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Enhanced semantic priming in synesthetes independent of sensory binding

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ABSTRACT

Synesthesia is the phenomenon in which individuals experience unusual involuntary cross-modal pairings. The evidence to date suggests that synesthetes have access to advantageous item-specific memory cues linked to their synesthetic experience, but whether this emphasis on item-specific memory cues comes at the expense of semantic-level processing has not been unambiguously demonstrated. Here we found that synesthetes produce substantially greater semantic priming magnitudes, unrelated to their specific synesthetic experience. This effect, however, was moderated by whether the synesthetes were projectors (their synesthetic experience occurs in their representation of external space), or associators (their synesthetic experience occurs in their 'mind's eye'). That is, the greater a synesthetes's tendency to project their experience, the weaker their semantic priming when the task did not require them to semantically categorize the stimuli, whereas this trade-off was absent when the task did have that requirement.

1. Introduction

There is a subset of the population, called synesthetes, who appear to have a qualitatively richer experience of the world around them. Synesthesia is defined as the involuntary experience of largely idiosyncratic cross-modal bindings, where a particular stimulus ('inducer') evokes a given sensory experience ('concurrent') for that individual. For example, an individual with grapheme-color synesthesia can experience the color forest-green as a consequence of reading the letter 'A', an individual with music-color synesthesia may experience a distinct shade of purple in response to the note F#, and an individual with sound-taste synesthesia can experience a salty taste in response to the sound of a friend's voice (e.g., Galton, 1880; Mattingley, Rich, Yelland, & Bradshaw, 2001; Ramachandran & Hubbard, 2001; Simner, 2007; Watson, Akins, Spiker, Crawford, & Enns, 2014). The purpose of this study is to elucidate the nature of the semantic processing of individuals with synesthesia.

A substantial body of evidence demonstrates that synesthetic sensations are genuine experiences that are involuntary consequences of perceiving the inducing stimulus. A given individual's synesthetic associations tend to be highly reliable over time (Edquist, Rich, Brinkman, & Mattingley, 2006). Moreover, adaptations of classic cognitive interference tests, such as the Stroop test (Stroop, 1935), demonstrates the involuntary nature of these bindings. For example, if a given synesthete associates the word 'May' with the color blue, then this synesthete will be faster to identify the physical color in which the word is presented when it matches their synesthetic experience (e.g., May in blue) compared with when it appears in a

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conflicting color (e.g., May in red). Such response-time congruity effects demonstrate that the synesthetic association is involuntary, in that it is elicited even when it is unhelpful to task at hand (Dixon, Smilek, Cudahy, & Merikle, 2000; Mattingley et al., 2001; Smilek, Dixon, Cudahy, & Merikle, 2001). Moreover, there is activation in areas of the brain that process color during synesthetic experience of color (Sperling, Prvulovic, Linden, Singer, & Stirn, 2006), and finally, the underlying brain anatomy of synesthetes differs from that of non-synesthetes, such that it is characterized by stronger and more diffuse connectivity (Bargary & Mitchell, 2008). Altogether, these imply that synesthetic experiences are genuine, involuntary experiences.

The most common forms of synesthesia reported are grapheme-color and lexical-color synesthesia, in which a particular grapheme (letter or digit) or words reliably elicits the experience of a particular color (Simner et al., 2006). But many other different forms of synesthesia have also been identified, such as music-shape synesthesia in which different musical instruments elicit the experience of particular shapes (Mills, Boteler, & Larcombe, 2003), and lexical-gustatory synesthesia in which reading or hearing words evokes the sensations of particular flavors (Jones et al., 2011), and person-color synesthesia in which a halo of color surrounds given individuals (Ramachandran, Miller, Livingstone, & Brang, 2012). In addition to the existence of many different forms of synesthesia, a core distinction among synesthetes is whether their synesthetic experience occurs in their external representation of space (*projectors*) or whether it occurs internally, in the individual's "mind's eye" (*associators*) (Dixon, Smilek, & Merikle, 2004). This categorization is not just one of conventional nomenclature. Instead, the evidence suggests that the functional consequences of synesthesia can be qualitatively different for these different forms of synesthetic experience. Dixon et al. (2004) investigated the synesthetic Stroop procedure described above in synesthetes identified as projectors versus associators, with one modification: in one condition participants' task was to identify the synesthetic color induced by the word presented, and in the other, their task was to identify the physical color in which the word was presented. Projectors were quicker to name the synesthetic color, and produced the greatest congruency effect when they were naming the physical color (interference therefore created by synesthetic experience of color), whereas associators were faster to name the physical color, and obtained the strongest congruency effect when they were naming the synesthetic color (interference therefore created by the physical color) (Dixon et al., 2004).

