Echoes from the Past: Synesthetic Color Associations Reflect Childhood Gender Stereotypes

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Grapheme-color synesthesia is a neurological phenomenon in which linguistic symbols evoke consistent color sensations. Synesthesia is believed to be influenced by both genetic and environmental factors, but how these factors interact to create specific associations in specific individuals is poorly understood. In this paper, we show that a grapheme-color association in adult synesthetes can be traced to a particular environmental effect at a particular moment in childhood. We propose a model in which specific grapheme-color associations are "locked in" during development in children predisposed to become synesthetes, whereas grapheme-color associations remain flexible in non-synesthetes. We exploit Western gender-color stereotypes to test our model: we found that young girls *in general* tend to associate their first initial with the color pink. Consistent with our model, adult female synesthetes are influenced by their childhood environment: they associate their first initial with pink. Adult female non-synesthetes do not show this bias. Instead, in our study non-synesthetes tended to associate their first initial with their *current* favorite color. The results thus support the "locking in" model of synesthesia, suggesting that synesthetic associations can be used as a "time capsule", revealing childhood influences on adult linguistic associations. Grapheme-color synesthesia may thus offer an extraordinary opportunity to study linguistic development.

Keywords: synesthesia; multisensory perception; gene-environment interactions; child development

Grapheme-color synesthesia is a phenomenon in which graphemes elicit specific, and automatic sensations of color: a synesthete might say that "The letter R is sky-blue." Synesthetic associations are a genuinely perceptual experience – they really do *see* the colors (Ramachandran & Hubbard, 2001; Palmeri, Blake, Marois, Flanery, & Whetsell Jr., 2002). Synesthetes typically find these additional experiences pleasant and useful – synesthesia is not related to a psychological, psychiatric or neurological "disease". Synesthetes report having had their grapheme-color associations for as long as they can remember, and their specific associations (which letter is which color) are consistent across months or even years (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006). Synesthesia is thought to be related to excess connectivity between brain regions, , and brain imaging studies have found both structural and functional brain connectivity differences between synesthetes and controls (van Leeuwen et al, 2011; Zamm et al., 2013; Rouw & Scholte, 2007; Sinke et al, 2012; Banissy et al 2012; for a review see Rouw, Scholte, & Colizoli, 2011). Synesthesia tends to run in families: 42% of synesthetes report a first-degree relative with synesthesia (Barnett et al 2008; see Brang & Ramachandran, 2011 for a review), and studies suggest that the propensity to develop synesthesia is partly, but not completely, attributable to genetics (Asher et al., 2009; Tomson et al., 2011; Tilot et al., 2018).

Nevertheless, the specific grapheme-to-color associations of a synesthete (which letter is which color) cannot be attributed to genetic predispositions, since graphemes are part of a culturally-defined, learned writing system – we are not born knowing letters. Indeed, previous studies have provided concrete examples of letter-color combinations in certain synesthetes that can be explained by toys from the synesthete's childhood, such as "colored alphabet" refrigerator magnets (Witthoft & Winawer, 2013; Witthoft, Winawer & Eagleman, 2015; but see also Rich et al., 2005)[1]. Thus, although the *propensity* to develop synesthesia is plausibly genetic, the *specific manifestation* (including *which* letter is associated with *which* color) is shaped by environment and learning influences (Barnett et al., 2008; Newell & Mitchell, 2016). However, the exact *nature* of this interaction is not yet known: how does the synesthetic trait shape the particular letter-to-color experiences that set synesthetes apart from non-synesthetes? Several models explore the relationship between genes and environmental influences, attributing differences between synesthetes and non-synesthetes to differences in implicit learning mechanisms (Bankieris & Aslin, 2017; Bankieris et al., 2018), to particular idiosyncratic differences in white matter structure (Rouw & Scholte, 2007; Newell & Mitchell 2016), and to conditioned mental imagery in response to letters (Witthoft & Winawer, 2013; Witthoft et al., 2015). Understanding the underlying mechanisms is not only interesting in its own right, but can also offer important insights into how a particular gene-environment interaction can result in a "different" conscious experience.

