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Echoes from the past: synaesthetic colour associations reflect childhood gender stereotypes

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Grapheme–colour synaesthesia is a neurological phenomenon in which linguistic symbols evoke consistent colour sensations. Synaesthesia 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–colour association in adult synaesthetes can be traced to a particular environmental effect at a particular moment in childhood. We propose a model in which specific grapheme–colour associations are 'locked in' during development in children predisposed to become synaesthetes, whereas grapheme–colour associations remain flexible in non-synaesthetes. We exploit Western gender–colour stereotypes to test our model: we found that young girls *in general* tend to associate their first initial with the colour pink. Consistent with our model, adult female synaesthetes are influenced by their childhood environment: they associate their first initial with pink. Adult female non-synaesthetes do not show this bias. Instead, in our study, non-synaesthetes tended to associate their first initial with their *current* favourite colour. The results thus support the 'locking in' model of synaesthesia, suggesting that synaesthetic associations can be used as a 'time capsule', revealing childhood influences on adult linguistic associations. Grapheme–colour synaesthesia may thus offer an extraordinary opportunity to study linguistic development.

This article is part of a discussion meeting issue 'Bridging senses: novel insights from synaesthesia'.

1. Introduction

Grapheme–colour synaesthesia is a phenomenon in which graphemes elicit specific sensations of colour: a synaesthete might say that 'The letter R is sky-blue'. Synaesthetic associations are a genuinely perceptual experience—they really do *see* the colours [1,2]. Synaesthetes typically find these additional experiences pleasant and useful—synaesthesia is not related to a psychological, psychiatric or neurological 'disease'. Synaesthetes report having had their grapheme–colour associations for as long as they can remember, and their specific associations (which letter is which colour) are consistent across months or even years [3]. Synaesthesia 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 synaesthetes and controls ([4–8]; for a review, see [9]). Synaesthesia tends to run in families: 42% of synaesthetes report a first-degree relative with synaesthesia ([10]; see [11] for a review) and studies suggest that the propensity to develop synaesthesia is partly, but not completely, attributable to genetics [12–14].

Nevertheless, the specific grapheme-to-colour associations of a synaesthete (which letter is which colour) 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–colour combinations in certain synaesthetes that can be explained by toys from the synaesthete's childhood, such as 'coloured alphabet' refrigerator magnets ([15,16]; but see also [17]).[1] Thus, although the *propensity* to develop synaesthesia is plausibly genetic, the *specific manifestation* (including *which* letter is associated with *which* colour) is shaped by environmental and learning influences [10,18,19]. However, the exact *nature* of this interaction is not yet known: how does the synaesthetic trait shape the particular letter-to-colour experiences that set synaesthetes apart from non-synaesthetes? Several models have explored the relationship between genes and environmental influences, attributing differences between synaesthetes and non-synaesthetes to differences in implicit learning mechanisms [20,21], to particular idiosyncratic differences in white matter structure [1,19], and to conditioned mental imagery in response to letters [15,16]. 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–colour associations are not unique to synaesthetes: non-synaesthetes, when forced to choose a colour for a grapheme, share some patterns of grapheme–colour associations with synaesthetes [22–24]. However, studies comparing synaesthetes and non-synaesthetes show that while some patterns of grapheme–colour associations are shared, others are unique to synaesthetes or non-synaesthetes [22]. These seemingly contradictory findings have led to a debate about the degree to which synaesthetic associations are 'different' from cross-modal associations in non-synaesthetes (e.g. [25–30]). Why would some patterns of grapheme–colour association be unique to synaesthetes, whereas others are present in both synaesthetes and non-synaesthetes?

As several authors have pointed out, to answer this question and fully understand the synaesthetic condition, it is necessary to understand how synaesthesia develops during childhood [16,19,30] Currently, only a few studies have examined synaesthesia in children. These important studies showed that average consistency—taken as the 'gold standard' in diagnosing synaesthesia—is relatively low in synaesthetic children at age 6/7, and increases by age 10/11 [31,32]. Synaesthetic children with coloured numbers also showed learning and memory deficits when to-be-remembered numbers were written in a colour incongruent with their own synaesthetic colours [33]. Together, these findings suggest both protracted development of synaesthesia and reduced flexibility in synaesthetes when compared with non-synaesthetes. This links synaesthesia to the literature on functional specialization [19]: over time, a particular function, such as face recognition [34] or letter and phoneme perception [35,36], becomes more fixed and fluent at the expense of flexibility. The current study builds upon and extends previous models of differences between the synaesthetic and non-synaesthetic developmental processes. In particular, we show that the combination of protracted development and reduced flexibility in synaesthetes makes a testable prediction about why letter–colour associations in synaesthetes and non-synaesthetes are sometimes similar and sometimes different.

