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Synaesthesia: A Case Study of Discordant Monozygotic Twins

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Abstract

We describe a study of 11-year-old twin sisters who are physically identical in appearance but who have considerably different conscious experiences. One twin appears to be a synaesthete in that she states that she has specific colour experiences (i.e. photisms) whenever she views, hears or thinks of digits. The other twin does not report such conscious experiences when viewing, hearing or thinking about digits. A genotypic analysis using eight microsatellite loci plus the gender of the twins and their parents confirmed that the twins are monozygotic. A phenotypic analysis using a modification of the Stroop task confirmed that only one twin is a synaesthete. We suggest that the discordance in synaesthesia may be due to either an epigenetic event, X chromosome inactivation, or a mutation of a synaesthesia gene.

Introduction

Synaesthesia is a fascinating phenomenon in which ordinary stimuli can lead to extraordinary conscious experiences. For some synaesthetes, the stimuli and the subsequent conscious experiences occur in the same modality. For example, printed black digits or printed black letters may lead to colour experiences (e.g. Dixon *et al.*, 2000). For other synaesthetes, the stimuli and the subsequent conscious experiences cross modalities. For example, tastes may elicit tactile experiences (e.g. Cytowic, 1989, 1993) or sounds may elicit colour experiences (e.g. Wheeler, 1920).

Here we describe a study of 11-year-old twin sisters (EB and JB). Based on their physical appearance, EB and JB appear to be identical. However, despite their identical physical appearance, their conscious experiences differ radically. One twin (EB) reports that she experiences colours whenever she views, hears or thinks of the digits 1–9. She further states that digits have triggered specific colour experiences (i.e. photisms) as long as she can remember and that the colour associated with each digit has not changed over time. In contrast to EB, her twin sister (JB) does not report any colour experiences when she views, hears or thinks of digits. These observations suggested to us that EB and JB may be monozygotic twins but that only EB experiences a form of digit–colour synaesthesia.

Verification that EB and JB are monozygotic twins and that only EB experiences digit–colour synaesthesia are important to the study of synaesthesia for two reasons. First, this case offers a unique opportunity to compare a synaesthete with a non-synaesthete who is matched as closely as possible in terms of both genetic and environmental influences. Second, this case has the potential to increase our understanding of the genetic basis of synaesthesia. Although there has been considerable discussion concerning whether synaesthesia is an inherited trait (e.g. Galton, 1883; Cytowic, 1989; Bailey and Johnson, 1997; Harrison and Baron-Cohen, 1997), there have been relatively few investigations regarding the role genetics may play in the development of synaesthesia.

Our study of EB and JB consisted of two components. First, a genotypic analysis was conducted to determine whether EB and JB are in fact monozygotic twins. Second, a rigorous phenotypic analysis was carried out to corroborate EB and JB's radically different reports of their conscious experiences. In particular, we wanted to establish that viewing black digits leads to colour experiences for EB whereas viewing black digits leads to no associated colour experiences for JB.

Genotypic analysis

Methods

EB and JB have lived most of their lives in rural areas of the eastern USA. To date, all of their schooling has been at home. At the time of testing, EB and JB were 11 years old.

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Table 1. Genotypes for eight microsatellite loci and a gender-specific locus

Sample	Gender	D3S1358	D8S1179	D5S818	VWA	D21S11	D13S317	FGA	D7S820
EB	XX	17:18	13:14	11:13	17:18	29:30	10:13	22:22	8:11
JB	XX	17:18	13:14	11:13	17:18	29:30	10:13	22:22	8:11
AB	XY	17:18	12:14	11:13	17:18	29:29	11:13	21:22	8:12
pTB	XY	15:18	12:13	11:13	17:18	29:30	12:13	22:22	8:10
pJM	XX	17:18	14:14	11:11	17:18	29:31	10:11	21:22	11:12
HB	XX	15:17	13:14	11:13	17:18	29:29	10:12	22:22	no amp
FB	XX	15:18	12:14	11:11	17:18	29:29	10:12	22:22	no amp
CON	XX	11:15	13:13	11:11	17:18	30:30	11:11	23:24	10:11

DNA was extracted from hair samples obtained from EB and JB as well as from the other members of their immediate family. These other family members included their parents (pTB and pJM), two sisters (HB and FB) and one brother (AB). A human control sample (CON) was also included in the DNA profiling.