This question becomes even more relevant when considering that grapheme-color associations are not unique to synesthetes: non-synesthetes, when forced to choose a color for a grapheme, share some patterns of grapheme-color associations with synesthetes (Simner et al., 2005; Rouw, Case, Gosavi, & Ramachandran, 2014; Mankin & Simner, 2017). However, studies comparing synesthetes and non-synesthetes show that while some patterns of grapheme-color associations are shared, others are unique to synesthetes or non-synesthetes (Simner et al., 2005). These seemingly contradictory findings have led to a debate about the degree to which synesthetic associations are "different" from crossmodal associations in non-synesthetes (e.g., Martino & Marks 2001; Brang, Kanai, Ramachandran, & Coulson, 2011; Simner, 2012; Eagleman, 2012; Deroy & Spence 2013; Watson, Akins, Spiker, Crawford, & Enns, 2014). Why would some patterns of grapheme-color

[1] Similar findings have been obtained in other types of synesthesia; for example, linguistic and conceptual knowledge shapes associations in lexical-gustatory synesthesia (Ward & Simner, 2003).

association be unique to synesthetes, whereas others are present in both synesthetes and non-synesthetes?

As several authors have pointed out, to answer this question and fully understand the synesthetic condition, it is necessary to understand how synesthesia develops during childhood (Watson et al., 2014; Newell & Mitchell, 2016; Witthoft et al., 2015) Currently, only a few studies have examined synesthesia in children. These important studies showed that average consistency – taken as the "gold standard" in diagnosing synesthesia – is relatively low in synesthetic children at age 6/7, and increases by age 10/11 (Simner et al., 2008; Simner & Bain, 2013). Synesthetic children with colored numbers also showed learning and memory deficits when to-be-remembered numbers were written in a color incongruent with their own synesthetic colors (Green & Goswami, 2008). Together, these findings suggest both protracted development of synesthesia, and reduced flexibility in synesthetes as compared with non-synesthetes. This links synesthesia to literature on functional specialization (Newell & Mitchell, 2016): over time, a particular function, such as face recognition (Haan, Pascalis, & Johnson, 2002) or letter and phoneme perception (Werker & Tres, 1984; Brem et al., 2010), becomes more fixed and fluent at the expense of flexibility. The current study builds upon and extends previous models of differences between the synesthetic and non-synesthetic developmental processes. In particular, we show that the combination of protracted development and reduced flexibility in synesthetes makes a testable prediction about why letter-color associations in synesthetes and non-synesthetes are sometimes similar and sometimes different.

We propose that genetically-determined differences in synesthetes (e.g., increased connectivity, Tilot et al, 2018) do not cause grapheme-color associations per se, but instead cause existing, environmentally-influenced grapheme-color associations to be strengthened and "locked in": made stable over time. As a result of this "locking in" mechanism, synesthetes, when asked to report a grapheme-color association for an experiment, will report an association that was formed *at a specific moment in development*. In contrast, non-synesthetes, whose associations were never "locked in", report an association that they *generate in the present moment*. This model can account for both similarities and differences in the associations of synesthetes and non-synesthetes. Associations will be the same when the *current* influences on adult non-synesthetes create the same color as the *childhood* influences did in synesthetes. They are different when this is not the case; for example, associations which were present in childhood but not adulthood, should influence the grapheme-color associations of adult synesthetes, but not adult non-synesthetes.

To test this prediction, it would be necessary to find an association between a letter and a color that is common in children *in general* – in both synesthetes and non-synesthetes – during the time period in early childhood when synesthetic associations begin to develop and become increasingly consistent (Simner et al., 2008; Simner & Bain, 2013). During exploratory analysis of previously-collected data from a small group of adult American synesthetes, we observed an association that we believe satisfies these constraints: female synesthetes in our dataset seemed unusually likely to associate their first initial with the color pink.