Further evidence that there are distinct perceptual consequences for projector versus associator synesthetes is that whether the synesthetic experience of color produces pop-out in visual search in the way of normal color (e.g., Treisman & Gelade, 1980) depends on whether the synesthete is a projector or an associator. That is, the concurrent experience of color appears to influence attention and speed visual search for a projector synesthete (Smilek, Dixon, & Merikle, 2003), but not in samples where the associator/projector distinction was not analyzed (Edquist et al., 2006). Moreover, in samples where the projector/associator distinction was not drawn, awareness of the inducing stimulus appears necessary for the synesthetic experience to be elicited, such that the concurrent experience does not survive masking of the inducer (Bacon, Bridgeman, & Ramachandran, 2013; Mattingley et al., 2001). In contrast, it has been reported that for one projector synesthete, their synesthetic experience of color protected against object-substitution masking (Wagar, Dixon, Smilek, & Cudahy, 2002), a form of visual masking in which target awareness is impaired due to object-updating processes (for a review see Goodhew, Pratt, Dux, & Ferber, 2013). This suggests that projector versus associator synesthesia has different perceptual consequences and that the associator/projector distinction is an important one for making sense of different patterns of results with synesthetes.

More recently, the research focus in the field has shifted from the perceptual consequences of synesthesia, to the condition's cognitive consequences, including the implications for language processing and memory. The evidence is accumulating to indicate that, consistent with their subjective reports of superior memory, synesthetes can strategically use their experience to facilitate objective performance on memory tasks (Gross, Neargarder, Caldwell-Harris, & Cronin-Golomb, 2011; Pritchard, Rothen, Coolbear, & Ward, 2013; Rothen & Meier, 2010; Rothen, Meier, & Ward, 2012; Watson, Blair, Kozik, Akins, & Enns, 2012; Yaro & Ward, 2007). For example, Radvansky, Gibson, and McNerney (2011) compared 10 grapheme-color synesthetes against controls on a series of memory tasks that indirectly measure semantic processing. The first of these tested the von Restorff effect, in which memory is enhanced for an item in a list when that item is presented in a distinctive way. For example, a word presented in red is likely to enjoy superior memory recall when it is embedded in a list of items presented in black, because the red item is uniquely defined along the given (color) dimension (Hunt, 1995). Radvansky et al. (2011) found that when the distinctiveness of the critical item was defined in terms of color in a word list, synesthetes showed a reduced von Restorff effect (i.e., reduced memory advantage for the critical item) compared to controls. As the authors pointed out, this is likely due to the fact that the synesthetes experienced color for some or all of the words in the list as colored, thus diluting the distinctiveness of the physically-colored item. However, a reduced von Restorff effect was also observed in these same synesthetes when the item's distinctiveness was manipulated by virtue of semantics. That is, the critical word belonged to a distinct semantic category compared with the other items on the list (Radvansky et al., 2011). This result could be interpreted as indicating a general reduced semantic processing capacity in synesthetes. Another possibility, however, is that the synesthetic surface features induced an item-specific mode of processing, that attenuated the depth of semantic processing for the synesthetes in this context. This would suggest a trade-off between item-specific and relational processing in synesthetes.

The second major test was the Deese–Roediger–McDermott (DRM) false memory paradigm. That is, non-synesthetes typically show a strong and reliable false memory effect, whereby after exposure to a list of semantically-related words, a critical lure that is semantically related to the presented words but was not actually shown, tends to be incorrectly identified as having been presented (Deese, 1959; Roediger & McDermott, 1995). This is a judgment that participants endorse with a high degree of confidence. For example, after being presented with words such as 'thread', 'pin', 'eye', 'sewing', 'sharp', 'point', 'pricked', 'thimble', 'haystack', 'pain', 'hurt', and 'injection', they will falsely recall having seen the semantically-related item of 'needle', whereas they will not tend to falsely recall unrelated items (such as 'sleep'). Radvansky et al.'s (2011) grapheme-color synesthetes were less prone to such false-memory effects. One possible explanation for this is that synesthetes have a generic tendency to process information in an item-specific way that deemphasizes relational encoding, which renders them resilient to the potential false memory effect induced by the semantically-related critical lure. Another possible explanation, however, and the one that Radvansky et al.'s (2011) favored, is that since their sample consisted of grapheme-color synesthetes, the synesthetes processed and recalled the information in the same way as non-synesthetes, and then just strategically used their synesthetic experience to be able to correctly reject the critical lures. For example, with the list described above, they may initially falsely recall 'needle' given the semantic context, but then determine that they had not experienced their unique color associated with this term, and so then subsequently rejected it. Such perceptual distinctiveness has been found to reduce false memories in non-synesthetes (Israel & Schacter, 1997).

To summarize, there is compelling evidence that synesthetes can use the experience of color to enhance memory for stimuli that elicit their synesthetic experience. One question that has been raised, therefore, is whether this entails a trade-off between a relatively superficial way of processing information that emphasizes the appearance of the items ('item-specific encoding') on the one hand, and a relational style of processing, which emphasizes broader, categorical connections between stimuli (for the first introduction of these terms, see Hunt & Einstein, 1981) on the other. That is, while synesthetes have an advantage in memory tasks for stimuli that elicit a synesthetic experience, presumably due to the additional cues, one possibility is that this advantage comes at the expense of deeper, semantic, or relational processing (Gibson, Radvansky, Johnson, & McNerney, 2012). The results of Radvansky et al. (2011) cannot tell us that, because they cannot distinguish between using perceptual distinctiveness as a heuristic versus intrinsically reduced semantic processing.