The QIAamp (Qiagen) extraction protocol was used and the DNA from all samples was amplified at eight microsatellite loci: D3S1358, D8S1179, D5S818, VWA, D21S11, D13S317, FGA and D7S820 (AmpFISTR profiler kit; Perkin-Elmer). A gender-specific locus (amelogenin) was also amplified. The amplified products were separated on an ABI 377 automatic DNA sequencer.

Results

Allelic patterns from all samples were ascertained, and the results are shown in Table 1. As can be seen from Table 1, EB and JB have identical DNA profiles across the eight microsatellite loci, whereas the DNA profiles for the remaining samples reveal different multilocus genotypes. DNA samples from two family members, HB and FB, did not amplify at locus D7S820 (designated 'no amp' in Table 1). The samples obtained from EB, JB, pJM, HB and FB were found to be female in origin, whereas the samples obtained from AB and pTB were male in origin. Based on the genotypic analysis of the eight microsatellite loci and the gender of the parents (pTB and pJM) and the twins (EB and JB), the probability that EB and JB originated from independent fertilization events (i.e. dizygotic) rather than from a single fertilized egg (i.e. monozygotic) is 0.0002441 or 1 in 4096. Therefore, the results of the genotypic analysis strongly suggest that EB and JB are monozygotic twins.

Phenotypic analysis

The phenotypic analysis used to corroborate EB and JB's radically different reports of their conscious experiences when viewing digits was based on a version of the Stroop task (Stroop, 1935). Performance on a variety of Stroop tasks has been used in numerous studies to distinguish synaesthetes from non-synaesthetes (Wollen and Ruggiero, 1983; Mills *et al.*, 1999; Odgaard *et al.*, 1999; Dixon *et al.*, 2000; Mattingley *et al.*, 2001). The version of the colour-naming Stroop task used with EB and JB was similar to that used in previous studies (e.g. Dixon *et al.*, 2000). The basic task was for EB and JB to view coloured digits on a computer monitor and to name the video colour of each digit as fast as possible. To establish whether viewing digits leads to conscious colour experiences for EB but not for JB, the digits were coloured so that the colours of the digits were either congruent or incongruent with EB's photisms for the digits. For example, EB reports that the digit 2 leads to a conscious experience of blue and that the digit 4 leads to a conscious experience of green. Therefore, for congruent trials, the digit 2 was blue and the digit 4 was green, whereas for the incongruent trials, the digit 2 was a colour other than blue and the digit 4 was a colour other than green. The rationale for this contrast between congruent and incongruent conditions is that if EB experiences photisms when viewing digits, then her photisms should interfere with her ability to name the colours of the digits on incongruent trials relative to congruent trials. Such interference on incongruent trials should result in EB taking longer to name the colours of the digits on incongruent trials than on congruent trials. In contrast, JB, who does not report experiencing photisms when viewing digits, should take approximately the same time to name the colours of the digits on congruent and incongruent trials. Given the success of previous studies based on this logic in distinguishing synaesthetes from non-synaesthetes, we expected EB, who reports experiencing photisms to digits, to show a large difference in her reaction times between the congruent and incongruent conditions, whereas we expected JB, who reports not experiencing photisms to digits, to show no difference in her reaction times between the same conditions.

Methods

Both EB and JB have normal vision, and both were paid $20.00 for their participation in the behavioural tests used to establish their phenotypes.

All behavioural testing was conducted using a Dell Lattitude laptop computer with a Pentium II 366 processor interfaced to an IBM colour monitor. The stimuli were presented and the reaction times were recorded using Micro Experimental Laboratory software (Schneider, 1990).

Prior to the administration of the colour-naming Stroop task, EB's photism colour for each digit was matched to a

video colour displayed on the computer screen. EB was shown each digit five times beside a colour-adjustable square. For each presentation of each digit, she first named the photism colour elicited by the digit. The experimenter then adjusted the red, green and blue values of the monitor until the colour displayed on the monitor matched the colour of her photism for the digit. EB's base colour-naming responses were 100% consistent across the five repetitions of each digit[1]. Based on these photism–colour matches, we selected four digits to be used on the congruent and incongruent trials in the colour-naming Stroop task: 1, 2, 4 and 9. These digits were associated with the colours orange-yellow, light blue, forest green and maroon, respectively.