We propose that genetically determined differences in synaesthetes (e.g. increased connectivity [14]) do not cause grapheme–colour associations *per se*, but instead cause existing, environmentally influenced grapheme–colour associations to be strengthened and 'locked in': made stable over time. As a result of this 'locking in' mechanism, synaesthetes, when asked to report a grapheme–colour association for an experiment, will report an association that was formed *at a specific moment in development*. By contrast, non-synaesthetes, 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 synaesthetes and non-synaesthetes. Associations will be the same when the *current* influences on adult non-synaesthetes create the same colour as the *childhood* influences did in synaesthetes. They are different when this is not the case; for example, associations that were present in childhood but not adulthood should influence the grapheme–colour associations of adult synaesthetes, but not adult non-synaesthetes.

To test this prediction, it would be necessary to find an association between a letter and a colour that is common in children *in general*—in both synaesthetes and non-synaesthetes—during the time period in early childhood when synaesthetic associations begin to develop and become increasingly consistent [31,32]. During exploratory analysis of previously collected data from a small group of adult American synaesthetes, we observed an association that we believe satisfies these constraints: female synaesthetes in our dataset seemed unusually likely to associate their first initial with the colour pink.

In early childhood, pervasive cultural stereotypes cause girls to associate their gender identity with the colour pink. As early as 2.5 years of age, girls prefer pink items (e.g. toys, room furniture and clothing), boys actively *avoid* pink items and children between 3 and 5 years of age will judge that pink-coloured items are 'for girls' [37,38]. These gender-specific colour 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 and 7 years of age [39]. Crucially, these gender–colour associations weaken significantly after this peak as children's beliefs become increasingly tolerant and flexible [40]. Thus, during early childhood, but not adolescence or adulthood, colour 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–colour stereotype 'pink is for girls' influences girls' grapheme–colour associations, and is 'locked in' in female synaesthetes, but disappears in adult female non-synaesthetes.

2. Experiment 1: young girls associate their first initial with pink

Of any letter, the first initial is the closest proxy for an individual's identity. 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 [41]. Since young girls have a preference for the colour pink in situations related to their own identity, we predict that young girls will associate their first initial with the colour pink. We sought to test this prediction in girls aged 5–7 years who did not show any signs of synaesthesia. We excluded potential synaesthetes 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 synaesthetic trait.

(a) Methods

Seventeen girls aged 5–7 years (mean age = 5.76 years) in San Diego were recruited from a child database via an e-mail that 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 synaesthetes (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 colour matching task modelled after Simner *et al*. ([31]; see electronic supplementary material, figure S1), in which they matched 6 letters of the alphabet to 12 colours (we included all Berlin–Kay basic colours except black, plus a dark variant of blue and green to match the test of [31]). One of the letters was the child's first initial and the other five (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 this study, we wanted to exclude potential child synaesthetes; we excluded one subject whose consistency on the retest was statistically significantly higher than average (the same cut-off used by Simner *et al*. [31]). We further planned to exclude any subject with the first initial 'P'—since 'P' is commonly associated with pink in adult synaesthetes and non-synaesthetes [22]—but none of our subjects had the first initial 'P' (i.e. 0 subjects excluded). From these 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-synaesthetic subjects' responses on the first trial were least likely to be contaminated by previous answers.

(b) Results

Qualitatively, these non-synaesthetic 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 colour pink (figure 1, left pink dot). Of all reported associations for the first initial (16 associations total, 1 for each subject), 31.3% were with the colour 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 colour association (pink versus not pink) was dependent on letter (first initial versus not first initial). Non-synaesthetic 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).

3. Experiment 2: adult female synaesthetes, but not non-synaesthetes, associate their first initial with pink

Having shown that young girls tend to associate their first initial with the colour pink, we next sought to test our primary hypotheses. First, we predict that during childhood, female synaesthetes 'locked in' the association between their first initial and pink, and thus that adult female synaesthetes 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 synaesthetes, and also aim to replicate our finding in a dataset of Dutch-speaking synaesthetes. 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, we predict that synaesthetes are different from non-synaesthetes: female non-synaesthetes do not 'lock in' any grapheme–colour associations during childhood development, so adult female non-synaesthetes 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-synaesthetes.

