM-ANOVA showed no significant difference in accuracy between synesthetes and non-synesthetes ($F_{1,15}$=3.879, p=0.068, η^2=0.21, Figure 6). There was a significant effect of congruency in which accuracy was higher in congruent trials as opposed to incongruent trials ($F_{1,15}$=7.277, p= 0.016, η^2=0.33). No interaction was seen between congruency and synesthetes ($F_{1,15}$=3.588, p=0.078, η^2=0.19).

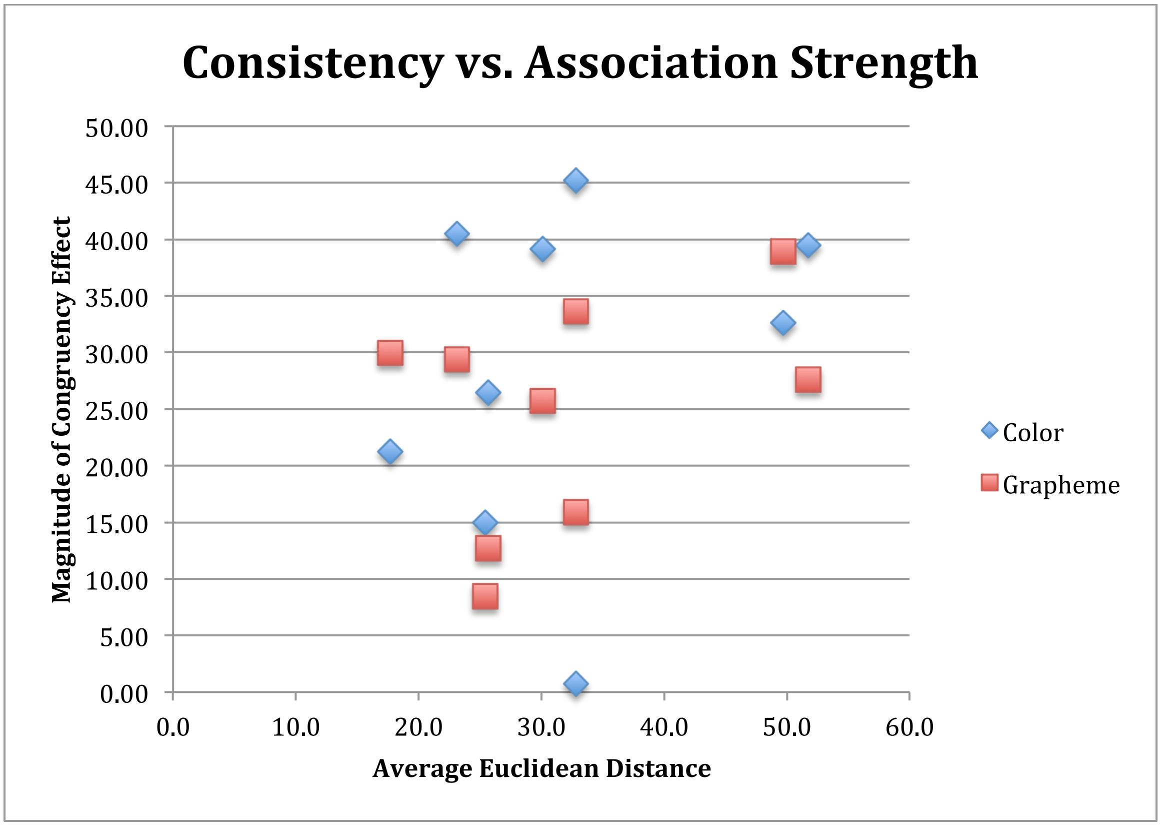

Figure 7. Scatterplot of Consistency vs. Association Strength No relationship was seen between in consistency and association for either stimulus type.

Scatterplots were created to assess whether there might be a relationship between consistency (as measured by Euclidean distance determined from SB or manual-SB) and strength of associations (as measured by the IAT). No correlation was seen for grapheme ($r=0.40$, $p=0.29$) or color ($r=0.27$, $p=0.49$). Because of the small sample size, we also tested for nonparametric correlations (Kendall's tau), this also showed no significant correlation for grapheme ($\tau=0.20$, $p=0.46$) or color ($\tau=0.20$, $p=0.46$).

Discussion

Main findings

To our knowledge, this is the first study to use an IAT to test the strength of a particular synesthete's associations. Synesthetes had significantly larger congruency effects than non-synesthetes indicating the IAT's ability to differentiate synesthetes from non-synesthetes. This is apparent even in the case of participants 010 and 014 where, because the associated graphemes match the first letter of the written color, a control could reasonably have a slight association. However, there was still a larger magnitude congruency effect when comparing the synesthete's IAT results to the control's results.