Both congruent and incongruent trials involved the presentation of a coloured digit against a grey background at the centre of a computer monitor[2]. On each congruent trial, the digit was displayed in the colour that corresponded to the colour of EB's photism for the digit. There were 108 congruent trials, 27 for each digit. On each incongruent trial, the digit was displayed in one of the three colours that were different from the colour of EB's photism for that digit. There were 324 incongruent trials, 81 for each digit, and each digit was presented 27 times in each of the three incongruent colours. We included three times as many incongruent trials as congruent trials in order to minimize strategic influences[3].

There were eight practice trials prior to the beginning of the experiment. For the experiment proper, the congruent and incongruent trials were presented in random order. EB and JB were instructed to ignore the digits and to name the colours in which the digits appeared as quickly as possible while maintaining high accuracy. Each digit remained on the screen until the colour of the digit was named, and each naming response triggered a voice key. The reaction time from the onset of the digit to the onset of the naming response was measured. The experimenter recorded the naming responses.

Results

Reaction time. Prior to analysing the correct reaction times, outliers were removed using a recursive procedure (Van Selst and Jolicoeur, 1994). A total of 2.49% of EB's responses and 2.46% of JB's responses were removed in this manner. The remaining reaction time data were analysed using independent sample *t*-tests to compare EB and JB's performance on the congruent and incongruent trials.

Figure 1 shows the mean reaction times associated with the congruent and incongruent trials for EB (left side) and JB (right side). As can be seen from Fig. 1, EB, who reports experiencing synaesthetic photisms to digits, was much slower when she named the colours of the incongruently coloured digits than when she named the colours of the congruently coloured digits ($t_{(405)} = 2.80$, $P < 0.006$). In contrast, JB, who does not report any synaesthetic experiences, was able to name the incongruently coloured digits as fast as she was able to name the congruently coloured digits ($t_{(409)} = 1.10$, $P > 0.271$). These results are completely consistent with other findings in the literature showing that synaesthetes show large congruent/incongruent differences when naming the colours of digits whereas non-synaesthetes do not show such differences (e.g. Wollen and Ruggiero, 1983; Mills *et al.*, 1999; Odgarrd *et al.*, 1999; Dixon *et al.*, 2000; Mattingley *et al.*, 2001). More importantly, the present results corroborate EB and JB's very different reports of their conscious experiences when viewing digits.

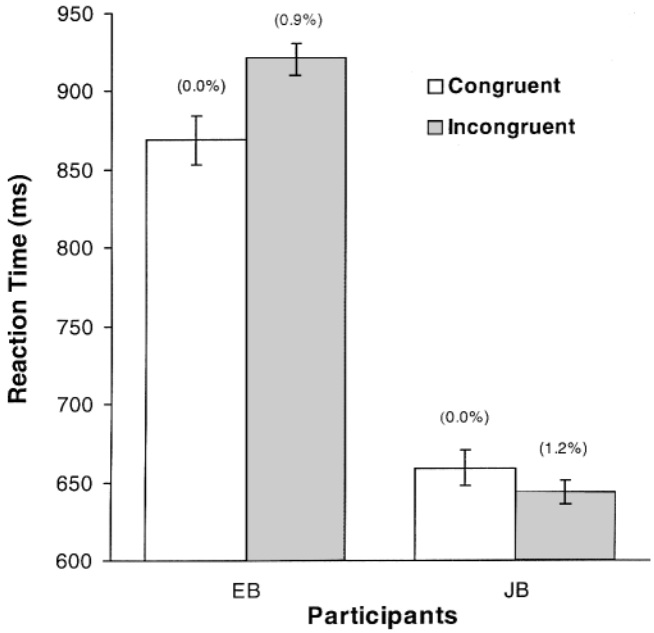

Fig. 1. Mean reaction times and errors (in parentheses) for naming colours of digits for EB and JB. Error bars depict one standard error of the mean.

Error data. The mean error rates associated with each condition are shown in parentheses in Fig. 1. Independent sample *t*-tests revealed that there were no differences in errors between the congruent and incongruent conditions for either EB ($t < 1$) or JB ($t_{(424)} = 1.15$, $P > 0.250$). Thus, interpretation of the reaction times does not appear to be compromised by speed/accuracy trade-offs.