In early childhood, pervasive cultural stereotypes cause girls to associate their gender identity with the color pink. As early as 2.5 years of age, girls prefer pink items (e.g., toys, room furniture, and clothing) and boys actively *avoid* pink items, and children between 3 and 5 years of age will judge that pink-colored items are "for girls" (Cunningham et al 2011; LoBue & DeLoache, 2011). These gender-specific color preferences develop in stages: after learning about gender-related characteristics in preschool years, children demonstrate highly rigid beliefs about stereotypic sex typing – peaking between 5-7 years of age (Huston, 1985). Crucially, these gender-color associations weaken significantly after this peak as children's beliefs become increasingly tolerant and flexible (Trautner et al., 2005). Thus, during early childhood, but not adolescence or adulthood, color becomes an implicit gender label, where pink is "for girls" while the absence of pink is "for boys". In this study, we test the hypothesis that the gender-color stereotype "pink is for girls" influences girls' grapheme-color associations, and is "locked in" in female synesthetes, but disappears in adult female non-synesthetes.

Experiment 1: Young girls associate their first initial with pink

The first initial is the closest proxy for an individual's identity of any letter. Children typically learn their first initial of their first name before other letters from the alphabet, and use the first initial to distinguish their name from other names (Treiman & Broderick, 1998). Since young girls have a preference for the color pink in situations related to their own identity, we predict that young girls will associate their first initial with the color pink. We sought to test this prediction in girls aged 5-7 who did not show any signs of synesthesia. We excluded potential synesthetes from this experiment because a key assumption of our model is that the propensity for girls to associate their first initial with pink is not caused by the synesthetic trait.

Methods

Data from 17 girls ages 5 – 7 (mean age = 5.76 years) in San Diego were recruited from a child database via an email which asked parents to participate with their child in an online study. Our sample size was determined solely by the size and response rate of our child database, but our sample size of 17 yields 89.9% power to detect an effect equal to that observed in our exploratory analysis of adult English-speaking synesthetes (this effect size, as well as the others reported in the paper, were calculated using the *power.fisher.test* function in R's *statmod* package, with 100,000 simulations each). With the help of their parents, children completed a simplified color matching task modeled after Simner et al. (2008; see Supplemental Figure S1), in which they matched six letters of the alphabet to 12 colors (we included all Berlin-Kay basic colors except black, plus a dark variant of blue and green to match the test of Simner et al., 2008). One of the letters was the child's first initial, and the other 5 (selected from the letters A, B, E, R, T, Y) were included to estimate the proportion of the time pink would be chosen for letters that were not the first initial. Participants were then administered a surprise retest after a short break. In the current study, we wanted to exclude potential child synesthetes, so we excluded one subject whose consistency on the retest was statistically-significantly higher than average (the same cutoff used by Simner et al., 2008). We further planned to exclude any subject with the first initial "P" – since "P" is commonly associated with pink in adult synesthetes and non-synesthetes (Simner et al., 2005) – but none of our subjects had the first initial "P" (i.e., 0 subjects excluded). From this data ($N = 16$), we used only the first set of responses made by each of the 16 children included in the analyses; we reasoned that non-synesthetic subjects' responses on the first trial were least likely to be contaminated by previous answers.

Results

Qualitatively, non-synesthetic girls were likelier to choose pink for their first initial than for other letters. Of all reported associations for letters other than the first initial (80 associations total, 5 for each subject), 7.5% were with the color pink (Figure 1, left pink dot). Of all reported associations for the first initial (16 associations total, one for each subject), 31.3% were with the color pink (Figure 1, right pink dot). The critical effect here is not the proportion of pink for the first initial (31.3%), but rather *relative* preference for pink: the first initial is 4.17 times likelier to be pink than other letters[2]. To quantify this observation, we ran a Fisher exact test to determine whether color association (pink *vs*. not pink) was dependent on letter (first initial *vs*. not first initial). Non-synesthetic girls associate their first initial with pink significantly more often than they associate other letters with pink (p = 0.0173, Risk Ratio RR = 4.167).

