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Few studies have measured how the memory of individuals with synesthesia, a perceptual phenomenon in which a stimulus triggers a separate sensory experience, is affected because of their novel perceptual experiences. The studies that have examined synesthesia and enhanced memory have been inconclusive, as some have found those with synesthesia exhibit superior memory capabilities, while other studies have not. This study sought to replicate previous studies that have found effects of color congruency. The participant M.P., a female with grapheme-color synesthesia, was given lists of words that were either congruent to her synesthetic experience, random colors, or words in black ink, then tested over her memory for the lists. Results were then compared to mean scores of a control group (n = 15). Results indicate a deviation from the hypothesis, as M.P. did not exhibit superior memory for congruent information, but rather a potentially enhanced ability to suppress color information.

Synesthesia has been described as a condition in which one stimulus triggers an image or experience in a separate sensory modality, such that a sound may not be just heard but also tasted, smelled, or even felt as a physical touch; the word literally meaning "experiencing together" (Baron-Cohen, Wyke, & Binnie, 1987). Many forms of synesthesia have been documented, including colors arising from written words, sounds eliciting a certain taste, or even the feeling of touch accompanying a smell (Cytowic & Eagleman, 2009). For example, if someone with sound-color synesthesia heard the sound of a violin playing, it may evoke the color green or the sound of a furnace igniting may elicit a variety of red shades. Someone with sequence-location synesthesia, a type of synesthesia in which an individual perceives numbers or time units in specific spaces, may describe the number 6 as slightly above them to the left. In literature, the common terminology for the initial stimulus is an inducer and the separate sensory perception is termed the concurrent. In the example given above, the sound of a violin playing would be described as the inducing stimulus and the color green would be the concurrent. These sensory experiences are most often unidirectional, as an inducer will lead to the experience of the concurrent but there is no reversed effect (Grossenbacher & Lovelace, 2001). Once again using the above example, the inducing stimulus of the furnace igniting may trigger a sensation of red colors, but seeing the same red shades may not trigger the sensation of a furnace igniting.

Different kinds of synesthesia occur at different rates in the population. The experience of colors from letters, or grapheme-color synesthesia, has been shown to be the most frequent, occurring in 45-65% of those with synesthetic experiences (Radvansky, Gibson, & McNerney, 2011). While other common forms of synesthesia include sound-touch, vision-taste, and spatial-sequence synesthesia, the most common inducer is linguistic-based and the most common concurrent is color (Cytowic & Eagleman, 2009; Rouw & Sholte, 2007).

In addition to the various forms of synesthesia, there are a few core features apparent for those who experience this neurological phenomenon. The two core features most agreed upon in literature are that synesthetic experiences are automatic, occurring uncontrollably and not easily suppressed by the perceiver, and that the specific perceptual experiences are relatively consistent over time (Grossenbacher & Lovelace, 2001). In regards to the consistency found in synesthesia, when those with grapheme-color synesthesia were asked to map out the colors they experience, they could accurately choose the same color 92% of the time upon retest one year later as compared to non-synesthetes who were only consistent 38% of the time (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993). This reveals that those with synesthesia do not report color experiences simply based off of loose criteria, such as the letter "W" appearing white because of the name of the color starting with that letter, or the letter "A" appearing red based off of a relational context such as a red apple. Rather, these experiences are innate and do not have to be "remembered," instead experienced all over again when retested.

The best example that can be used in regards to the automaticity of these perceptual experiences is with Stroop-like tasks. In this task, participants view the name of a color printed in ink, such as the word blue printed in blue ink, and are asked to state the word presented. There is a certain level of interference when the word presented is incompatible to the ink color, such as the same word blue instead being presented in red ink. Similarly, when those with synesthesia are asked to state the color of a grapheme that is incongruent to their perception, they experience a similar level of interference (Spector, & Maurer, 2009; Mills, Boteler, & Oliver, 1999). On the opposite side of this spectrum, when these same graphemes are presented congruently, or in colors matching their sensory experiences, they facilitate rather than interfere with their perception. Evidence for this facilitating effect from color congruency can be traced to memory.

The Neuroanatomy of Synesthesia

The study of neuroscience has advanced significantly over the past few decades, thus a greater understanding of the neural correlates of synesthesia has grown. Research has shown that there is a distinct familial pattern in synesthesia, (Barnett et al., 2008; Rothen, Meier, & Ward, 2012) as 42% of synesthetes have a family member who also has some form of synesthesia. While this indicates that different forms of synesthesia are fundamentally related at the genetic level, the exact genotype involved is not well understood.