Discussion

Our study of EB and JB was prompted by the observation that they appeared to be physically identical, yet only EB reported experiencing synaesthesia. The genotypic analysis confirmed that EB and JB are genetically identical, and the phenotypic analysis established that the twins are discordant for synaesthesia. We believe that these findings have important implications for understanding the role of genetics in the development of synaesthesia.

Other researchers have noted a potential genetic contribution to synaesthesia (Cytowic, 1989; Baron-Cohen *et al.*,

1993, 1996). Based on a phenotypic analysis and a skewed female to male ratio, Baron-Cohen *et al.* (1996) concluded that synaesthesia is an X-linked dominant trait with possibly 50% *in utero* lethality for affected males.

In this context, a plausible explanation for the discordance observed in the present study is that an X-linked gene for synaesthesia is inactivated in EB and not in JB. In previous studies, X chromosome inactivation (X inactivation) (Lyon, 1961, 1999) was invoked to account for discordance among female monozygotic twins for conditions as diverse as red–green colour blindness (Jorgensen *et al.*, 1992), haemophilia B (Revesz *et al.*, 1972), and muscular dystrophy (Richards *et al.*, 1990). Among pairs of twins, X inactivation occurs either before or after the twinning process is established (Monteiro *et al.*, 1998; Chitnis *et al.*, 1999). In those instances when X inactivation occurs after the twinning process, each member of a pair of twins may have a substantial number of cells with a different inactivated X chromosome. For this reason, a particular X-linked condition is found in only one monozygotic twin. Specifically, EB, the twin with synaesthesia, would have a greater proportion of cells with an active affected chromosome in comparison with her sister, JB, who does not have synaesthesia.

There are other explanations for a phenotypic difference of an inherited condition between monozygotic twins. The occurrence of a mutation in one DNA strand of a putative synaesthesia gene of a fertilizing gamete would after replication and cell division of the zygote be present in one of the daughter cells. If twinning occurred at this stage, then one twin would carry a dominant synaesthesia mutant gene and would manifest the synaesthesia phenotype. The other twin would have the wild-type version of the synaesthesia gene and not show the synaesthesia phenotype. Or, a mutation of a synaesthesia gene might have occurred in one of the twin embryos. And, subsequently, a disproportionate number of cells carrying this mutation might have become concentrated in a critical organ, presumably the brain, and caused discordance.

In summary, molecular genetic analyses of families with two or more members with synaesthesia will determine whether there is a single gene for synaesthesia and where it is located. If the X inactivation hypothesis presented here is valid, one would expect no male monozygotic twins who are discordant for synaesthesia and twins who are discordant for synaesthesia to show a greater difference between their patterns of X inactivation than twins who are concordant (Chitnis *et al.*, 1999).

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Notes

[1]When EB was asked to report the names of the colours that she associated with each digit 6 months following the initial session, she was 100% consistent (cf. Baron-Cohen *et al.*, 1987, 1993).

[2]The digits measured 0.7 cm in width and 1.0 cm in height. At a viewing distance of 57 cm, the digits subtended 0.7° of visual angle in width and 1.0° of visual angle in height.

[3]In addition to these trials, we also included 108 trials in which a coloured square was presented in the centre of the screen. These trials are not important to this study.

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Abstract
We describe a study of 11-year-old twin sisters who are physically identical in appearance but who have considerably different conscious experiences. One twin appears to be a synaesthete in that she states that she has specific colour experiences (i.e. photisms) whenever she views, hears or thinks of digits. The other twin does not report such conscious experiences when viewing, hearing or thinking about digits. A genotypic analysis using eight microsatellite loci plus the gender of the twins and their parents confirmed that the twins are monozygotic. A phenotypic analysis using a modification of the Stroop task confirmed that only one twin is a synaesthete. We suggest that the discordance in synaesthesia may be due to either an epigenetic event, X chromosome inactivation, or a mutation of a synaesthesia gene.

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Primary diagnosis of interest
Digit–colour synaesthesia

Author's designation of case
EB, JB

Key theoretical issue
- The role of genetics in synaesthesia

Key words: synaesthesia; genetics; monozygotic twins; X chromosome inactivation

Scan, EEG and related measures
QIAamp extraction protocol used to amplify DNA at eight microsatellite loci: D3S1358, D8S1179, D5S818, VWA, D21S11, D13S317, FGA and D7S820

Other assessment
Variant of the Stroop task

Language
English