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DIGIT SYNAESTHESIA: A CASE STUDY USING A STROOP-TYPE TEST

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Two experiments tested the effect that synaesthesia has on the processing of digits for a single participant, a 22-year-old female college student, who experiences colour mental images (photisms) for digits, music, sounds, etc. The experiments used Stroop-type materials that were digits in the colours of her photisms for two tasks: colour naming and digit naming. For colour naming, the hypothesis was that when the colour of the actual print of the digit mismatched the colour of the participant's digit photism, colour naming times would be slower than when the print and digit photism matched, or when the digit was in black print. For digit naming, it was predicted that naming the digit corresponding to a coloured circle (that corresponded to one of her photisms for digits) would take longer than naming digits printed in any colour. ANOVAs and Tukey tests supported these hypotheses ($P < .01$). Synaesthesia seems to occur automatically, involuntarily, and unidirectionally for this participant. Details of her synaesthesia and its implications are discussed.

INTRODUCTION

The word synaesthesis derives its root from the Greek words *Syn*, meaning union, and *Aisthesis*, meaning senses. The phenomena of synaesthesia involves a union of the senses in which stimulation in one sensory modality causes a perception in another sensory modality. For example, hearing a noise (e.g. an auditorily presented digit) could cause a synaesthete to see a mental visual image called a photism (e.g. a specific colour) in addition to hearing the noise. In some cases, synaesthesia also causes an additional perception in the *same* sensory modality. For example, seeing an object or symbol (digit) may cause an additional mental visual image (a specific colour).

Although synaesthesia is fairly rare in adults, estimated to be in the range of 1 per 100,000 (Cytowic, 1989, 1997) to 1 per 2,000 (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996), it is nonetheless an interesting and important topic. For more than 200 years, papers about synaesthesia have appeared in the scientific literature. Marks (1975, 1978) reviewed the literature on coloured hearing, the most frequent type of synaesthesia, and Cytowic (1989) reviewed the literature and presented 42 brief case studies of many types of synaesthesia. Baron-Cohen and Harrison

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(1997) recently edited a book containing classic and contemporary studies on synaesthesia. Perhaps the most familiar descriptions of synaesthesia in the psychological literature are provided by Luria (1987) concerning the mnemonist, S, who experienced visual images for sounds. Most of the previous studies and observations have consisted of presenting stimuli to synaesthetes and recording their subjective experiences to the stimuli.

The present study differs from previous studies by examining not only what a synaesthete reports experiencing, but also by objectively measuring the impact that synaesthesia has on her cognitive processing. Synaesthetes report that their synaesthetic experiences are very "real" to them and seem to occur automatically without their conscious control (e.g. Baron-Cohen, Wykes, & Binnie, 1987). This led us to expect that synaesthesia would have characteristics of an automatic process as defined by Posner and Snyder (1975). They stated (p. 56) that an automatic process occurs "without intention, without giving rise to any conscious awareness, and without producing interference with other ongoing mental activity". Synaesthesia seems to fit this definition. It just seems to occur; intention for it to occur is not necessary for the experience. The process of deriving the synaesthesia experience is not a conscious one. Only the experience itself, the end result of the process, seems to be open to conscious awareness. The synaesthetic experiences occur at the same time that actual stimuli are perceived normally and therefore do not seem to interfere with other ongoing experiences. However, experimental situations can be created in which an automatic process comes into conflict with another ongoing activity and in those cases interference can occur.

In fact, one method of studying automatic processing is to set up such a situation. The Stroop colour-word test is frequently used for this purpose (Stroop, 1935). In the original Stroop test, participants see colour words (e.g. RED) printed in either red or another colour, e.g. green. When the colour of the print is different from the colour word, participants take longer to name the print colour than when the colour word and the print colour match or when they just name the colour of a colour patch.

The present experiments used a variation of the Stroop test designed especially for our participant who experiences synaesthesia for digits. The participant named the colour of the print of digits. The colour of the print either matched or mismatched the colours of her synaesthesia for the digits. The participant also named colour patches and her synaesthesia colours for black digits.