What has emerged from recent research is a greater understanding of the brain structures that may relate to the phenomena. The most common explanation of synesthesia is evidence of cross-wiring between area V4 of the visual cortex, which processes color perception (Ramachandran, & Hubbard, 2001; Nunn et al., 2002) and the fusiform gyrus, which is associated with both color and word information (J¨ancke, Beeli, Eulig, & Hanggi, 2009; Rouw & Scholte, 2007). In the normal population, areas within the fusiform gyrus have been found to show activation when individuals are presented the inducing stimulus, such as a word or letter. However, concurrent areas in the V4 color region are typically only activated by experiencing real colors in normal individuals, but in those with synesthesia both regions show activation when only presented the inducing stimulus (Bargary, & Mitchell, 2008; Nunn et al. 2002). Cross-activation between these regions is generally unidirectional, and is stable in its associations of specific inducers leading to activation in areas correlated with the concurrent that follows (Bagary et al., 2008). Studies of event-related potentials, a measurement of electrophysiological brain activity, have also shown enhanced positive activation in more anterior regions of the scalp at around 200 ms after the presentation of a given stimulus (Radavensky et al., 2011). Because this difference occurred later in processing than in the first 100 ms, which is a peak more based solely on the physical parameters of a stimulus, this suggests a difference in perceptual processing rather than a difference in early sensory processing.

The Effect of Synesthesia on Memory

Many case studies have revealed that there may be potential memory benefits of synesthesia. The most famous of these was by Luria (1968) and his groundbreaking book in which he studied S., or Solomon Shereshevsky. S., who was described as having a memory that "had no distinct limit" and could be tested flawlessly over a list of 50 matrices, even remembering this list when tested again years later. He reportedly had multiple different forms of synesthesia, and while one could posit that this was linked to his distinct perception, this theory can no longer be tested. One other outstanding report is the case of C, a 21 year old student researchers investigated because of her memory capabilities (Smilek, Dixon, Cudahy, & Merikle, 2002). The case of C differs from Luria's study in that the synesthetic experiences that affect memory could be tested rather than theorized. C was presented with three lists of matrices that were either printed in congruent colors, (colors that match her sensory experiences), incongruent colors, (colors that did not match her sensory experiences) or black. As had been hypothesized, C's memory performance for these matrices was superior to a control group of non-synesthetes when congruent or black, but when tested over incongruent colors C's performance was strikingly poorer than her former performance and the performance of the control group. This presents more concrete evidence that C's memory capabilities were likely enhanced by her synesthesia.

While these extraordinary cases exhibit intriguing possibilities about the effects that may come from synesthesia, they also exhibit some clear issues. First, each of these cases were approached not due to their synesthetic experiences but rather based on their apparent superior memory (Rothen, & Meier, 2010; Yaro & Ward, 2007). Based on the reasoning for studying these individuals, they serve as merely examples of individuals with superior memory, thus presenting some issues of generalizability to the synesthetic population.

Only a number of group studies have sought to find generalizability and how significant the potential memory benefits are within synesthesia. In general, those with synesthesia do self-report having better memory than non-synesthetes, (Yaro & Ward, 2007) but not all results have been as astounding as case reports have exhibited (Rothen, Meier, & Ward, 2012). The results found by Smilek et al. (2002) regarding color congruency effects have been replicated in some cases using similar materials (Radvansky, Gibson, & Mcnerney, 2011) yet not replicated by others (Yaro & Ward, 2007; Rothen & Meier, 2010). Other studies have found evidence of greater memory for tasks not directly associated with synesthesia, which suggests enhanced general memory benefits (Rothen et al, 2012). This research still indicates a need for more evidence of memory benefits based off of color congruency.

One may argue that an issue with these studies is a lack of consistent and effective methodology. One important factor in the study conducted by Smilek et al. on C was that incongruent information drastically diminished memory resources. This may suggest that the material used, specifically material that manipulates for color congruency, is crucial to gathering consistent findings. As stated above, some case studies have manipulated color congruency and found results consistent with past findings. However, other studies have utilized standard memory tests (Rothen & Meier, 2010) without manipulation of color congruency and have found more ordinary results. This suggests that the framework under which enhanced memory and synesthesia is explored requires some revision. Revisiting the use of a case study design may prove to be useful in adapting the methodology in which these studies are conducted. It is of equal importance that the case study used within the study not be approached due to their superior memory capabilities, as has been the case in other studies, and rather simply based on their novel perceptual experiences. Therefore, the subject in mind would be more similar to the general population of synesthetes and in turn provide more generalizable results.