Gibson et al. (2012) directly tested the possibility that the synesthetic memory advantage comes at the cost of relational encoding. These authors found that while 10 grapheme-color synesthetes outperformed non-synesthetes overall in memory recall for word lists, presumably due to their additional concurrent color experience, they had equivalent serial-order encoding as compared with non-synesthetes (Gibson et al., 2012). From this, it was concluded that there is no trade-off between item-specific and relational encoding in synesthetes. One might argue, however, that serial-order, while a form of relational encoding, is not actually gauging depth of semantic processing. In a nutshell, then, the nature of semantic processing and its interaction with item-specific encoding in synesthetes remains to be definitely established.

The purpose of the present study, therefore, was to provide a direct test of semantic processing in synesthetes, independent of their synesthetic experience. To do this, we used *semantic priming*, which refers to the subconscious cognitive process whereby activation of a particular word meaning activates near-neighbor semantic nodes in the network (McNamara, 2005; McRae & Boisvert, 1998; Meyer & Schvaneveldt, 1971; Tulving & Schacter, 1990). This can be measured via a simple reaction time task. That is, priming is evident if participants are faster to respond to the word 'eagle' after first seeing the word 'hawk', compared to if they first see a semantically-unrelated word such as 'bus'. That is, the meaning of the word is processed and so "primes" the system for efficient processing and thus response to a subsequent semantically-related word. This means that if synesthetes have normal semantic processes, then they should show equivalent semantic priming relative to controls. Alternatively, if synesthetes have a pervasive cognitive style that is characterized by reduced semantic processing, then they should show reduced semantic priming relative to controls. In order to provide the greatest possible clarity of interpretation, we also wanted to be able to distinguish the possibility that synesthetes strategically trade-off between item-specific and relational processing, versus the possibility of a pervasive cognitive style that may accompany synesthesia (a reduced tendency to process semantic relations). To do this, we did not limit our sample to grapheme-color synesthetes, and in the analysis we directly compared the results of those synesthetes for whom our word stimuli evoked concurrent experiences versus those who they did not. This means that if synesthetes only emphasize item-specific encoding at the cost of semantic processing when processing stimuli for which they have a concurrent synesthetic experience, then reduced semantic priming would be evident in the grapheme and lexical inducer forms of synesthesia, but normal in other forms of synesthesia.

We were also interested in how context-specific synesthetes' semantic processing might be. One possibility, for example, is that while synesthetes' default processing style is to focus on the item-specific cues provided by the concurrent synesthetic experience, that this tendency could be overcome when a task *compels*, rather than merely indirectly *measures*, semantic processing. To delineate such a possibility, we had two semantic priming tasks. In both, semantic priming was still measured based on the semantic relationship between prime and target pairs. However, the task that participants performed with respect to the target differed: in separate blocks, they performed either a lexical decision task (where participants judged whether the stimulus presented was a meaningful word or a nonsense non-word), or a semantic categorization task (where participants identified whether the meaning of the word referred to an entity that is abstract or concrete). Since a lexical decision task does not compel semantic-relational processing, whereas the semantic categorization task does, our predictions were as follows. If synesthetes can only process information in an item-specific manner, at the expense of more abstract semantic processing, then they should show reduced or absent priming, regardless of task. If synesthetes' default style of processing is item-specific, but they can be compelled to cognate more abstractly and semantically, then they should show reduced/absent priming in the lexical decision condition, but equivalent priming to non-synesthetes in the semantic categorization condition. Or, finally, if their cognitive processing really is equivalent to controls and their differing performance on cognitive tasks was due to selective use of their synesthetic experience, then they should show priming equivalent to non-synesthetic control participants in both conditions.

2. Method

2.1. Participants

A total of 56 participants were recruited from Canberra. Both control and synesthetic participants were recruited via multiple means: a research participation website, fliers around the Australian National University campus, and an article in a local newsletter. Participants were included in the synesthete group if they self-reported synesthesia, and this was verified via the objective and validated standardized online battery for the study of synesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Participants were included as controls if both their self-reports and the initial battery screening confirmed an absence of synesthesia.[1] Participants (7) who did not meet these criteria were excluded from analysis. One control participant was also excluded for anomalous responses, see results section. Altogether, then, there were 26 control participants and 22 in the synesthete group. All participants provided written informed consent and were paid in exchange for their participation. Demographic data for the two groups are shown in Table 1, and detailed information about the synesthetic experiences of the synesthete group can be found in Appendix A.

2.2. Apparatus

Stimuli were presented on a CRT monitor running at a refresh rate of 75 Hz. Participants used a chin rest, positioned 44 cm from the screen to ensure that viewing distance remained constant.