In a second task, our participant named the digits instead of the colours for the stimuli. MacLeod (1991), in his review of the Stroop literature, suggests that the inclusion of such a task is crucial because it provides a basis of comparison for interpreting Stroop tests that study individual differences, as this experiment does. A previous Stroop-type study with a different type of synaesthesia did not do this (Wollen & Ruggerio, 1983).

Before discussing the specific hypothesis it will be useful to describe the synaesthesia of our participant, concentrating primarily on her synaesthesia to digits.

Case History

The participant, who will be called GS, was a 22-year-old female college senior at the time of the study, majoring in psychology and music composition. Since then she has graduated from college and enlisted in the Navy, where she has learned computer repair. She is left-handed with no obvious impairment of vision or hearing.

GS experiences synaesthesia to a wide variety of stimuli including written and spoken digits, music, environmental noises, the sound of people's voices, emotions, body sensations, smells, and some foods. Her strongest synaesthesia responses are to digits and music. She reports that all of these synaesthesia experiences involve seeing a mental visual image. These images are usually coloured. They may also have varied shapes and movements and appear three-dimensional. For some stimuli there is auditory or tactile synaesthesia as well.

For digits, the synaesthesia images seem only to be colours. When she either hears or sees a number she reports seeing a colour or colours "in her head". GS experiences a unique colour for each digit from

0 to 9. The correspondences between the digits and the exact colour names as she describes them are: 0 = clear, 1 = white, 2 = yellowish orange, 3 = bright red, 4 = cornflower blue, 5 = kelly green, 6 = brown, 7 = pink, 8 = dark greenish blue, and 9 = dark purple. For numbers above 9, the individual digits which make up the number swirl together, but do not blend. For multi-digit numbers, the first digit on the left determines the dominant colour in the swirl and each additional digit contributes less and less. For example, for the number 257, the swirl consists of yellowish orange as the dominant colour, green as the next most dominant, and lastly there is a small amount of pink. GS reports that her synaesthesia only occurs in one direction: Digits elicit colours but colours do not elicit digits.

GS has had synaesthesia for as long as she can remember. Her first memory of synaesthesia was when she was about 4 years old and listening to music. GS also remembers an incident when she was aged 6 or 7 years and she was studying flash cards with her mother. She told her mother that the digits were "in the wrong colour". In an interview, GS's mother also remembered this incident but did not understand it until about 15 years later when we started studying GS's experiences.

In many ways GS is similar to many other synaesthetes that have been described in literature (e.g. Cytowic, 1989, 1993; Marks, 1975, 1978) and she has predominantly coloured-hearing synaesthesia, the most frequently reported type.

Hypotheses

Based on GS's description of her synaesthesia, we developed specific hypotheses for the Stroop-like stimuli—two concerning colour naming and one concerning digit naming.

Hypothesis 1. GS will name colours more slowly for digits printed in colours that do not match her synaesthesia colour (Mismatched condition) than for digits printed in colours that match her synaesthesia colours (Matched condition). This outcome is predicted because, for GS, seeing digits causes her to image a specific colour. If the synaesthesia colour occurs fast enough, this colour may interfere with the naming of the actual colour of the print when the synaesthesia colour and the actual colour are not the same. This interference should occur because there are images of two colours present and the correct one needs to be selected so that it can be named. The synaesthesia colour would not interfere with the naming of the actual colour when the synaesthesia colour and the actual colour are the same. If this hypothesis is supported, it will indicate that imaging the synaesthesia colour occurs very rapidly and automatically and in time to interfere with the naming of the actual colour. Mismatched should be slower than Matched even if GS if trying to ignore her synaesthesia.

This hypothesis is consistent with the results obtained by Wollen and Ruggiero (1983) with a letter-colour synaesthete and by Walker and Smith (1984, 1985, 1986) with non-synaesthetes for Stroop-type tasks. However, it is inconsistent with our participant's conscious experience. Prior to the study, GS stated that synaesthesia had very little effect on her because she was able to ignore it most of the time. Also *after* the first experiment, she did not think that having the digits printed in different colours from her synaesthesia had had any effect on her colour naming times.