Case Study

The participant, M.P., is a twenty-two year old female with grapheme-color synesthesia. M.P. is a friend of the author, who in the past reported she had experienced something similar to synesthesia. To verify her synesthesia, a sensory map was completed. To do this, M.P. described the color experience she felt from each letter of the alphabet and was encouraged to be as descriptive as she felt, such as the letter K which she described as "like a grape. Imagine an oil painting of a bowl of fruit. The K is the grapes." Following this, three months later she was asked to repeat this process, in which 85% of her answers remained consistent. (See Appendix D). As an additional test, on a separate occasion, an online battery was conducted in which each letter was presented to M.P. on three separate trials at random. She would then choose from a color spectrum the color that most closely resembled her perceptual experience of the letter. After all three trials, the online battery reported her consistency at 92%. (for more information on this online battery, refer to Eagleman D., Kagan A., Nelson S., Sagaram D., Sarma A. 2007). Given that answers in the range of 85-100% indicate an association between the grapheme and colors, M.P. would qualify as having synesthesia. These tests also helped to avoid relying on merely a self-diagnosis given by M.P. and concretely verify her synesthetic experiences.

M.P. reported that she had only recently discovered what the phenomena was, thinking of it as a "funny little habit" and that she did not know that it was a well-documented condition. She describes her synesthesia as not overwhelming but rather quiet background noise that she has grown accustomed to overtime. She does report that she cannot handle too much noise, describing it as "a sensory overload." Though she is not aware of any family members that also have synesthesia, she did report that ADHD runs in her family, which is a common correlate in those with synesthesia.

In regards to her color experience, she reports that words are experienced "inside my head," rather than outside in the world. This type of synesthesia is described as a non-localizer— those that experience color out in the world are referred to as localizers; they are also commonly referred to as "projectors" and "associators" (Cytowic & Eagleman, D. 2009). M.P. also stated that, on occasion, she has a color experiences when hearing words spoken, and she believes this "depends on how strong or bright the color is to me." She offered an example of when she recently received a mail key, and when she heard the word mail spoken she had an experience of the color pink (the color that she associates with the letter M.) This also relates to her description of how she experiences words, rather than just letters. She stated that the first letter "definitely stands out to me;" however, if she reads the letters individually rather than reading the word as a whole, she experiences each individual color she associates with the letters. This detail was crucial when designing the memory task for M.P. and determining in which color the words would be printed, as the perception of the first letter dominates the color of the whole word.

Finally, M.P. also reports that she believes she has "an excellent memory," which is in line with Yaro and Ward's (2007) finding that those with synesthesia frequently self-report having above average memory. While she could not say for sure if it directly correlates with her synesthesia, she believed it may be helpful.

Hypothesis

The current study intended to replicate the results of past research. It was expected that M.P.'s memory for items within a list of words would be superior to the control group for items that are congruent to her synesthetic experience as well as for items printed in black ink, and inferior for items that are presented incongruently. It was also expected that reaction times for the Stroop-task would be faster for M.P. when printed in colors congruent to her synesthetic experience but not matching the name of the color, and would be inferior to the control group when presented in ink matching the name of the color but incongruent to her synesthesia.

The Stroop task is used as a supplement to the memory task, as it has been argued that cognitive control and working memory are functionally and anatomically interrelated (Soutschek, A., Strobach, T., & Schubert, T. 2013). The Stroop-task is a common test of cognitive control, and this additional testing may lend to the results found from the memory task. For instance, an incongruent set of words may cause an additional strain cognitively, impeding working memory resources. It could be argued that the Stroop-task is a strict test of cognitive control and the memory task utilized is both a test of cognitive control and working memory demands, thus both tests are useful towards analyzing this study's findings.

In regards to the control group, it was assumed they would have a typical Stroop-effect, with higher reaction times for any incongruent set. It was also assumed they would remember more details from memory tasks with materials printed in any color of ink as compared to plain black ink.

Method

Participants

The study included one synesthetic participant, M.P., as well as fifteen non-synesthetic students from the Introduction to Psychology research pool at Ball State University as a control group. These participants were predominantly female, Caucasian, and were all between the ages of 18-22. Participants were given one research credit for their participation, and were offered an alternative assignment if they did not wish to participate in the study.