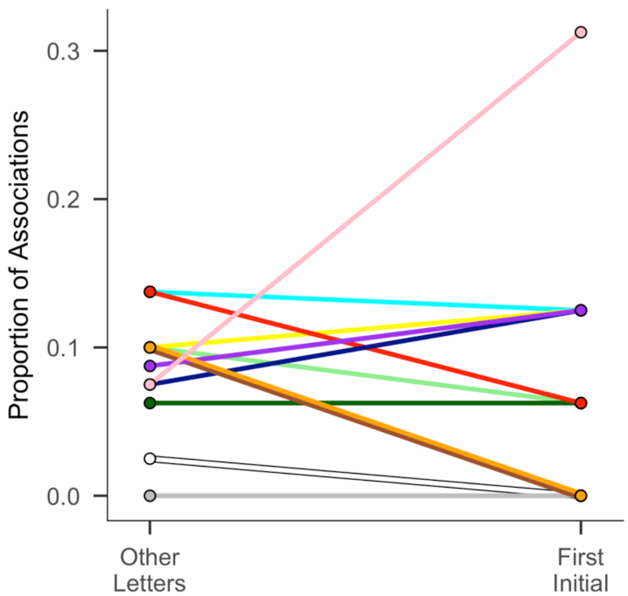

Figure 1: The proportion of associations between a letter and each of the 12 color choices, for non-synesthete girls, for the first initial (right) and for all other letters (left). The first initial is likelier than other letters to be associated with pink.

Experiment 2: Adult female synesthetes, but not non-synesthetes, associate their first initial with pink

Having shown that young girls tend to associate their first initial with the color pink, we next sought to test our primary hypotheses. First, we predict that during childhood, female synesthetes “locked in” the association between their first initial and pink, and thus that adult female synesthetes’ will associate their first initial with pink more often than expected by chance. Qualitatively, this was true in our exploratory analysis; here, we will quantify this observation in our full dataset of English-speaking synesthetes, and also aim to replicate our finding in a dataset of Dutch-speaking synesthetes. In addition to cross-validating our exploratory result, this would also allow us to test if our findings generalize cross-culturally and cross-linguistically. Second,

[2] One concern is that since color names influence trends in adult grapheme-color associations (Simner et al., 2005), existing trends – “B” is blue/brown, “R” is red, “Y” is yellow – might lead us to underestimate the true proportion of pink associations in our control letters. However, by Fisher exact tests, our child non-synesthetes do not associate “B” with blue/brown (p = 0.076), “R” with red (p = 0.11), or “Y” with yellow (p = 0.19) more than would be predicted by chance. Thus, we have no evidence that trends in the control letters confound the results of Experiment 1.

we predict that synesthetes are different from non-synesthetes: female non-synesthetes do not "lock in" any grapheme-color associations during childhood development, so adult female non-synesthetes will *not* associate their first initial with pink more often than expected by chance. We will test this prediction in both Dutch and English non-synesthetes.

Methods

Synesthetes. We analyzed grapheme-color associations in a combination of data from synesthetes used in a previous study (Root et al., 2017) and newly-collected data. All subjects had completed the Eagleman Synesthesia Battery (synesthete.org), a standardized battery for Synesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007) and qualified as synesthetes using the test-retest consistency threshold which maximizes sensitivity and specificity, derived in Rothen, Seth, Witzel, & Ward (2013): average Euclidean distance in CIELuv of test-retest associations less than 135 (smaller numbers indicate more consistent associations). In total, data from 78 English-speaking synesthetes and 157 Dutch-speaking synesthetes contributed to this study. We excluded from our data any synesthete who did not report a consistent color for at least 50% of graphemes (14 English- and 36 Dutch-speaking synesthetes excluded). We further excluded subjects who were male or for whom gender information was not present (20 English- and 21 Dutch-speaking synesthetes excluded), and subjects who did not report a color for their first initial (5 Dutch-speaking synesthetes excluded). Finally, we excluded 3 English-speaking subjects who chose black for more than 80% of their letters, suggesting that they misunderstood the task and chose the printed grapheme color; and 3 English-speaking subjects who admitted using memorization tricks to artificially increase their consistency score rather than providing their natural associations. Our final dataset contained 38 female English- and 95 female Dutch-speaking synesthetes (mean consistency in CIELuv = 70.48, consistency range [27.87 - 130.04]).