Hypothesis 2. GS's naming time of the colours of the print of the digits when they match her synaesthesia colours should be equivalent to her naming times for her synaesthesia colours for digits printed in black (Black Digits condition). Furthermore, the naming times in these two conditions should be equivalent to those in a condition in which she names the colour of coloured circles which match her synaesthesia colours (Circles condition). GS reports that black digits produce vivid colour synaesthesia images, which occur very quickly and with no apparent effort. Hence, it was predicted that GS could name the colours of her photisms for black digits as rapidly as she could name the actual colour of the print of digits or of coloured circles.

Hypothesis 3. GS's times for naming the digits corresponding to the colours of coloured circles will be slower than the naming times for digits of any colour. This prediction was made because for GS colours do not seem to elicit digits in the same way that digits elicit colour. Her synaesthesia only seems to work in one direction. For GS, retrieving a digit based on a colour seems to require an extra process and therefore should take longer than naming a digit printed in any colour. Unlike for the colour naming task, the Mismatched condition should not be any slower than the Matched condition for the digit naming task since colours do not produce digits without extra processing.

EXPERIMENT 1 AND 2

Method

Conditions and Tasks
Four conditions (Mismatched, Matched, Black Digits, and Circles) were used in both Experiment 1 and 2 for two tasks (Colour Naming and Digit Naming).

The procedures and methods were the same in the two experiments except for two things. One was different procedures used to link the colour with the digit for the Mismatched condition, as will be described below. The second was that in Experiment 2, GS understood the results of Experiment 1 and was instructed to keep the mismatched colours and digits from interfering with her performance. Also, Experiment 2 was conducted 4 months after Experiment 1 and, therefore, was a test of the consistency of her responses over time.

Participant
The participant was GS, described previously.

Materials
The numbers 1 through 9 were used to create the stimuli for the four conditions. GS selected colours from assorted colour markers that matched her photism colours. A colour match for the number "4" could not be found so this digit was excluded from the experiment.

A total of 56 matrices of 5 × 5 digits or circles were prepared to use as stimuli. To do this, 14 different 5 × 5 matrices of numbers were randomly generated by computer. The computer program ensured that: each matrix included the digits 1–9 (excluding the number 4) at least once, and no digit appeared more than once in any row or column. Each matrix was then used to generate a corresponding stimulus matrix for each of the four conditions. For the Black Digits condition the digits in the computer-generated matrices were used as the digits in the matrix. In the Matched condition the digits determined the order of both the digits and the colours. The Circles condition used the same order of colours as the Matched condition. In the Mismatched condition in Experiment 1, the order of the colours was the same as in the Matched condition and different digits were randomly assigned to a colour (excluding its photism colour) each time it occurred. In the Mismatched condition in Experiment 2, the same digits and colours were linked throughout the experiment. This was done by randomly pairing the colours and digits. The pairs for the Mismatched condition were: 1 = green, 2 = dark greenish blue, 3 = pink, 5 = yellowish orange, 6 = dark purple, 7 = white, 8 = brown, 9 = bright red. This was done in Experiment 2 to ensure that slower colour naming times in the Mismatched condition could not be due to continual changing of the digit/colour pairs.

The digits and circles in the stimulus matrices were drawn using a stencil and the coloured markers GS had selected. The numbers in the matrices were approximately $^3/_8$" × $^3/_4$" high and the circles were $^1/_2$" diameter. Each matrix was approximately $3^1/_2$" × $5^1/_2$". Grey paper was used as a background for the matrices because this colour did not interfere with any of the colours in the matrices and showed the colour "white" clearly. Eight of the resulting matrices were used as practice and 48 were used as actual stimulus matrices.

The order of the matrices was blocked so that for every four stimulus matrices, one matrix from each condition appeared without a repeat of the same computer-generated matrix. Each of the four conditions occurred an equal number of times in each serial position within the blocks.