2.3. Materials

Two semantic priming tasks were developed using the Matlab Psychophysics Toolbox (version R2012a): a lexical decision task and a semantic categorization task. A core list of congruent and incongruent prime–target word pairings, originally developed by McRae and Boisvert (1998), were used for both the lexical decision task and the semantic categorization task. Semantically congruent pairings included two words that conveyed similar semantic meaning (e.g., 'truck'–'van'). Semantically incongruent pairings included two words that were not semantically related in any way (e.g., 'truck'–'budgie'). Four target words from the original core list were modified to better reflect Australian English: 'beets' was replaced with 'beetroot', 'caribou' was replaced with 'deer', 'hoe' was replaced with 'spade', and 'subway' was replaced with 'train'. Additionally, two target words were changed to eliminate any ambiguity between concrete and abstract word meaning in the semantic-categorization task: 'prune' was replaced with 'peach', and 'squash' was replaced with 'eggplant'.

Both tasks used subsets of the same semantically-related prime–target word pairs, but differed in that they used semantically different distractor words which targeted different overt task requirements. The lexical decision task contained non-word distractors, which were defined as phonetically viable words that had no conceptual meaning in the English language (e.g., 'furjey'), and the semantic categorization task contained abstract words as distractors, which were defined as words that represented an abstract or intangible concept (e.g., 'midnight'), feeling (e.g., 'love'), or action (e.g., 'pretend'). The complete lists can be seen in Appendix B.

2.4. Procedure

Participants first completed an initial questionnaire within the Synesthesia Battery, from which if they were identified as having synesthesia completed any necessary specific sub-tests to verify synesthetic ability. Then participants completed the two semantic priming tasks (blocked, order counterbalanced). The word lists were divided into two sets, and each participant was exposed to a different set for the two tasks (e.g., Set 1 for the lexical decision task and then Set 2 for the semantic categorization task), and again the assignment of sets to conditions was counterbalanced.

Twelve practice trials preceded each experimental block, where feedback on the accuracy of each response was provided via the computer screen, in order to confirm that the participants understood the instructions. As the semantic priming paradigm used a single presentation design (McRae & Boisvert, 1998), participants were required to respond to every word. Response times (RTs), however, were only analyzed from responses to the second item in each pair (e.g., if 'truck', and then 'van' were presented, the response time to 'van' would be analyzed as a congruent trial response). In the lexical decision task, participants were instructed to press 'z' in response to a viable English word or '/' for a non-word, and similarly to press 'z' for a concrete word, and '/' for an abstract word in the semantic categorization task. Each word was presented until participants responded and they were instructed to respond as quickly and accurately as possible. The screen was blank for a 200 ms inter-stimulus interval between words. When two consecutive words were semantically related, this was defined as 'congruent', whereas when two consecutive words were semantically unrelated, this was defined as 'incongruent'. Each block consisted of 114 trials.

[1] One self-reported grapheme-color synesthete scored 1.05 on the battery, where the cut-off is 1.0 and below for synesthesia. The pattern of results was unchanged irrespective of whether this participant was included, and therefore we included this dataset in the analysis.

Table 1
Demographics for the synesthetic and control groups.

	Age (years)	Gender	Handedness
Synesthete group ($N = 22$)	38.1 (SD = 20.6) Range: 17–76	19 F/3 M	20 R/2 L
Control group ($N = 26$)	35.0 (SD = 21.1) Range: 18–76	18 F/8 M	21 R/5 L

3. Results and discussion

Trials were excluded from the analysis if they were faster than 100 ms, or slower than 2.5 standard deviations above the participant's mean RT (2.9%). Average accuracy was high for both groups (range 93–97% across conditions). This is expected, given that the stimuli were presented until participants made a response. Data from one control participant was excluded as she was unfamiliar with computers and thus did not comply with the instruction to place her fingers on the response keys, but instead located the response keys on each trial after the stimulus was presented. This made her response times, especially in her first block, particularly long (average 1048 ms, whereas the average for the remaining participants was 582 ms). Her data were therefore excluded from further analysis. The priming magnitudes for the remaining 26 controls and 22 synesthetes for each of the tasks can be seen in Fig. 1, and the raw accuracy and RT for each condition can be seen in Table 2.

These RT data were submitted to a 2 (task: lexical decision versus semantic categorization) × 2 (congruency: congruent versus incongruent) × 2 (group: controls versus synesthetes) mixed-ANOVA. This revealed a significant main effect of task, $F(1,46) = 44.46$, $p < .001$, $\eta_p^2 = .492$, such that responses were faster for the lexical decision task than for the semantic categorization task. This main effect did not interact with group ($F < 1$). The main effect of group was significant, $F(1,46) = 9.86$, $p = .003$, $\eta_p^2 = .177$, such that synesthetes were on average slower than controls. There was also a significant

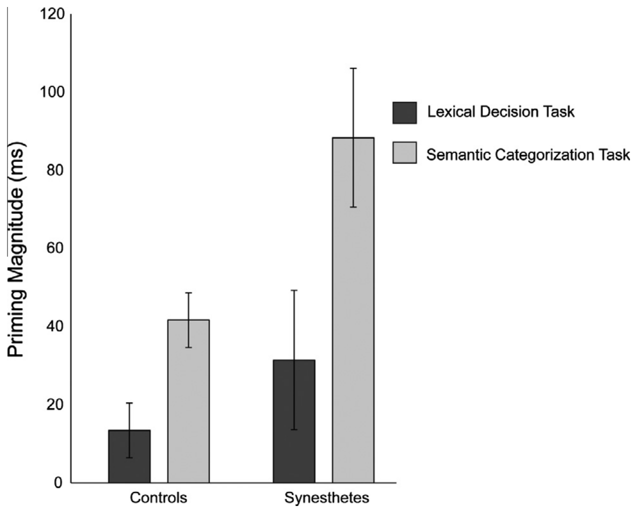

Fig. 1. Priming magnitude (difference in RT between incongruent and congruent trials) for controls and synesthetes for the lexical decision task and the semantic categorization task. The error bars depict standard errors that were calculated according to within-subjects correction reported in Cousineau (2005).