Materials

Stroop-task. First, a simple Stroop-like recognition task was used. Lists of color names (red, green, blue, etc.) were created in three separate conditions. One list consisted of words in ink matching the name of the color (the word red = red ink), one list of words matching how the word is perceived synesthetically by M.P., based on the first letter of the word (red = green ink, the color she perceives for the letter r), and one list in ink that does not match either the name of the color or MP's synesthetic experience for the word (red = yellow ink) (See Appendix A). Colors used in this task were determined by the online battery referenced previously that tested M.P.'s consistency for color experiences (See Appendix C). Participants were asked to state the colored word presented and were timed over how long it took them to verbally complete the entirety of the list using a stop watch. The amount of time it took to read each list in milliseconds was measured as the dependent variable.

Short-Term Memory Task. The second test was a free-recall memory task over lists of words in which the color of the word was varied. One third of the word lists were printed in black and the rest were printed in color. Lists consisted of colors that were congruent with the synesthetic experience of M.P., based on the first letter of the word, or incongruent colors (See Appendix B). These colors were also determined by the same online battery used for the Stroop-task. There were three lists of ten words for each condition (ninety words and nine lists in total.) Lists consisted of 1-4 syllable words with between 5-8 letters, such as "traffic," "compass," and "visitor." This criteria is similar to the criteria used by Radavensky et al. (2011) and words were pooled from an online random common word generator.

Procedure

Participants were seated in front of a computer screen and were administered the Stroop-task on paper. Participants were shown each list individually and asked to state the name of the color of each word out loud. The time it took each participant to name all of the words in each set was timed with a stopwatch once the list was presented. After completing all three sets from the Stroop-task, participants moved on to the memory task. Before beginning, participants were asked to remember as many words as they could. Lists of words were presented on the screen for the duration of ten seconds, then participants were shown a blank screen. Participants were shown all nine identical lists, given one by one for a full minute each in varied order, and were asked to free-recall as many items from each list that they could. The screen remained blank for a duration of one minute, and during this time participants wrote down as many of the words that they could recall within that time. Once the minute was up, the next list of words was presented and the procedure continued until all nine lists were completed. Once finished, participants were debriefed and thanked for their participation.

Results

Control Group

For the Stroop-task, one-factor (black, congruent, incongruent) repeated measures ANOVAs were conducted on all three tasks within the control group to analyze the effects within a non-synesthetic population.

Initial results showed a large significant difference within the Stroop-task, $F(1, 14) = 24.624, p < .001$. Post hoc tests demonstrated a typical Stroop-effect between both the congruent and normal lists, $F(1, 14) = 9.451, p < .01$, and between the incongruent and normal lists, $F(1, 14) = 24.624, p < .001$, supporting the hypothesis that the control group would do significantly worse on any list printed in colors deviating from the name of the color.

Results within the control group for the word list task demonstrated no significant effect, $F(1, 14) = 3.527, p > .05$. However, post hoc tests demonstrated a marginally significant effect between the black word lists and the congruently colored list, with participants recalling colored information more, $F(1, 14) = 4.176, p = .06$. No significant effects were found between the incongruent and black word conditions or between the incongruent and congruent conditions. A non-significant finding between the incongruent and congruent conditions was expected, as these distinctions were based on M.P.'s experiences and a control group should see no significance in their differences.

Case Study

To calculate a comparative analysis between the control group means and M.P.'s individual scores on each task, a series of one sample t-tests were conducted to determine if there were significant differences for both the Stroop-task and the memory task (refer to Table 1 for all control group means and M.P.'s scores). The most notable difference was between M.P.'s Stroop reading time and the control group. There was a significant difference found between the normal list, $t(14) = 2.26$, $p < .05$, the congruent list, $t(14) = 3.946$, $p = .01$, and the incongruent list, $t(14) = 6.02$, $p < .001$, with M.P.'s reaction times faster for all three conditions. These results not only demonstrate a significant difference in M.P.'s scores but also demonstrates a lack of a normal Stroop effect, which does not support the hypothesis (refer to Figure 1).

These results lend explanation toward the contrary results of the short-term memory task, with no significant difference in the normal list, $t(14) = .49$, $p > .05$, and the congruent list scores, $t(14) = .43$, $p > .05$. However, a significant difference was found within the incongruent word list, $t(14) = 2.47$, $p < .05$, with M.P. recalling incongruent information more than the control group (Figure 2).

Discussion

The purpose of this study was to replicate past findings of color congruency effects on memory in those with grapheme-color synesthesia. While some previous research has found that color congruency may facilitate memory in these individuals, as well as color incongruency interfering with memory, results have been inconsistent (Smilek, Dixon, Cudahy, & Merikle, 2002; Rothen, Meier, & Ward, 2012). However, the hypothesis that color congruency may have an effect on memory recall was not supported due to inconclusive results. While M.P. recalled significantly more items within the incongruent word list set, contrary to the hypothesis, this finding can likely be accounted for by other factors besides assumed memory benefits of color congruency.