Procedure

A total of 4 trials of all 56 matrices occurred with 2 trials for each task in the order: Colour Naming, Digit Naming, Digit Naming, Colour Naming. In the second trials of Colour and Digit Naming the order of the matrices was reversed. Testing sessions occurred within a 2-week period in the same room at approximately the same time of day. Before each of the four trials, the experimenter described the four conditions. Then the experimenter gave instructions about what GS was to do for each condition. For the Colour Naming trials GS was to name the colours of the print for the Matched, Mismatched, and Circles conditions. For the Black Digits GS was asked to name the colour that she experienced for the printed digit. In the Digit Naming trials, GS was asked to name the digits for the Matched, Mismatched, and Black Digits conditions. For the Circles condition GS was asked to name the digit that corresponded to the colour of the circle. In Experiment 2 GS was instructed not to let the Mismatched condition slow down her naming times.

Each stimulus matrix had been placed in a numbered folder. GS read the number on the folder and when she was ready, she said "start", opened the folder and began naming either the colours or the digits as the trial required. The experimenter timed from the moment GS said "start" until she finished reading the matrix. GS performed two practice matrices from each condition (eight matrices). GS reported simple colour names, e.g. blue, green, etc., rather than her descriptive labels. A short break was given midway through each trial. Each session was tape-recorded.

Results and Discussion

The mean naming times per matrix for each of the four conditions for both experiments are shown separately for the two tasks in Table 1. For each experiment a within-participant ANOVA was performed on the naming times with Condition (Mismatched, Matched, Black Digits, vs. Circles), Task (Colour Naming vs. Digit Naming), Trial (1 vs. 2 of each task type), and Half (first half of trials vs. second half of trials) as factors. The latter two factors were included in the analyses to check the consistency of the results across different sets of matrices and amounts of practice.

Table 1. *Mean Naming Time per Matrix in Seconds for the Four Conditions in the Two Different Tasks in Experiment 1 and 2*

	Task			
	Colour Naming		*Digit Naming*	
Condition	*Expt. 1*	*Expt. 2*	*Expt. 1*	*Expt. 2*
Mismatched	24.87	24.99	9.69	9.02
Matched	15.44	13.63	9.56	8.88
Black Digits	15.32	13.28	9.54	8.91
Circles	16.54	12.82	12.27	10.38
Means	18.04	16.18	10.27	9.30

$N = 24$ per condition for each task.

Since the pattern of results was so similar in the two experiments, only the ANOVA from the second one will be reported in detail. The ANOVA for Experiment 2 revealed significant main effects for all four factors: Condition, $F(3,15) = 355.22$, $P < .001$, $MSe = 1.10$; Task, $F(1,5) = 4235.59$, $P < .001$, $MSe = .54$; Trial, $F(1,5) = 22.55$, $P < .01$, $MSe = 1.42$; Half, $F(1,5) = 20.16$, $P < .01$, $MSe = .59$. The effect of Half (first half = 12.97 vs. second half = 12.49 sec) and of Trial (first trial = 13.15 vs. second trial = 12.33 sec) showed that the more GS practised the task, the faster she got. There was a large effect of Task with Colour Naming times (16.18 sec) being longer than Digit Naming times (9.30 sec). A Tukey post hoc test of the means for Conditions combining tasks showed that the Mismatched condition was slower than the other three conditions ($P < .01$), which did not differ.

However, the most interesting finding in terms of the hypotheses was a significant interaction between Condition × Task, $F(3,15) = 355.22$, $P < .001$, $MSe = 1.10$. A Tukey post hoc test showed that for each condition, Colour Naming was longer than Digit Naming ($P < .01$). For Colour Naming, the Mismatched condition was slower ($P < .01$) than the other three conditions which did not differ significantly from each other. These results supported the first hypotheses by showing that when the colour of the digit mismatched GS's photism for that digit, the synaesthesia colour interfered with naming the actual colour. Furthermore, there was no significant difference in Colour Naming between the Matched, Black Digit, and Circles conditions. This supports Hypothesis 2 and indicates that GS can name the photism colour of black digits just as quickly as she can name colours of print in which digits or circles are actually printed.