Non-synesthetes. We collected data from 60 English-speaking and 24 Dutch-speaking university students. Subjects completed the Eagleman synesthesia battery, but were given adjusted instructions to account for the fact that they were reporting abstract associations rather than perceptual experiences. We explained synesthesia, and explained that the test they were taking was meant for synesthetes, but in this study would be used to study how non-synesthetes associated colors. We asked the non-synesthetes to report which color is best for the letter, and emphasized that they should not think cognitively or use an explicit strategy, but rather report the "first color that came to mind" for each letter. We also emphasized that the task might seem strange to them, but that there is no "right" or "wrong" answer. We processed this data in the same way as with synesthetes: we excluded subjects who did not report a color for at least 13 letters (i.e. 50% of the alphabet; 3 Dutch-speaking and 3 English-speaking subjects excluded), any subject that was male or of unknown gender (19 English- and 5 Dutch-speaking subjects excluded), any subject that did not choose a color for their first initial (0 subjects excluded), and any subject who chose the same color for more than 80% of letters (0 subjects excluded). Additionally, as in Experiment 1, we analyzed only the first trial for each grapheme. Our final dataset contained 38 English-speaking non-synesthetes and 16 Dutch-speaking non-synesthetes.

For data from both synesthetes and non-synesthetes, we transformed the provided color associations (256 x 256 x 256 possible colors) into the 11 basic color terms of Berlin and Kay (1991) using a previously-collected dataset of 1,354 colors that were categorized into the Berlin-

Kay color categories by 1,177 subjects (Jraissati & Douven, 2018). For each grapheme-color association in our dataset, the association was categorized as the modal Berlin-Kay color term used by Jraissati & Douven's subjects for the color in their dataset with closest Euclidean distance in CIELuv to our subjects' reported colors.

We used the effect size from our exploratory analysis from the English-speaking synesthetes to estimate the power of our sample sizes, and obtained an estimate of 99.9% power for the Dutch synesthete data, 93.7% power for the Dutch non-synesthete data, and 99.9% power for the English non-synesthete data.

Results

Qualitatively, synesthetic females (Figure 2, black lines) look like non-synesthete girls (Figure 2, dotted line): they are much likelier to associate their first initial with pink than to associate other letters with pink (English: 4.4 times likelier; Dutch: 3.6 times likelier). To quantify this observation, for each language we ran a Fisher exact test to determine whether color association (pink *vs*. not pink) was dependent on letter (first initial *vs*. not first initial). Both English- and Dutch-speaking synesthetes associate their first initial with pink significantly more often than they associate other letters with pink (English: $p < 0.001$, $RR = 9.226$; Dutch: $p < 0.001$, $RR = 5.242$). This effect remains highly significant when data from both languages are combined ($p < 0.001$, $RR = 6.621$)

For non-synesthetes, color association (pink *vs.* not pink) does not seem to depend on letter (first initial *vs*. not first initial) as much as in synesthetes. Again, the important measure is not the absolute proportion of pink first initials but rather the *relative* preference: we are measuring how much *likelier* the first initial is to be pink, compared to other letters. For example, the proportion of pink first initials is similar in Dutch synesthetes and non-synesthetes (Figure 2, right panel, right dots), but the base rate of pink letters is much higher in Dutch non-synesthetes than in Dutch synesthetes (Figure 2, right panel, left dots), so the effect of first initial vs. other letter is much stronger in Dutch synesthetes. To quantify this observation, we ran the same analysis on non-synesthetes as on synesthetes (Fisher exact tests). Indeed, for both Dutch- and English-speaking non-synesthetes, there was not a statistically significant relationship between color association and letter: they do *not* associate their first initial with pink significantly more often than they associate other letters with pink (English: $p = 0.067$, $RR = 2.36$; Dutch: $p = 0.635$, $RR = 1.51$). Importantly, this null result is not likely to be caused by a lack of statistical power: as mentioned in the methods, we had 94% power in Dutch and 99% power in English to detect an effect as large as that observed in synesthetes. Indeed, even when data from both languages are combined we do not see a statistically significant relationship ($p =0.085$, $RR = 2.03$). We do note that the relationship between first initial and pink is marginally significant in English (and thus trending in the combined dataset); however, the effect size is quite small compared to in synesthetes[3].