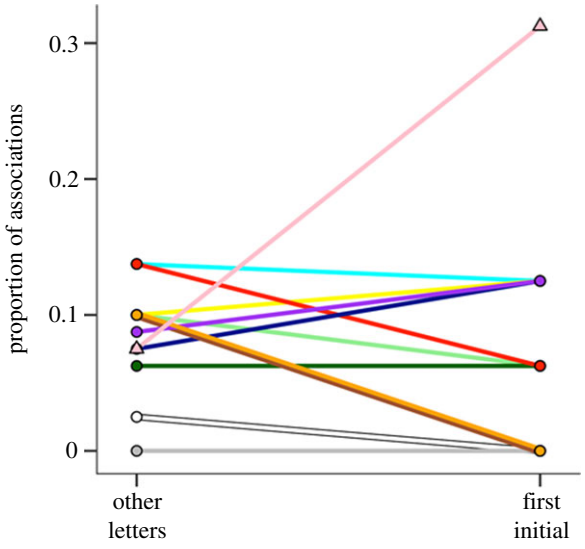

Figure 1. The proportion of associations between a letter and each of the 12 colour choices, for non-synaesthete girls, for the first initial (right) and for all other letters (left). The first initial is likelier than other letters to be associated with pink (triangles). (Online version in colour.)

(a) Methods

(i) Synaesthetes

We analysed grapheme–colour associations in a combination of data from synaesthetes used in a previous study [42] and newly collected data. All subjects had completed the Eagleman Synesthesia Battery (synaesthete.org), a standardized battery for synaesthesia [43], and qualified as synaesthetes using the test–retest consistency threshold that maximizes sensitivity and specificity, derived in Rothen *et al*. [44]: average Euclidean distance in the CIELuv perceptual colour space of test–retest associations less than 135 (smaller numbers indicate more consistent associations). In total, data from 78 English-speaking synaesthetes and 157 Dutch-speaking synaesthetes contributed to this study. We excluded from our data any synaesthete who did not report a consistent colour for at least 50% of graphemes (14 English- and 36 Dutch-speaking synaesthetes excluded). We further excluded subjects who were male or for whom gender information was not present (20 English- and 21 Dutch-speaking synaesthetes excluded) and subjects who did not report a colour for their first initial (five Dutch-speaking synaesthetes excluded). Finally, we excluded three English-speaking subjects who chose black

for more than 80% of their letters, suggesting that they misunderstood the task and chose the printed grapheme colour, and three 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 synaesthetes (mean consistency in CIELuv = 70.48, consistency range (27.87–130.04)).

(ii) Non-synaesthetes

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

For data from both synaesthetes and non-synaesthetes, we transformed the provided colour associations (256 × 256 × 256 possible colours) into the 11 basic colour terms of Berlin and Kay [45] using a previously collected dataset of 1354 colours that were categorized into the Berlin–Kay colour categories by 1177 subjects [46]. For each grapheme–colour association in our dataset, the association was categorized as the modal Berlin–Kay colour term used by Jraissati & Douven's [46] subjects for the colour in their dataset with closest Euclidean distance in CIELuv to our subjects' reported colours.

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

(b) Results

Qualitatively, synaesthetic females (figure 2, black lines) look like non-synaesthete girls (figure 2, dashed 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 colour association (pink versus not pink) was dependent on letter (first initial versus not first initial). Both English- and Dutch-speaking synaesthetes associate their first initial with

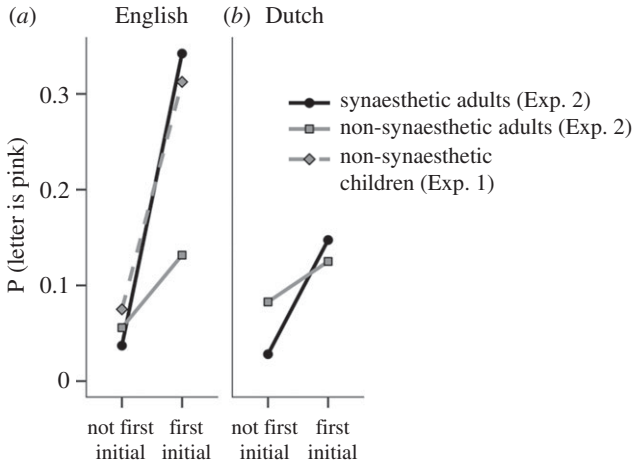

Figure 2. The proportion of letters associated with pink, for the first initial versus all other letters (*x*-axis), in synaesthetes versus non-synaesthetes (black versus grey) and in English versus Dutch (*a* versus *b*). The dashed grey line depicts the data from non-synaesthetic girls from Experiment 1 (this line is the same as the pink line in figure 1).