Table 2
Mean accuracy (%) and RT (ms) for each of the conditions for controls and synesthetes. Cont = controls, Syn = synesthetes. LDT = lexical decision task, SCT = semantic categorization task. Cong = congruent, Incong = incongruent.

	Cont LDT Cong	Cont LDT Incong	Cont SCT Cong	Cont SCT Incong	Syn LDT Cong	Syn LDT Incong	Syn SCT Cong	Syn SCT Incong
Accuracy	93.7	96.5	94.1	94.6	96.3	96.1	95.5	95.3
RT	574.8	588.6	670.5	711.8	678.8	710.2	780.3	868.6

main effect of congruency, $F(1,46) = 32.81$, $p < .001$, $\eta_p^2 = .416$, such that responses were faster on congruent trials than on incongruent trials. This indicates that priming was obtained. Crucially, however, this main effect was qualified by a significant interaction between congruency and group, $F(1,46) = 4.51$, $p = .039$, $\eta_p^2 = .089$, whereby synesthetes demonstrated a larger priming effect than controls. There was also a significant interaction between task and congruency, $F(1,46) = 5.56$, $p = .023$, $\eta_p^2 = .108$. This was driven by the fact that priming was greater for the semantic categorization task than in the lexical decision task, as per (McRae & Boisvert, 1998). The three-way interaction among task, congruency, and group was not significant ($F < 1$).

It is striking that synesthetes produced substantially greater semantic priming than controls, as this was not one of our predictions from the outset. Synesthetes do have more diffuse brain connections (Bargary & Mitchell, 2008) and so a more abstract, relational encoding is a possible product of this underlying neuroanatomy. At a more functional level, synesthetes have been identified as an unusually creative group, with higher than average proportions of artists, writers, and such creative occupations (Domino, 1989; Ward, Thompson-Lake, Ely, & Kaminski, 2008). A greater tendency toward semantic priming is consistent with such creativity. For example, metaphors and similes in creative writing are fundamentally about drawing relational connections between stimuli that are abstractly rather than superficially related. Thus, a greater tendency to recognize such broad, abstract relational properties would lend itself to such creative pursuits.

Another possible explanation for the synesthetes' enhanced semantic priming, however, is that the response time effects were driven by the synesthetic experience of color. We did not envisage the synesthetic experience as bearing any relation to the semantic priming tasks employed. However, if it is the case that (a) semantically related words tend to be the same color for a given synesthete, and (b) responses to lexical decisions and semantic categorizations are facilitated when the two consecutive stimuli to be judged appear in the same color compared to different colors, then this could have produced the strong effect of congruency on RT for synesthetes. To our knowledge, neither (a) nor (b) has been demonstrated, and thus does not appear a likely candidate mechanism for the observed pattern of results. That said, our heterogeneous sample of synesthetes allows us to test this possibility. Premise (a) can only be true for synesthetes who experience grapheme-color or lexical-color synesthesia. While the synesthesia battery categorizes the various forms of synesthesia, and records the color experienced for some common forms (e.g., days of the week), it obviously does not test the color experienced for all words, including those in our priming task. It does, however, allow us to classify the synesthetes for whom this is a viable possibility: we compared the pattern of results for those synesthetes who identified any form of grapheme-color or lexical-color synesthesia (letters or words elicit color). This group consisted of 14 synesthetes, with the other 8 in the non-lexical group. We then performed a 2 (group: lexical versus non-lexical synesthete) $\times$ 2 (task) $\times$ 2 (congruency) mixed ANOVA. This revealed a significant main effect of task, $F(1,20) = 14.55$, $p = .001$, $\eta_p^2 = .421$, and a significant main effect of congruency, $F(1,20) = 14.68$, $p = .001$, $\eta_p^2 = .423$, neither of which interacted with group (Fs < 1). The task by congruency interaction was not significant, $F(1,20) = 2.33$, $p = .143$, $\eta_p^2 = .104$, and did not further interact with group ($F < 1$). This tells us that the large priming effect observed in the synesthetic group did not differ as a function of whether the synesthesia was lexical or grapheme-based in nature or not. This implies that the enhanced semantic priming effect observed was not a product of experienced synesthetic color facilitating responses on congruent relative to incongruent trials.