[3] To verify that the effect is stronger in synesthetes than non-synesthetes, we ran a logistic mixed effect regression with color (pink *vs.* other) as dependent variable, letter status (first initial *vs.* other) and synesthesia status (synesthete *vs*. non-synesthete) as fixed effects, and subject as random effect. As predicted, the letter*synesthesia interaction was significant (Wald $z = 2.7$, $p = 0.007$)

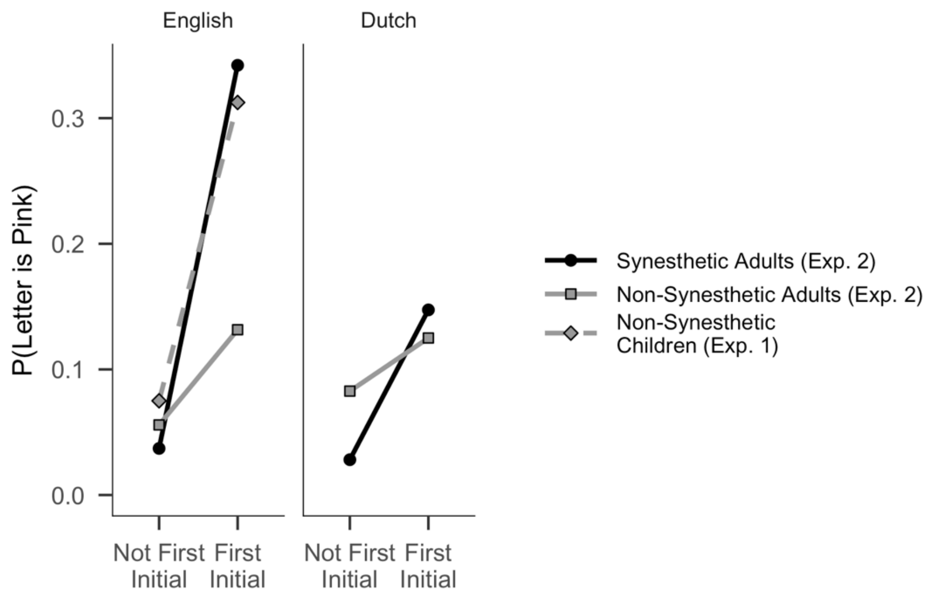

Figure 2. The proportion of letters associated with pink, for the first initial vs. all other letters (x axis), in synesthetes vs. non-synesthetes (black vs. grey), and in English vs. Dutch (left vs. right panel). The dotted grey line depicts the data from non-synesthetic girls from Experiment 1 (this line is the same as the pink line in Figure 1).

We also performed an additional *post-hoc* analysis to control for the possibility that our non-synesthetes did not take the test seriously (i.e., chose colors randomly): we tested whether non-synesthetes associated "A" with red, a frequently-reported association in non-synesthetes (e.g. Simner et al., 2005; Rouw et al., 2014). Consistent with previous research, our non-synesthetes associated "A" with red significantly more often than they associated other letters with red (Fisher Exact tests; English: $p < 0.001$, Dutch: $p = 0.011$). Since graphemes in the task were presented in random order, it seems unlikely that our subjects were engaged in the task when "A" was presented, but not when their first initial was presented.

Experiment 3: Non-synesthetes associate their first initial with their favorite color

In Experiment 2, we established that non-synesthetic adult females do not associate their first initial with pink more than would be expected by chance. This is consistent with our model: we propose that non-synesthetes generate their associations at the time of the test, and the association between female and pink disappears by adulthood (Trautner et al., 2005). Could the color associated with non-synesthetes' first initial now be influenced by a different factor? Here we perform a *post-hoc*, exploratory test, hypothesizing that non-synesthetes would associate their "special" first initial letter with their current favorite color.

Methods

Several weeks after they were initially tested, we re-contacted all English-speaking adult female non-synesthetes, asking them to indicate their favorite of the 11 Berlin-Kay colors. Three of the 38 original subjects did not respond, yielding a total of 35 subjects.