One explanation for this significance is M.P.'s absence of Stroop-effect as compared to the control group for all three conditions. This finding was both contrary to what was hypothesized and previous research, (Mills, Boteler, & Oliver, 1999) with the assumption that when the color of the word was incongruent she would have a more difficult time reading the list. Instead, each list had nearly identical times, including the list of color words printed in ink matching the word. What could account for this novel finding is M.P.'s description of her synesthesia as more like background noise rather than consistently overwhelming to her. This may suggest that M.P.'s synesthetic experience may give her an enhanced ability to suppress incoming color information. For the synesthete, it may be necessary to accustom to the phenomena, rather than let it dominate the individual's perception. Rather than the dual color information causing normal interference in perception, synesthesia may facilitate the ability to separate the name of the color from the color of the printed ink, enhancing the ability to read a list of typically interfering information.

Given this possibility, it becomes easier to explain the greater effect of incongruency rather than congruency in regards to the memory for word list. Color congruency could be suppressing, rather than facilitating, M.P.'s memory capabilities, causing her to focus more on the words themselves rather than their ink color. However, incongruent information may indeed cause a greater pop-out effect in memory due to the greater difficulty of suppressing mismatched color information.

This finding may suggest that an individual's specific experience of synesthesia is more important to memory benefits rather than a simple color congruency effect.

One of the greatest limitations of this study, which has also been the case in past research, is the implementation of a case study. While the use of a case study did allow for a finding that individual differences in synesthesia may hold greater weight on how to measure the potential of memory benefits, more power may have been given toward the hypothesized outcome if a larger sample of synesthetes had been recruited. It could also be said that these particular results may only apply to the experiences of the case study and not to the entire synethetic population, limiting the generalizability of the results.

There are also some potential issues with the particular case study in question. For starters, as mentioned previously, M.P. has been recently diagnosed with synesthesia. For others with synesthesia that have exhibited superior memory, they may be more aware and active with their unique experiences. Perhaps they have developed tricks, similar to mnemonic devices, to aid their memory that M.P. may not utilize. Given M.P.'s description of her synesthesia as similar to background noise, this could explain how the results deviated from expectations, however it may not be a feature of each individual with synesthesia and a unique aspect of her own perception.

Another potential issue is the difficulty in recreating a synesthete's particular sensory experience. This is a more pressing issue in regards to using word lists. While M.P. did state that the first letter does predominate the color of a word, there may be more variability than what is presented in the word lists. More importantly, there may have been some issues with the color of font used for both the Stroop task and memory task. While the font used was taken from M.P.'s choices on the online battery previously mentioned, this still poses some issues. For instance, while M.P.'s responses were consistent throughout the task, they still were not perfectly so, leaving some room for error. Even more pressing is the fact that it may be impossible to perfectly replicate a synesthetic experience with a font. As an example, M.P. described the letter B as two distinct colors, separate from each other but experienced simultaneously. There would be no font that could represent such a perceptual experience. Though this may have had no effect on her memory for the word lists, it is worth noting when looking at future research and designing a memory task specific to someone with synesthesia.

Future Research

In regards to future research conducted in the realm of synesthesia, a stronger focus should be given to analyzing individual differences between synesthetes. Often this area of research bypasses intense observance of perception, as well as interviews that may assist in interpreting results, thus some findings may be lost to a misunderstanding of the participant. Some have argued that case study results may not be representative of the entire synesthetic population when observing memory effects (Rothen & Meier, 2010). However, it could be argued that group studies may have had less consistent results when looking at color congruency due to a lack of focus on their synesthetic participants, losing important information on the individual and only focusing on the condition. When group studies are employed in the future, extensive analysis of each individual with interviews about their personal perception and in depth sensory mapping should be conducted to fully understand each member of the sample. It is important to understand that the experience of synesthesia exists on a continuum, and it is false to assume that each person who lives with this particular phenomena sees the world in identically abstract ways.

Another area that could be explored in future research is how synesthesia may effect memory recall in a real world setting. To this point, studies have attempted to replicate past findings by focusing on word and letter lists to interpret their findings. This may not represent how information is encoded into memory as accurately as a full text of information, such as a short story or persuasive argument. While a measure that manipulates color congruency for this form of memory has yet to be developed, it is an intriguing extension to synesthetic research.

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