As we noted in the Introduction, differences have been observed between projector and associator synesthetes on visual tasks. Here, therefore, we sought to test whether semantic priming differed as a function of this variable. The Projector/Associator (P/A) subtest[2] on the synesthesia battery (Eagleman et al., 2007) provides a measure where scores below zero are indicative of an associator, whereas scores greater than 0 are indicative of projector status (these scores are reported for each synesthete in Appendix A). We therefore entered P/A scores as a covariate along with the congruency and task factors. This confirmed a significant main effect of task, $F(1,18) = 17.82$, $p = .001$, $\eta_p^2 = .498$, which did not interact with P/A score, $F(1,18) = 1.82$, $p = .194$, $\eta_p^2 = .092$. There was also a significant main effect of congruency, $F(1,18) = 7.12$, $p = .016$, $\eta_p^2 = .284$, and the interaction between congruency and P/A score approached significance, $F(1,18) = 4.12$, $p = .057$, $\eta_p^2 = .186$. This suggests that the semantic priming effect was differing as a function of synesthetes's tendency to project versus associate their synesthetic experience. The other interactions were not significant (Fs < 1.71, ps > .208, η_p^2s < .087).

Given that the relatively small sample size was likely constraining statistical power, and the fact that the interaction between P/A score and congruency was so close to significance, we decided to follow up this effect. For P/A scores, 0 is the point that defines classification as 'Projector' versus 'Associator', but the scores are continuous such that a higher positive value indicates a greater tendency project. We had two participants score at zero (borderline), four above zero (projectors), and the rest were below zero (associators). In other words, projector synesthetes were relatively rare, consistent with previous reports (Dixon et al., 2004). Given the small number of projectors, and the fact that P/A scores are continuous, we reasoned that the optimal analysis approach was to compute Pearson's correlation coefficients between the continuous P/A scores and priming magnitudes in the lexical decision task and semantic categorization tasks for all of the synesthetes. This revealed a significant negative correlation between P/A score and priming magnitude on the lexical decision task ($r = -.48$, $p = .032$), whereas the correlation between P/A score and priming magnitude on the semantic categorization task was not significant ($r = -.15$, $p = .540$). In order words, the greater the tendency to project one's synesthetic experience out in space, the weaker one's priming in the lexical decision task. The semantic categorization task, in contrast, did not appear to

[2] Note that two synesthetes did not complete the Projector/Associator subtest of the battery, and therefore were not included in the Projector/Associator analyses.

be impacted by P/A score. Why might this be? It could be because projector synesthetes are the individuals who have more dominating perceptual experiences. This rich and vivid sensory experience may have enhanced their item-specific encoding, downplaying their semantic-relational processing when the task did not demand semantic processing. In other words, for projector synesthetes, there appears to be a trade-off between relational and item-specific encoding when making a lexical decision, but this trade-off disappears when the task requires semantic processing (semantic categorization task).

4. General discussion

The most striking result to emerge here was that synesthetes showed greater semantic priming relative to non-synesthete controls. We were able to rule out the possibility that the synesthetic experience of color was responsible for this effect, as whether the individuals who had letter or word induced forms of synesthesia or not had no impact on priming magnitude among the synesthetes. This suggests, therefore, that synesthetes as a group process semantic relations among items more strongly than controls. That is, far from having a potential disadvantage in semantic processing, at least in some circumstances, synesthetes can actually enjoy an advantage.

A caveat to this result, however, was what appears to be a difference between associator and projector synesthetes. Specifically, projector synesthetes demonstrated a context-specificity in their priming magnitude, such that their priming was diminished in the lexical decision task only. The fundamental difference between the lexical decision task and the semantic categorization task is that the latter demands semantic-level processing, whereas a lexical decision does not. Given that projector synesthetes have a richer and more vivid synesthetic experience than associator synesthetes, this suggests that they emphasize the surface characteristics of items (i.e., item-specific encoding) by default, but that this tendency can be overcome, to reveal enhanced semantic priming when they were forced to categorize the stimuli along a semantic dimension. That is, projector synesthetes exhibit a trade-off between item-specific and semantic processing, such that item-specific processing is emphasized when the task does not demand semantic-level processing. Associator synesthetes, in contrast, demonstrated enhanced semantic processing invariant to task.

These results are consistent with and even reconcile some discrepancies in previous literature. As noted in the 1.0 Introduction section, one possible interpretation of Radvansky et al.'s (2011) results was that synesthetes may have a reduced tendency to draw semantic relations between stimuli, given their reduced susceptibility to semantic distinctiveness advantages in memory (von Restorff effects) and semantic-relation-induced false memories (DRM false memory paradigm). However, for both of these memory tasks, the synesthetic experience of color was likely strategically used to confer an advantage on these tasks, and thus do not provide a clear metric of synesthetes capacity for semantic processing. That is, synesthetes may have initially recalled the critical lure in the false memory paradigm to an equal or even greater extent than controls, but given that they were all grapheme-color synesthetes, they could have strategically used their synesthetic experience to subsequent reject these false recalls (Radvansky et al., 2011). Even though the reduced von Restorff effect for synesthetes persisted when the critical item was semantically defined, given that synesthetes report using their experiences to enhance their memory (Yaro & Ward, 2007), and that this was a memory-task, it was likely that they were emphasizing this aspect of the stimuli, and this may have diluted the apparent distinctiveness of that item. Even if they were equally cognizant of its semantic distinctiveness, since many of the items would have also been perceptually distinct, all of the items might have enjoyed an advantage, diluting any differential effect. Consistent with this interpretation, the synesthetes showed a strong overall memory advantage in all conditions over the controls. Thus, the results of these memory-based tasks do not provide direct evidence regarding semantic processing, whereas the present semantic priming results do.