For Digit Naming, the Circles condition took significantly longer than the other three conditions ($P < .01$), which did not differ from each other. This result supports Hypothesis 3. Naming digits from colours took a measurable amount of time as can be seen by comparing the Circles condition with the Black Digit condition for Digit Naming. This contrasts with the results for the Colour Naming task in which no difference was found between the Circles and Black Digit conditions. This difference in the pattern of results for the two tasks indicates that a digit appears to automatically elicit a colour but a colour does not automatically elicit a digit. This conclusion is further supported by the fact that there were no "interference" effects in the Mismatched condition compared to the Matched condition for Digit Naming. If the digits had been automatically elicited by the colours in the Mismatched condition, the times in Mismatched condition would have been slower than in the Matched condition. None of the other two- or three-way interactions in the ANOVA were significant.

The total number of misreading errors (wrong colour or digit) plus the number of self-corrections after misreading is shown in Table 2 for both experiments. The number of errors is extremely small—about 1% of the naming responses—and most were self-corrections (72% and 83% in the two experiments). Therefore, most of the errors she made she was aware of. Also the number of errors mirrors the naming times, with the Mismatched condition having the most errors in Colour Naming and the Circles being one of the conditions with the most errors in Digit Naming. This shows there was no speed-accuracy tradeoff. Lastly, the errors that GS made in Colour Naming in the Mismatched condition are evidence that she confused the photism colour with the actual colour since most were synaesthesia based. In the other conditions for colour naming and for digit naming the errors were mostly anticipations (said a digit one digit early and then corrected herself) or reversals (reversed the order of two digits).

Table 2. *Total Number of Errors and Self-corrections as a Function of Condition and Task in Experiment 1 and 2*

	Task			
	Colour Naming		Digit Naming	
Condition	Expt. 1	Expt. 2	Expt. 1	Expt. 2
Mismatched	12	15	1	3
Matched	7	10	5	2
Black Digits	3	5	3	3
Circles	11	6	5	6
Totals	33	36	14	14

$N = 600$ (24 trials x 25 digits per matrix).

GENERAL DISCUSSION

The results support all three hypotheses. First, they support the idea that synaesthesia is an automatic process. The effects of synaesthesia only become apparent when they come into direct conflict with other ongoing cognitive processing. GS's synaesthesia comes into play in the perception of digits as revealed by the longer colour naming times when the printed colours of digits mismatched her photisms. GS perceived the colour both of the actual digit and of her photisms. When the colours were different, this caused her to have conflict between the two colours. Her synaesthesia is also evident in the synaesthesia-based colour errors that occurred without her intention. The fact that in the two experiments her colour naming times were almost identical in the Mismatching condition show that the different instructions had no effect, which is consistent with earlier Stroop studies (c.f. MacLeod, 1991). The lack of an effect of instructions suggests that her synaesthesia was not under her conscious control. Furthermore, synaesthesia seems to consume few, if any, conscious resources because she named the synaesthesia colours related to black digits just as easily as she named the colours of coloured digits that matched her synaesthesia or the colours of the circles. If naming the synaesthesia colours related to black digits had used conscious resources then that task should have taken longer than naming actual colours. These results do not support the idea that synaesthesia is a consciously mediated process. Mediation implies that there is an intermediate step or level of processing that is required for synaesthesia to occur.

Another conclusion supported by our results is that synaesthesia is a unidirectional process, which is consistent with GS's and other synaesthetes' subjective reports (cf. Cytowic, 1989). For GS, colours did not elicit digits in the same way that digits elicited colours. Naming a digit related to a colour took additional time but naming a colour related to a black digit did not.

The naming times and the pattern of results was very similar within experiments, as shown by consistency across the different trials and halves. The results were also similar across the two studies, which were 4 months apart. This stability in responses is consistent with earlier studies with synaesthetes (Baron-Cohen et al., 1987; Baron-Cohen, Harrison, Goldstein, & Wyke, 1993) and supports the genuineness of our participant's synaesthesia.

This research goes beyond the usual highly subjective research with synaesthetes, in which they are simply asked to report their experiences. These experiments showed that synaesthesia is a "real", ongoing experience that can be studied objectively. These objective measurements for the most part corroborate the subjective reports. However, these objective measurements also reveal that the synaesthesia can have more influence than GS realises.