Results

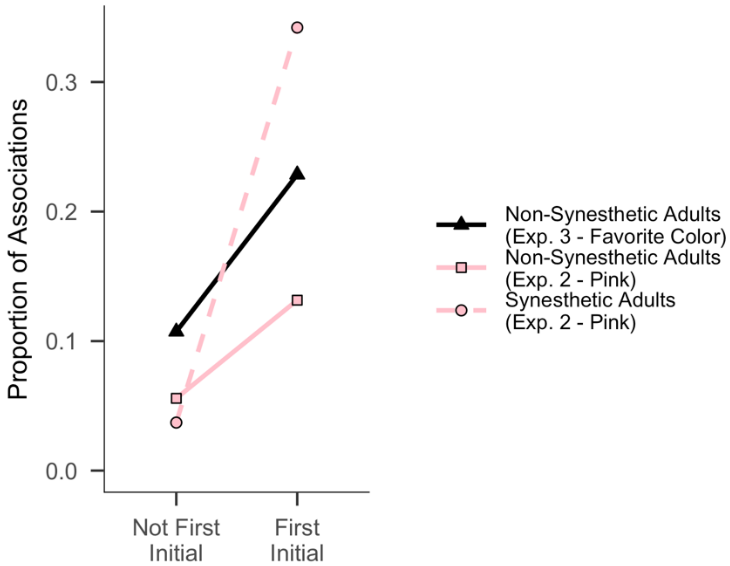

Figure 3. The black line depicts the proportion of letters associated with the favorite color (y axis), for the first initial vs. all other letters (x axis) for English-speaking non-synesthetes. The pink lines depict the data from English-speaking subjects in Experiment 2 (these lines are the same as the solid lines in the left panel of Figure 2): the proportion of letters associated with pink (y axis), for the first initial vs. all other letters (x axis), in synesthetes vs. non-synesthetes (dotted vs. solid).

Consistent with the weakening of gender-color stereotypes with age (Huston, 1983; Trautner et al., 2005), English-speaking adult female non-synesthetes were no likelier than chance to pick pink as their favorite color (Binomial test, $p = 0.628$). Consistent with our hypothesis, English-speaking female non-synesthetes associate their first initial with their current favorite color significantly more often than they associate other letters with their favorite color (Fisher test, $p = 0.048$, $RR = 2.345$)[4]. Figure 3 depicts this result, plotted together with the data from Experiment 2; the synesthetes' data from Experiment 2 (dotted pink line) more closely resembles the non-synesthetes' favorite color data (solid black line) than the non-synesthetes' pink data from Experiment 2 (solid pink line). In other words, while adult synesthetes were influenced by a childhood color association, this association is not present in non-synesthetes. Instead, it was replaced by an association with their current favorite color, an influence present at the moment the non-synesthetes were tested.

Discussion

We find that in both Dutch and English samples, female synesthetes associate their first initial with the color pink more often than expected by chance. In contrast, adult non-synesthetes do not

[4] We noticed that of the five adult non-synesthetes who chose pink, two indicated that pink was still their favorite color; the marginally-significant trend for English non-synesthetes to associate their first initial with pink could instead be driven by these subjects' favorite color.

associate their first initial with pink more than would be predicted by chance; instead, they associate their first initial with their current favorite color. This is consistent with a model in which environmental factors evoke associations between grapheme and color in all people (children, adults, synesthetes, non-synesthetes), but only individuals with the genetic predisposition to develop synesthesia "lock in" particular associations during development, creating the stable associations in adulthood that are typical of synesthesia. Our results demonstrate how differences in the pattern of grapheme-color associations in synesthetes and non-synesthetes can be attributed to changes in environment across the lifespan: associations that are unique to synesthetes in adulthood (e.g. in Simner et al., 2005) may actually be present in non-synesthetes during early childhood, but disappear during development, whereas these associations are maintained in synesthetes. More generally, our results demonstrate how a shared environmental factor in childhood can have differential effects on adult cognition, depending on genetic predisposition for synesthesia.