The results of Gibson et al. (2012) suggest the absence of a trade-off between item-specific and relational encoding. However, encoding of serial order, while a form of relational processing, is likely quite different to true semantic processing. In this vein, Radvansky, Gibson, and McNerney (2014) reported that despite synesthetes having an enhanced working memory span relative to controls, this did not translate into any advantage for situation or meaning-based textual analysis. All of the tasks these authors used, however, indirectly *measured* semantic processing, but from the participant's point of view, the task did not *require* it. Tasks included those that gauged performance on sentence memory, understanding causal connections and functional relations, and temporal shifts in stories (Radvansky et al., 2014). These, however, involved tests of memory. While some of the tasks are related to semantic processing, such as recalling sentences, in that condition participants' purported task was to rate the pleasantness of the sentences. It is plausible that participants could make this kind of judgment without deep semantic processing (e.g., do they find the colors associated with that sentence pleasant)? None of these tasks, therefore, compelled semantic processing in the way of the semantic categorization task here. It is possible, therefore, that especially if Radvansky et al.'s (2014) sample contained a substantial proportion of projector synesthetes (this distinction was not reported), then in a context where semantic processing was not absolutely required, these synesthetes emphasized item-specific ways of encoding the stimuli, and thus not revealing any enhanced semantic processing.

5. Conclusions

In conclusion, synesthetes show greater semantic priming than controls, independent of their specific sensory experience. This effect, however, appeared most robust in the associator synesthetes, whereas projector synesthetes had a tendency to show reduced semantic priming in the lexical decision task, where semantic-level processing was not required. This highlights the importance of the Projector/Associator dimension in understanding the cognitive processing hallmarks of synesthesia.

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Appendix A

Synesthete #	Types of synesthesia	Projector/Associator Score (negative = associator)
1	Sequence → Spatial Locations (sequences such as numbers, weekdays, or months) Personalities → Color Temperature → Color	−0.5
2	Letters → Color Weekdays → Color Months → Color Musical Pitch → Color Musical Chords → Color Musical Instruments → Color Smell → Color Pain → Color Personalities → Color Temperature → Color Vision → Sound Sound → Smell Sound → Touch Vision → Taste Greek Alphabet → Color	−2.67
3	Temperature → Color Vision → Sound Taste → Smell	0
4	Smell → Color Pain → Color	0
5	Absolute/Perfect Pitch Numbers → Color Letters → Colors Weekdays → Color Months → Color Taste → Color Personalities → Color Temperature → Color Vision → Smell	−2.83
6	Numbers → Color Letters → Color Weekdays → Color Months → Color Musical Chords → Color Personalities → Color Emotion → Color	1.83

Appendix A (*continued*)

Synesthete #	Types of synesthesia	Projector/Associator Score (negative = associator)
7	Numbers → Color Pain → Color Personalities → Color Emotion → Color	Did not complete subtest
8	Absolute Pitch/Perfect Pitch Numbers → Color Months → Color Musical Instruments → Color Personalities → Color Emotion → Color Vision → Sound Sound → Touch Vision → Touch	−0.5
9	Numbers → Color Letters → Color Weekdays → Color Months → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months) Musical Pitch → Color Sound → Taste	−2.17
10	Weekdays → Color Vision → Taste	−0.67
11	Numbers → Color Letters → Color	0.5
12	Numbers → Color Letters → Color Weekdays → Color Months → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months) Personalities → Color Emotion → Color	2.33
13	Voices-Shapes	0.17
14	Numbers → Color Letters → Color Weekdays → Color Months → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months)	−2
15	Absolute Pitch/Perfect Pitch Weekdays → Color Sound → Touch Sound → Taste Vision → Taste Vision → Touch	0
16	Absolute Pitch/Perfect Pitch Musical Instruments → Color Personalities → Color Emotion → Color	−0.17

(*continued on next page*)

Appendix A (*continued*)

Synesthete #	Types of synesthesia	Projector/Associator Score (negative = associator)
	Vision → Taste	
17	Absolute Pitch/Perfect Pitch Numbers → Color Letters → Color Weekdays → Color Months → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months) Personalities → Color Emotion → Color	Did not complete subtest
18	Numbers → Color Letters → Color Months → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months)	−2.67
19	Numbers → Color Letters → Color Weekdays → Color Month → Color Personalities → Color Emotion → Color Also reported smells have certain shapes associated with them, e.g., the smell of fresh air is rectangular, coffee is a bubbly cloud shape, people can smell round or square	−0.83
20	Musical Chords → Color Musical Instruments → Color Also reported Music causing perception of shapes which have Color	0
21	Absolute Pitch/Perfect Pitch Numbers → Color Letters → Color Weekdays → Color Months → Color Chinese Numbers → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months) Chinese Characters → Color Personalities → Color Japanese alphabet → Color	−2
22	Numbers → Color Letters → Color Sequences → Spatial locations (sequences such as numbers, weekdays, or months)	−2

Appendix B

Wordlists for lexical decision task and semantic categorization task.