We also found that there was no difference in accuracy between synesthetes and non-synesthetes. This was expected because participants were told to be as accurate as possible. Having the same accuracy in both groups ensures that congruency effects, and thus strength of associations, are the main measure of the IAT.

We found that there seems to be no relationship between synesthesia strength and consistency but because of our small sample size, this may be due to a lack of power. This contradicted our original predictions and served as an indication that the strength of associations might be unrelated to consistency. The idea that these two measures are disconnected was supported by anecdotal evidence from our study population. Participant 001 and Participant 014 who experienced grapheme-color synesthesia reported having difficulty selecting the exact color that is induced by certain graphemes. They noted this being due to their synesthetic color having a range of hues making it difficult to pinpoint one color. Participant 001 also noted after testing that they did not feel as if the synesthetic associations chosen were their strongest.

Alternatively, this lack of relationship might be due to the potentially wide range of the consistency of synesthetic associations within an individual synesthete. In our methods, we selected the most consistent grapheme-color pair to use in the IAT. However, the SB score is based on associations for all graphemes as was the Euclidean distance measure we used for the correlation analysis. Large differences in consistency for graphemes that are *not* being used in the IAT could be driving up the synesthesia battery score. Thus, this lack of relationship may be due to comparing the strength of an individual association to the consistency of all of a synesthete's associations. This could be addressed in a future study by utilizing the IAT to test for the strength of multiple grapheme-color pairs within one synesthete. The two weakest and strongest synesthetic pairs (according to the SB) could be used as stimuli in the IAT to produce a measure that is more representative of the overall strength of that synesthete's associations.

Another consideration is the small range of synesthesia scores used in the correlation. Only synesthetes are currently included in the analysis. Thus, only SB scores of less than 1 are being used. To create a full continuum, it may be advantageous to also include participants who are categorized as non-synesthetes (SB score over 2) and indeterminate (SB score between 1 and 2). For non-synesthetes, participants would allocate any color they feel matches each grapheme and complete the synesthesia battery using these memorized associations. Because non-synesthetes would be using only memory to recall associations, we would expect them to be less consistent on the synesthesia battery (larger SB score) and have weaker associations (smaller congruency effect). Therefore, we'd expect to see a negative correlation with a high synesthesia battery score being associated with smaller congruency effects. A full continuum may lead to a better idea of how strength and consistency correlate. If IAT scores lie along a continuum as consistency does, this would signify that strength of associations are continuously distributed with true synesthetes being at one end.

Using our current data, we could calculate effect sizes and Bayes factor to estimate the optimal sample size (Dienes, 2014). If the correlation continues to be non-significant even with a larger sample size and including those with indeterminate SB scores, this might suggest that strength of association and consistency are two separate unrelated measures. One possibility is that strength of associations may be related to color saturation rather than the consistency with which a particular hue is perceived in conjunction with a particular grapheme. In other words, more strongly saturated synesthetic colors might result in stronger associations. This could be explored by converting RGB values to HSV (hue, saturation, value) space to see if saturation is correlated to association strength (as measured by the IAT). If there is a relationship between saturation and association strength, this may explain why older individual are less likely to self-report synesthesia (Simner, 2017). As age-related desaturation of colors in mental imagery develops, the strength of synesthetic associations may also decline. A future study could test this by testing the strength of synesthesia (IAT) over time as a group of synesthetes grow older.

Synesthesia is unidirectional in that sense that a grapheme induces color but seeing that same color will not induce the grapheme associated with it. Because of this feature, we previously expected that grapheme stimuli would cause more difficulties for synesthetes than their color counterparts. If a grapheme stimulus was presented, we believed that the induced color might create conflict (and thus a slower response time) when deciding which key to press during incongruent trials. However, this was not the case. There was no significant difference between congruency effect of color and grapheme stimuli.

One possible explanation for this is the distinction between projectors and associators. It has previously been seen that the photisms experienced by projectors can affect perceptual reality (Palmeri et al., 2002) and that another form of testing synesthesia, the Stroop Test, is affected by whether a synesthete is a projector or associator (Dixon et al., 2004). For projectors, there may be an effect of stimulus type, because when they see a grapheme, they would also physically perceive their induced color and thus, would take longer to decide whether to press the key associated with the grapheme or the physical color they see during an incongruent trial. However, for an associator, the color only appears in their "mind's eye", so they might not have more difficulty with grapheme stimuli than color stimuli. Currently, our data set only includes one known projector (Participant 002). This participant did not show greater congruency effects for graphemes than color stimuli indicating that this may not be reason why grapheme stimuli do not have larger congruency effects. However, a larger sample size may be needed to confirm.