What is the neural basis of the "locking in" effect in synesthetes? A growing number of studies demonstrate that learning a particular task increases both brain connectivity and brain volume in the brain areas most relevant to that task (Maguire et al., 2000; Draganski et al., 2006; Loui et al., 2011). How these changes relate to adaptations at the level of the brain is not yet understood. One possible mechanism of "locking in" is at the level of neurons: when synesthetic individuals experience associations between grapheme and color – the same associations that we all experience – their additional neuronal connectivity might cause self-reinforcing patterns of activity (e.g., "Hebbian" learning; see also Newell & Mitchell, 2016). As a result, associations between grapheme and color are quickly strengthened in synesthetes in a "winner-take-all" (Kaski & Kohonen, 1994) fashion, whereas non-synesthetes maintain more flexible associations. This explanation is in line with research showing stronger implicit learning in synesthetes as compared with non-synesthetes (Rothen et al., 2013; Watson et al., 2014; Bankieris & Aslin, 2017; Bankieris et al., 2018). In addition, it is consistent with the finding that average consistency is relatively low in young synesthetic children and increases with age (Simner et al., 2008; Simner & Bain, 2013). Taking all these lines of evidence together, synesthetic associations in early childhood should go from flexible to increasingly solid and consistent, due to the "locking in" process taking place over time in childhood.

This proposal leads to testable predictions: the differential developmental pattern of "locking in" color associations can explain more than just this "pink initial" effect. It should be possible to attribute other differences between synesthetic and non-synesthetic color associations to the time period in which the associations were formed (e.g. children read different words/texts than adults). In turn, non-synesthetes are relatively more flexible; this can be examined in the 'training synesthesia' paradigm. Non-synesthetes might "lock in" more permanent associations if the input is strong and consistent enough to overcome their lack of genetic predisposition. Indeed, strong training programs can mimic synesthetic behavior and even brain functions (Bor et al., 2014; ; Colizoli et al., 2014; Colizoli, et al., 2017), although training programs thus far have not induced a permanent "locking in": the effects in existing research stop several months after the end of training (Bor et al., 2014).

Future research could extend current findings beyond female English and Dutch speakers, who share relatively similar language features. It would be interesting to see if results replicate in very different cultures and languages, though we would predict that our results *only* replicate in cultures where "pink is for girls" (pink is only as special as a culture decides it to be). In addition, since boys have a preference *against* pink (LoBue & DeLoache, 2011), male synesthetes should *not* associate their first initial with pink[5]. Furthermore, researchers with databases of child synesthetes (which requires screening very large numbers of children) could confirm that, at a young age, child synesthetes and child non-synesthetes generally share the same pattern of associations, including associating the first initial with pink.

Another important question for future research is why *certain* associations lock in sooner than others: Simner et al.'s (2008) study of childhood synesthesia found that only 29% of synesthetes' letters/digits are consistent by ages 6/7. Indeed, in our child data, three strong, well-replicated trends in adults, blue/brown "B", red "R", and yellow "Y" (Simner et al., 2005; Rich et al 2005; Mankin & Simner, 2017), were not present yet[2]. This suggests that the obtained pink first initial effect is amongst the earliest associations to be "locked in" - plausibly because children learn their first initial before they learn other letters (Treiman & Broderick, 1998). Thus, the order in which associations "lock in" could provide valuable insights into the acquisition of reading skills during development.

In sum, we report the first example of grapheme-color associations in adult synesthetes that could be traced back to grapheme-color associations measured in non-synesthetic children. We show how these environmentally-influenced associations in early childhood are later "locked in" for synesthetes, but not for non-synesthetes. An exciting prospect for future research is that by measuring particular influences on synesthetic color associations across different ages, synesthetes can be used as a "time capsule" to trace the development of specific linguistic, cognitive, and perceptual representations to specific moments in development.

Declarations of Interest

None

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Data Availability

Data and R code necessary to replicate all analyses and figures from this paper are included in the supplementary information.

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[5] Indeed, 0/11 of our English-speaking male synesthetes associated their first initial with pink, but a sample size of at least 500 would be required to test for significance at 80% power.

Ethics Statement

Adult data in Dutch was collected in accordance with the guidelines of UvA's Institutional Review Board; approval #2017-BC-7581. Adult data in English was collected in accordance with the guidelines of UCSD's Institutional Review Board; approval #141580; all subjects gave informed consent. Child data was collected in accordance with the guidelines of UCSD's Institutional Review Board; approval #150108. All parents gave informed consent, and children gave assent, in accordance with IRB guidelines.

Author Contributions

The research question and design was conceived by NR. The methods and data collection for adult data was performed by NR and RR. The design for child data was conceived by NR, RR, and KD; child data was provided by KD. Data analysis was carried out by NR. The manuscript was written by NR, RR, KD, and VR.

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