Prime–target pairs – Group 1		Prime–target pairs – Group 2		Distractors			
Similar	Dissimilar	Similar	Dissimilar				
Lexical decision task							
parakeet–budgie	crayon–toaster	microwave–toaster	whale–budgie	marawoot	bentie	gragon	toosher
finch–canary	shed–jar	bottle–jar	plum–canary	fliffs	muzary	gred	jur
goose–turkey	canoe–pencil	crayon–pencil	slippers–turkey	gooch	furjey	capoo	mencyl
eagle–hawk	bus–shovel	spade–shovel	pumpkin–hawk	eufle	harx	buk	brodel
duck–chicken	truck–sandpaper	file–sandpaper	lamp–chicken	dult	specken	sluck	saircaver
whale–dolphin	bottle–barn	shed–barn	duck–dolphin	whass	dombrin	bopple	bamb
moose–deer	rifle–ship	yacht–ship	radish–deer	mooth	deeg	piddle	brip
plum–peach	raft–missile	canoe–raft	finch–peach	frum	peath	missaws	ralk
coconut–pineapple	sword–train	bus–train	bra–pineapple	cocotym	purlappla	swoin	trame
radish–beetroot	axe–cart	wagon–cart	closet–beetroot	rudine	beefriet	aut	cawn
pumpkin–eggplant	microwave–van	truck–van	tie–eggplant	peshkin	ernstant	mistohasm	var
peas–beans	slingshot–dunebuggy	jeep–dunebuggy	parakeet–beans	peam	peams	dringfrot	durtnoggy
slippers–sandals	cannon–scooter	motorcycle–scooter	cushion–sandals	plappers	mindals	candin	freater
bra–camisole	wagon–tomahawk	axe–tomahawk	moose–camisole	cra	camimice	wizon	tomakitz
tie–belt	spade–bomb	missile–bomb	peas–belt	tou	bech	spath	bobe
lamp–chandelier	jeep–catapult	slingshot–catapult	mat–chandelier	lart	stundeloor	veep	catavoth
closet–dresser	file–pistol	rifle–pistol	goose–dresser	plopet	druller	fimp	pontol
cushion–pillow	motorcycle–bazooka	cannon–bazooka	coconut–pillow	custeen	pellaw	motangyple	bajouza
mat–carpet	yacht–spear	sword–spear	eagle–carpet	mab	barvet	ymphs	flear
Semantic categorization task							
parakeet–budgie	crayon–toaster	microwave–toaster	whale–budgie	ugly	harmony	freedom	midnight
finch–canary	shed–jar	bottle–jar	plum–canary	idea	willpower	gluttony	happy
goose–turkey	canoe–pencil	crayon–pencil	slippers–turkey	lost	destiny	sin	envy
eagle–hawk	bus–shovel	spade–shovel	pumpkin–hawk	alone	create	irony	love
duck–chicken	truck–sandpaper	file–sandpaper	lamp–chicken	listless	relate	delight	cold
whale–dolphin	bottle–barn	shed–barn	duck–dolphin	greed	increase	justice	melancholy
moose–deer	rifle–ship	yacht–ship	radish–deer	decrease	feeling	forever	finish
plum–peach	raft–missile	canoe–raft	finch–peach	tireless	angry	alive	pretty
coconut–pineapple	sword–train	bus–train	bra–pineapple	assume	wistful	gladness	begin
radish–beetroot	axe–cart	wagon–cart	closet–beetroot	among	enjoyment	joy	distraction
pumpkin–eggplant	microwave–van	truck–van	tie–eggplant	driven	beautiful	excitement	around
peas–beans	slingshot–dunebuggy	jeep–dunebuggy	parakeet–beans	impression	thought	anticipation	sustain
slippers–sandals	cannon–scooter	motorcycle–scooter	cushion–sandals	whimsical	warm	true	empathy
bra–camisole	wagon–tomahawk	axe–tomahawk	moose–camisole	lyrical	react	like	transient

(*continued on next page*)

Appendix B (*continued*)

Prime–target pairs – Group 1		Prime–target pairs – Group 2		Distractors			
Similar	Dissimilar	Similar	Dissimilar				
tie–belt	spade–bomb	missile–bomb	peas–belt	sad	pretend	meaning	actual
lamp–chandelier	jeep–catapult	slingshot–catapult	mat–chandelier	courageous	value	connect	daring
closet–dresser	file–pistol	rifle–pistol	goose–dresser	anonymous	mad	temper	dramatic
cushion–pillow	motorcycle–bazooka	cannon–bazooka	coconut–pillow	kind	under	over	hope
mat–carpet	yacht–spear	sword–spear	eagle–carpet	caring	left	peace	arrange

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