Significance

The major contribution of this work is providing an additional diagnostic measure for synesthesia that quantifies synesthesia strength. The previous method, the SB, only provides information on how consistent a person's synesthetic associations are, but does not evaluate the association strength (Eagleman et al., 2007). The Stroop test gives information about the effects of interference, but is highly affected by synesthesia type (associator vs. projector) (Dixon et al., 2004).

Another potential contribution of the IAT is its ability to be modified for multiple types of synesthesia. For this study, we only focused on the use of an IAT for testing the strength of associations in synesthetes with grapheme-color. However, the IAT could be given in person to incorporate synesthesia types such as sound-smell. Because the synesthesia battery is online, this testing method might not be possible for these certain types of synesthesia.

Potential for Scanner Use

A possible significant contribution of a synesthesia Implicit Association Test is its ability to be used in a brain-scanning setting. Various brain-imaging techniques are often used to study synesthesia. The most commonly used imaging technique is functional magnetic resonance imaging (FMRI). (Hupe and Dojat, 2015). A number of studies have used imaging techniques in an attempt to find the neural correlates of synesthesia. Sensory and motor regions, and some 'higher level' regions in the parietal and frontal lobes have been suggested to be involved in synesthesia (Rouw, 2011), but there is still doubt that any of these proposed correlates are actually valid (Hupe and Dojat, 2015). A large variety in methods, number, and types of synesthetes create difficulties when comparing results between various studies. Currently, there is no test of synesthesia that is easily adapted for scanner use. The IAT utilizes only one stimulus at a time and has a simple response system (only two buttons needed). If utilized in a scanner, the IAT would allow the brain response for each individual stimulus to be observed separately and allow for the comparison in brain activity when viewing the inducing grapheme stimulus and the resultant color. However, the nature of the IAT may also present difficulties for scanner use. The main measure of the IAT is reaction time. The large difference in reaction time between congruent and incongruent trials likely reflects greater cognitive effort to unlink automatic associations during incongruent trials. This task, thus, will activate other parts of the brain related to the cognitive task instead of purely neural correlates of synesthesia. This would have to be carefully controlled for. One possibility is using color trials as a control. Because synesthesia is unidirectional, only grapheme trials would include a synesthetic experience, but both types of trials would require cognitive effort; based on the current results, this effort appears to be roughly equal as there is no significant difference in congruency magnitudes between grapheme and color trials and no interaction with synesthesia status.

Female Study Population

The study population was completely female due to difficulties we encountered recruiting male synesthetes. Early reports indicated that synesthesia was up to 6 times more common in females than in males (Baron-Cohen et al., 1996; Rich et al., 2005). However, this has been argued to be untrue and a result of issues with the methods (Simner and Carmichael, 2014). The universal tendency of high rates of female self-referral may be responsible for earlier findings and later analyses were unable to find a significant difference between prevalence in females and males even with sufficient power (Simner and Carmichael, 2014).

Limitations

The inability to use the official synesthesia battery created by Eagleman is a major limitation of the current study. The following shortfalls will be addressed at a later time with the return of the online battery. Firstly, methods differed for stimulus selection for the IAT between the SB and manual battery. The original battery uses an algorithm that goes beyond Euclidian distance and includes a normalization process (Eagleman et al., 2007). Grapheme-color pairs selected in the manual version might differ slightly from those chosen in the official battery.

Secondly, there were no discrimination criteria for the synesthetes who took the manual battery. Categorization in the synesthesia category for these participants was based on self-report. It is possible that some of these participants may have not met the criteria set forth by the official synesthesia battery. In the manual battery, there was no maximum score established as a cutoff. Additionally, the manual battery did not include a speed-congruency test to rule out memorization.

The study population for this paper is small, and although the results are still significant, a larger population and further testing would be needed to more strongly establish the validity of this testing method and its ability to differentiate synesthetes from non-synesthetes.

Summary

This study was within our knowledge the first to use an implicit association test to measure synesthesia. The test was successful in its ability to differentiate synesthetes from non-synesthetes, and strength of association was the main measurement. This adds to the field because of its ability to measure strength of association instead of just the consistency of synesthetic associations. It is also scanner-friendly and can serve as an important tool in research regarding finding any neural correlates of synesthesia. Future directions for this study might include increasing the study population and including males. Testing the IAT's ability to differentiate synesthetes with various synesthetic associations with differing consistencies within one synesthete can also help validate this method.

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