TESIS DOCTORAL

DOCTORAL DISSERTATION

Synaesthesia: Senses without Borders

Sinestesia: Sentidos sin Fronteras

By / Por Matej Hochel

Supervisor: / Director: Emilio Gómez Milán

DEPARTAMENTO DE PSICOLOGÍA EXPERIMENTAL Y FISIOLOGÍA DEL COMPORTAMIENTO

Universidad de Granada

Editor: Editorial de la Universidad de Granada
Autor: Matej Hochel
D.L.: Gr. 692 - 2008
ISBN: 978-84-338-4930-4

Acknowledgements

It would not have been possible to write this doctoral thesis without the support of the people around me, to only some of whom it is possible to give particular mention here.

Above all, I would like to thank my supervisor Dr. Emilio Gomez. This work would not have been achieved without Emilio's guidance and support, not to mention his imaginative ideas and excellent knowledge in the area.

Some of the experiments would not have been possible without the technical knowledge and help of José Luis Mata from the University of Jaén. I am also grateful to Francisco Tornay whose unparalleled imagination as well as his understanding of statistical analysis helped to refine some of the ideas behind the experimental series included in the thesis. I would also like to thank Milagros Gallo for encouraging me to translate, submit and get the introductory review paper published.

I am most grateful to my dear friend Allison Crawley, who not only edited some of the texts included in the thesis, but also appreciably cultivated and refined my English speaking skills. Another big "thank you" goes out to Jana Spilková from the Department of Social Geography of the Charles University in Prague, who made my stay there the most enjoyable experience.

I would like to acknowledge the financial support of the Spanish Agency for International Cooperation (Agencia Española de Cooperación Internacional, AECI), specifically in the award of a Postgraduate Research Scholarship that provided me with the necessary financial means to successfully conclude this project.

Amongst my fellow postgraduate students in the department, I want to show my appreciation for José Luis Vilchez, whose friendly presence I enjoyed during many great conversations over coffee or beer. The same applies to Germán Gálvez who was a part of my small but important social background in Granada.

Last, but by no means least, I would like to thank my girlfriend Petra for her personal support and great patience while tolerating my extended absence, and a special thanks must also go out to my parents who have, as always, given me their unequivocal support throughout.

Acknowledgements in Slovak Language

Je niekoľko ľudí, ktorým určite dobre padne poďakovanie i v slovenskom jazyku. Nie je to z dôvodu, že by nerozumeli anglicky, ale preto že v slovenčine to jednoducho znie tak akosi inak, krajšie. V prvom ďakujem mojim skvelým rodičom, ktorí – ako vždy – boli pre mňa tou nenahraditeľnou rodinnou oporou počas mojich mnohých študijných i pracovných pobytov v zahraničí. Nemenej vďačný som mojej priateľke Petre za pochopenie, osobnú podporu i veľkú trpezlivosť v časoch mojej nie práve krátkej neprítomnosti. A napokon ďakujem všetkým „skalným" priateľom zo Slovenska i Čiech za to, že sú, boli a budú, a to napriek tomu, že sme sa v posledne dobe nevídali príliš často.

CONTENTS

Part III: Creativity in Synaesthesia

Research objectives

The first part of the present thesis is includes a thorough review of the current scientific knowledge concerning the phenomenon of synaesthesia in all its aspects (cognition, behavior, neurology, genetics and demographics).

Experimental studies included in the Part II are aimed at examining the role of emotion in an unusual case of emotionally mediated synaesthesia. In addition to the relatively common lexical-chromatic synaesthesia, R, the subject of this single case study, shows a rarely reported cross-modal perception in which a variety of visual stimuli elicit aura-like percepts of color. Initial interviews revealed that R's extraordinary synaesthesia was closely related to the affective valence of synaethetic inducers and typically brought out a consistent pattern of emotional responses. The goal of the experimental series presented in Part II was two-fold:

a) To empirically demonstrate the authenticity of R's "auras"
b) To examine the role of R's emotional perception of colors

Part III comprises a study examining the relationship between synaesthesia and creativity. Anecdotal data about synaesthete artists as well as demographic studies, reporting a higher prevalence of synaesthesia among artists, suggests for a seemingly strong relationship between synaesthesia and artistic creativity. Some authors even proposed that synaesthetes' "hyper-connective" brains could be the cause of their above-average creative potential. However, similar claims have only rarely been tested empirically. The main goal of this study was:

a) To assess different cognitive components of creativity in synaesthetes by means of appropriate psychometric tools
b) To contras synaesthetes' creative abilities with that of non-synaesthetes

Finally, the Part IV offers a comparative study that contrasts a relatively rare modality of emotionally mediated synaesthesia with so-called auric phenomena, described in mysticism and alternative medicine literature. It has been hypothesized that the purported ability of certain individuals to perceive the human aura could be explained in terms of a special subtype of synaesthesia; the one where visual perception of human faces and/or figures triggers the experience of mental colors or photisms. Our main objective was to see whether this hypothesis may or not be held true by examining phenomenological reports of synaesthetes and comparing them to descriptions of purported "special abilities" of clairvoyants and sensitives.