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-synaesthetes, the colour association (pink versus not pink) does not seem to depend on letter (first initial versus not first initial) as much as in synaesthetes. 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 synaesthetes and non-synaesthetes (figure 2*a*, right dots), but the base rate of pink letters is much higher in Dutch non-synaesthetes than in Dutch synaesthetes (figure 2*a*, left dots), so the effect of first initial versus other letter is much stronger in Dutch synaesthetes. To quantify this observation, we ran the same analysis on non-synaesthetes as on synaesthetes (Fisher's exact test). Indeed, for both Dutch- and English-speaking non-synaesthetes, there was not a statistically significant relationship between colour 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 §3a, we had 94% power in Dutch and 99% power in English to detect an effect as large as that observed in synaesthetes. 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 synaesthetes.[3]

We also performed an additional *post hoc* analysis to control for the possibility that our non-synaesthetes did not take the test seriously (i.e. chose colours randomly): we tested whether non-synaesthetes associated 'A' with red, a frequently reported association in non-synaesthetes (e.g. [22,23]). Consistent with previous research, our non-synaesthetes 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,

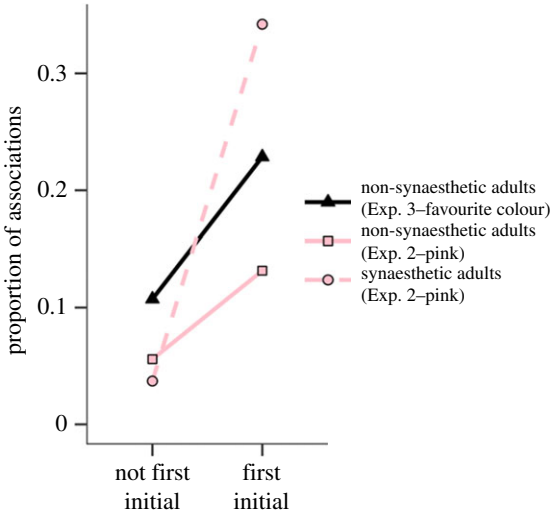

Figure 3. The black line depicts the proportion of letters associated with the favourite colour (*y*-axis), for the first initial versus all other letters (*x*-axis) for English-speaking non-synaesthetes. The pink lines depict the data from English-speaking subjects in Experiment 2 (these lines are the same as the solid lines in left figure 2*a*): the proportion of letters associated with pink (*y*-axis), for the first initial versus all other letters (*x*-axis), in synaesthetes versus non-synaesthetes (dashed versus solid). (Online version in colour.)

it seems unlikely that our subjects were engaged in the task when 'A' was presented, but not when their first initial was presented.

4. Experiment 3: non-synaesthetes associate their first initial with their favourite colour

In Experiment 2, we established that non-synaesthetic 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-synaesthetes generate their associations at the time of the test, and the association between female and pink disappears by adulthood [40]. Could the colour associated with non-synaesthetes' first initial now be influenced by a different factor? Here, we perform a *post hoc*, exploratory test, hypothesizing that non-synaesthetes would associate their 'special' first initial letter with their current favourite colour.

(a) Methods

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

(b) Results

Consistent with the weakening of gender–colour stereotypes with age [40,47], English-speaking adult female non-synaesthetes were no likelier than chance to pick pink as their favourite colour (binomial test, $p = 0.628$). Consistent with our hypothesis, English-speaking female non-synaesthetes associate their first initial with their current favourite colour significantly more often than they associate other letters with their favourite colour (Fisher test, $p = 0.048$, RR = 2.345).[4] Figure 3 depicts this result, plotted together with the data from Experiment 2; the synaesthetes' data from Experiment 2 (dotted pink line) more closely resemble the non-synaesthetes' favourite colour data (solid black line) than the non-synaesthetes' pink data from Experiment 2 (solid pink line). In other words, while adult synaesthetes were influenced by a childhood colour association, this association is not present in non-synaesthetes. Instead, it was replaced by an association with their current favourite colour, an influence present at the moment the non-synaesthetes were tested.