A comparison of the results for the coloured circles for the two different tasks is particularly interesting, but counterintuitive. The digit naming time was faster than the colour naming time for the coloured circles. This was true even though GS appeared to perform an extra process in the Digit Naming task for the circles. She perceived the colour of the circle, translated that colour into a digit, and then named the digit. She could do this faster than she could perceive the colour of the circle and name that colour. Obviously the difference between these two tasks cannot be explained by differences in the processing times of colours vs. digits per se, because she only saw coloured circles. This difference seemed to occur because it took longer to retrieve colour names than digit names. This is consistent with classic studies using the Stroop task, which showed faster colour word reading times than colour print naming times (e.g. MacLeod, 1991; Stroop, 1935).

Cognitive Model

To help visualise the cognitive processes that occurred in this experiment, a model is shown in Fig. 1. When a visual stimulus is presented, we assume that the visual system processes colour in parallel and independently of shape. Visual input is fed into the Colour Input Lexicon, which identifies that colour is present. The Colour Input Lexicon activates a representation of the colour in the Automatic Colour Analyser. The Automatic Colour Analyser allows the identification of the colour in the Colour Identifier to occur. Within the colour Identifier, the colour comes into conscious awareness and can then be named by the Colour Namer. At this point, information from the Colour Namer can be used to direct the Response Generator, which controls the peripheral processes that are necessary for physically producing the name of the colour if the task requires it.

Visual input of the stimulus is also fed into the Shape Input Lexicon, which identifies that a familiar shape is present. The Shape Input Lexicon has several connections to several different shape analysers, which are capable of a more detailed identification of the shape. Digits activate a stored representation in the Automatic Digit Analyser. From the Automatic Digit Analyser, information goes to the Digit Identifier, where the digit can then be consciously identified and named by the Digit Namer. If not consciously identified, naming cannot occur. Information from the Digit Namer, as in the case of the Colour Namer, activates the Response Generator, which controls the peripheral

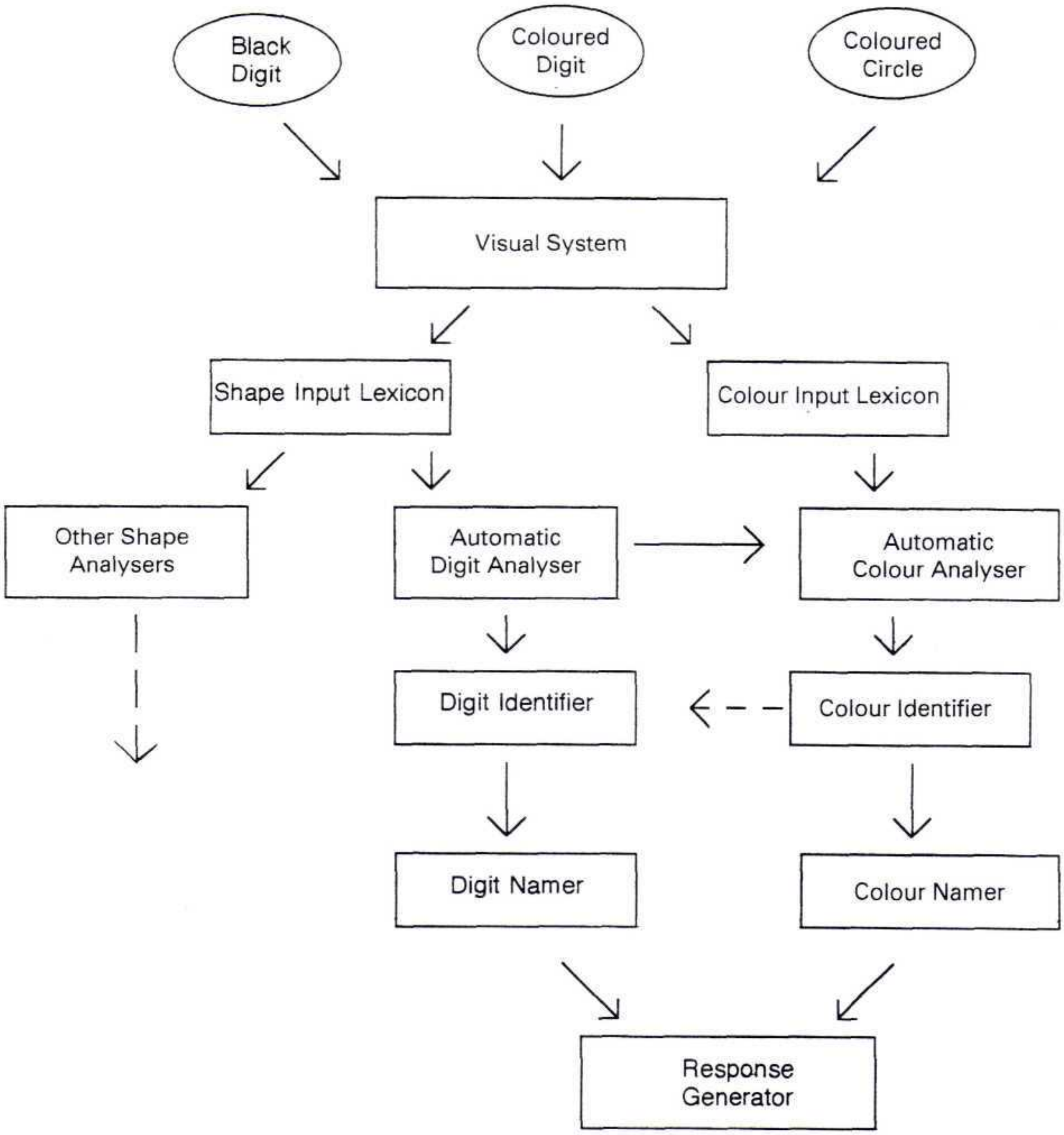

Fig. 1. *Schematic representation of the cognitive processes used by GS in the experiments.*

processes that are necessary for physically producing the name of the digit if the task requires it.

For GS, the Automatic Digit Analyser stimulates a corresponding representation in the Automatic Colour Analyser. This colour representation then proceeds through the system as a colour would if it were presented visually. Because GS's synaesthesia occurs prior to conscious awareness it appears that the intererence between the two colour representations takes place in the Colour Identifier. For coloured digits, two representations of colour enter the Colour Identifier: one generated by the Colour Input Lexicon and one generated by the Automatic Digit Analyser. When the two representations are the same, no interference occurs in the Colour Identifier. However, when the two representations are not the same, the colour identification is slowed down because the appropriate source of colour information has to be selected. Competition occurs because the Colour Namer cannot name two colours at once.

Within the Colour Identifier, black (as in black digits) does not appear to cause the same interference as do other colours. Hence it must not be processed as a colour per se. For coloured circles, the Colour Identifier may send information to the Digit Identifier if the task requires it. That is how a digit is named based on the colour. This is a conscious process and occurs later than naming a colour for a digit.

Cognitive Basis

The cognitive basis of the interference effect in these experiments and what aspect of the digit causes the synaesthesia are interesting considerations. We think the interference effects in the experiments were the result of mental images related to the digits rather than simple associations between the digit names and colour names. First, GS initiated her discussion with us about her synaesthesia based on her experience of "seeing colours" for digits and later made drawings showing her images. Also, when shown a colour patch alongside a digit, GS experiences seeing two separate colours. One is her synaesthesia colour for the digit and the other is the actual colour of the colour patch. These experiences would not have occurred if GS simply had relations between names of digits and colours. Related to this was GS's difficulty in verbally describing what she was experiencing. This particularly occurred with her multifaceted images of music and other sounds, but also occurred with digits. For digits, she had trouble expressing the precise colours of her images. A colour was not simply "blue", it was "sort of cornflower blue", etc. Another reason that we do not think that associations between names can account for the results is that she never performed the task of verbally naming her colours for digits before participating in Experiment 1. Practice had little effect on her response times because the pattern of results was very similar in the two experiments. Also the actual results of the experiments cannot easily be explained by simple associations between colour and digit names. If there was such an association between colours and names, the association should work for both tasks. The results clearly show that did not happen.