(c) Discussion

We find that in both Dutch and English samples, female synaesthetes associate their first initial with the colour pink more often than expected by chance. By contrast, adult non-synaesthetes do not associate their first initial with pink more than would be predicted by chance; instead, they associate their first initial with their current favourite colour. This is consistent with a model in which environmental factors evoke associations between grapheme and colour in all people (children, adults, synaesthetes, non-synaesthetes), but only individuals with the genetic predisposition to develop synaesthesia 'lock in' particular associations during development, creating the stable associations in adulthood that are typical of synaesthesia. Our results demonstrate how differences in the pattern of grapheme–colour associations in synaesthetes and non-synaesthetes can be attributed to changes in environment across the lifespan: associations that are unique to synaesthetes in adulthood (e.g. in [22]) may actually be present in non-synaesthetes during early childhood, but disappear during development, whereas these associations are maintained in synaesthetes. More generally, our results demonstrate how a shared environmental factor in childhood can have differential effects on adult cognition, depending on genetic predisposition for synaesthesia.

What is the neural basis of the 'locking in' effect in synaesthetes? 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 [48–50]. How these changes relate to adaptations in the brain is not yet understood. One possible mechanism of 'locking in' is at the level of neurons: when synaesthetic individuals experience associations between grapheme and colour—the same associations that we all experience—their additional neuronal connectivity might cause self-reinforcing patterns of activity (e.g. 'Hebbian' learning; see also [19]). As a result, associations between grapheme and colour are quickly strengthened in synaesthetes in a 'winner-take-all' [51] fashion, whereas non-synaesthetes maintain more flexible associations. This explanation is in line with research showing stronger implicit learning in synaesthetes when compared with non-synaesthetes [20,21,30,44]. In addition, it is consistent with the finding that average consistency is relatively low in young synaesthetic children and increases with age [31,32]. Taking all these lines of evidence together, synaesthetic associations in early childhood should go from flexible to increasingly solid and consistent, owing to the 'locking in' process taking place over time in childhood.

This proposal leads to testable predictions: the differential developmental pattern of 'locking in' colour associations can explain more than just this 'pink initial' effect. It should be possible to attribute other differences between synaesthetic and non-synaesthetic colour associations with the time period during which the associations were formed (e.g. children read different words/texts from adults). In turn, non-synaesthetes are relatively more flexible; this can be examined in the 'training

synaesthesia' paradigm. Non-synaesthetes might 'lock in' more permanent associations if the input is strong and consistent enough to overcome their lack of genetic predisposition. Indeed, strong training programmes can mimic synaesthetic behaviour and even brain functions [52–54], although training programmes thus far have not induced a permanent 'locking in': the effects in existing research stop several months after the end of training [52].

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 [38], male synaesthetes should *not* associate their first initial with pink.[5] Furthermore, researchers with databases of child synaesthetes (which requires screening very large numbers of children) could confirm that, at a young age, child synaesthetes and child non-synaesthetes 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 [31] study of childhood synaesthesia found that only 29% of synaesthetes' 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' [17,22,24], were not present yet.[6] This suggests that the obtained pink first initial effect is among the earliest associations to be 'locked in'—plausibly because children learn their first initial before they learn other letters [41]. 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–colour associations in adult synaesthetes that could be traced back to grapheme–colour associations measured in non-synaesthetic children. We show how these environmentally influenced associations in early childhood are later 'locked in' for synaesthetes, but not for non-synaesthetes. An exciting prospect for future research is that by measuring particular influences on synaesthetic colour associations across different ages, synaesthetes can be used as a 'time capsule' to trace the development of specific linguistic, cognitive and perceptual representations to specific moments in development.

Ethics. Adult data in Dutch were collected in accordance with the guidelines of University of Amsterdam's Institutional Review Board; approval #2017-BC-7581. Adult data in English were collected in accordance with the guidelines of University of California San Diego's Institutional Review Board, approval #141580; all subjects gave informed consent. Child data were 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.

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

Authors' contributions. The research question and design were conceived by N.B.R. and R.R. The methods and data collection for adult data were performed by N.B.R. and R.R. The design for child data was conceived by N.B.R., R.R. and K.D.; child data were provided by K.D. Data analysis was carried out by N.B.R. The manuscript was written by N.B.R., R.R., K.D., and V.R.

Competing interests. We declare we have no competing interests.

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Endnotes

[1]Similar findings have been obtained in other types of synaesthesia; for example, linguistic and conceptual knowledge shapes associations in lexical–gustatory synaesthesia [18].

[2]One concern is that since colour names influence trends in adult grapheme–colour associations [22], existing trends—'B' is blue/brown, 'R' is red and '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-synaesthetes 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.

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

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

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

[6]Statistics are in endnote 2.

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