A related question about the cognitive basis of the synaesthesia is what aspects of digits cause GS's photisms. Since she reports synaesthesia for both visual and auditory digits, it seems to be based on a "concept" of a digit rather than the actual physical stimulus. In some informal tests of this idea we presented some small objects (buttons, seeds, and scraps of paper) and noises (running taps and dropping small objects) to her to try to determine when colours that were related to the number of objects occur. When she looked at objects, e.g. three white buttons, all that she reported seeing was white buttons. When we asked her how many objects there were, she said "three" and immediately reported that she saw red, the synaesthesia colour for 3. GS reported that she got the colour corresponding to the number of objects if she just thought of the number, but the vividness of the colour was not as great as if she actually said it. This was true for all of the objects and numbers of objects that we tried. For the noises she experienced synaesthesia, but synaesthesia was related to the noise itself and not related to the number of noises. When asked about the number of noises, she reported experiencing the photism colour related to the number, but it was independent of the synaesthesia caused by the noise itself and the two types of synaesthesia did not mix together. These introspective reports are consistent with the idea that synaesthesia for digits is related more to the concept of the digit than to actually hearing or seeing.

Another interesting and related observation about her digit photisms is that the correspondence between digits and colours is specific to Arabic digits or to digits spoken in English. Other types of digits produce different and unrelated photisms. For example, digits written in Spanish, the language she took in college, do not elicit colours when GS reads them to herself. When spoken by someone else, the Spanish digits take on a colour that seems to be related to pitch of the voice. In addition, digits spoken in Spanish produce photisms of "curved lines with bumps and knots". The number of bumps seem to be related to the number of syllables in the Spanish word for the digit, while the knots seem to be related to particular phonemes. These Spanish-digit synaesthesia responses seem more related to the acoustic characteristics of the digits than to the underlying concept of the digit. They are more like her synaesthesia responses to environmental sounds and music than they are to digits spoken in English. It is as though the digits spoken in Spanish are not integrated into the same conceptual base as the digits spoken in English. This is probably what would be expected for second language learning when that language has never been used on a regular basis. Frequently the research on second language learning and bilinguals suggest that there are two separate representations for different languages (cf. Paivio & Lambert, 1981; Smith, 1991). These observations concerning GS's digits spoken in Spanish are consistent with those conclusions.

Another number system, Roman numerals, produces yet another set of synaesthesia responses for GS. She reports seeing "columns" of the appropriate number when she sees Roman numerals. Again this would suggest that these materials are not tied into the same conceptual system as Arabic digits or digits spoken in English.

Origin of Synaesthesia

An interesting question concerning synaesthesia is whether it is innate or learned. Cytowic (1989, 1993) and Harrison and Baron-Cohen (1997) have reviewed a number of the theories, which will not be repeated here, concerning how and why synaesthesia develops. A couple of observations about GS's synaesthesia number system are relevant to this question. First, as mentioned earlier, GS had synaesthesia very early in her life. This is not an ability that she decided to develop to impress her parents or friends. GS can only remember mentioning her synaesthesia experiences once to her mother and once to classmates when she was young.

The second observation related to the nature/nurture question is that GS's system of synaesthesia is based on a base 10 number system. Her colours for the digits 0 to 9 are unique while those for numbers greater than 9 are combinations of the synaesthesia colours corresponding to the different digits. It would seem highly unlikely that this system would have developed without some knowledge of the base 10 number system. GS was not even aware that she had a base 10 system for her synaesthesia until we started working with her and had her pick out and write down the colours of the digits between 1 and 100 from the *Munsell book of color* (Munsell, 1929). It was only at that point that she realised what the relationship was between her photisms and the numbers.

In summary, this case study provides insight into the experience of synaesthesia. The experiments showed that synaesthesia, a subjective experience, can be studied objectively in the laboratory, and that it influences cognitive processes in predictable ways.

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