Part I

Synaesthesia: The Existing State of Affairs

Chapter 1

Sinestesia: Status Quo

Introducción

Cuando R observa una cara, su mente genera colores que no existen en el mundo que nosotros, los “normales”, vemos como real. La contemplación de una figura humana le hace ver un halo de color que es congruente con la valoración afectiva que R hace en referencia a la persona que está observando (Milán y cols., aceptado). Hace un par de siglos, este tipo de percepción habría sido considerada brujería e incluso hoy en día hay personas que creen en la capacidad de ver el aura – la supuesta capa de energía psíquica invisible que rodea a todo ser vivo. Aunque R no mantiene creencias esotéricas ni proclama tener poderes sobrenaturales, en el pasado su extraordinaria manera de percibir el mundo podría haberle llevado al confinamiento en un hospital de enfermos mentales (Day, 2005; Cytowic, 1993). Debido a la frecuente hostilidad hacia lo extraño, las personas que sufren (o disfrutan de) sinestesia a menudo no hablan de su diferente manera de percibir el mundo, tratando de “pasar de normales” (Day, 2005). La palabra sinestesia proviene del término griego *aisthesis*, percepción, y literalmente significa “percepción unida” (*syn* = “unido”, “junto”). En los sinéstetas, la estimulación de un sentido (por ejemplo, el oído) conlleva una percepción en otra modalidad sensorial añadida (por ejemplo, la vista). En algunos casos, la experiencia sinestética implica la “transducción” de una categoría semántica aprendida (grafemas, números, caras humanas, días de la semana) en una experiencia sensorial (por ejemplo, la percepción de un color “fantasma”).

El primer dato científico sobre sinestesia se debe a Francis Galton (1880) quien observó que un pequeño porcentaje de personas poseían la peculiar capacidad de experimentar la estimulación sensorial en un sentido de manera multimodal, en dos o incluso más modalidades sensoriales (Ramachandran y Hubbard, 2003a). Desgraciadamente, muchas décadas tuvieron que pasar para que sinestesia volviese a ser digna del estudio científico. La idiosincrasia del fenómeno y la natural desconfianza de la comunidad científica hacia lo subjetivo hizo que durante mucho tiempo la sinestesia fue relegada a la periferia de la investigación. En consecuencia, la falta de información médica y psicológica llevó a numerosas desgracias personales cuando sinéstetas que “salieron del armario” fueron diagnosticados como esquizofrénicos, considerados drogadictos e incluso internados en hospitales psiquiátricos (Day, 2005). En el mejor de los casos los profesionales se mostraban incrédulos, suponiendo que el sinésteta que hablaba de una “melodía amarilla” o de una comida con “sabor puntiagudo” (Cytowic, 1993) simplemente estaba utilizando un lenguaje metafórico.

Los primeros estudios modernos sobre sinestesia pasaron en gran medida desapercibidos o eran considerados mera curiosidad. Lawrence Marks, por ejemplo, en su obra *The Unity of the Senses*, destacó la importancia científica de la sinestesia, subrayando su potencial en el estudio de las bases perceptuales de la metáfora (Marks, 1978). Diez años antes, Luria describió el caso de memoria eidética en un sinésteta “multimodal” con una extraña interconexión entre prácticamente todos los sentidos (Luria, 1968). Sin embrago, debido a la influencia del conductismo y su absoluta desconfianza hacia la subjetividad o incluso una negación de la misma, la psicología no consideró importante el estudio de un fenómeno que sólo podía revelarse a través de informes verbales. Aparentemente, “los científicos del siglo veinte intentaban insistentemente eliminar el papel subjetivo de un observador humano en la recolección de datos empíricos.” (Cytowic, 2002).

Afortunadamente, el panorama ha cambiado en las últimas dos décadas. La labor de algunos investigadores, a destacar Cytowic, Ramachandran y Hubbard, Sean Day, Daniel Smilek, Michael Dixon, entre otros, convirtió la sinestesia en un hecho científico cuya existencia puede ser demostrada y estudiada empíricamente. La confirmación experimental de la realidad del fenómeno dentro del paradigma psicométrico por fin ha convencido a la comunidad científica. De repente aparece un número importante de publicaciones sobre sinestesia en revistas internacionales de impacto. Aparte de los estudios psicométricos se ofrece la posibilidad de someter a los sinéstetas a las modernas y populares técnicas de neuroimagen. (Véase la revisión de Hubbard y Ramachandran, 2005.) En definitiva, la sinestesia es reconocida como un fenómeno que puede abrir puertas hacia enigmas científicos y filosóficos, tales como la naturaleza de la percepción y de los qualia, las bases neurofisiológicas de la metáfora y del lenguaje.

Diagnosticando sinestesia

Cuando la T lee una expresión, como por ejemplo el “*ARCO IRIS*”, cada letra le hace ver un particular tono de color. Si otro sinésteta grafema-color leyese las mismas palabras, su percepción sería marcadamente desigual; el patrón de correspondencia entre fotismos y grafemas cambiaría. Lo mismo puede decirse de cualquier tipo de sinestesia conocido. (Véase la Tabla 1 para apreciar la correspondencia entre números y colores en dos sinéstetas, R y N, estudiados por Milán y cols.)

Tabla 1: La correspondencia ente números y colores mentales en dos sinéstetas léxicos, N y R, estudiados por Milán y cols.

	1	2	3	4	5	6	7	8	9
N.	negro	amarillo	rojo	azul claro	azul oscuro	rosa	verde	rojo oscuro	color “carne”
R.	blanco	rojo-marrón	amarillo	azul	rojo	gris rosáceo	*	*	ocre

* En estos números, R no sabe decir cuál es el color del fotismo asociado.

Un sinésteta, cuyos fotismos son evocados por el sonido de instrumentos musicales, presenta una matriz de asociaciones tono-color particular y diferente de cualquier otro sinésteta “musical”. Asimismo, las descripciones subjetivas apuntan en otro tipo de discrepancias en la experiencia sensorial sinestética. Mientras que algunos sinéstetas describen sus fotismos como manchas de color que flotan “en su mente” de manera parecida a la imaginería visual voluntaria, otros hablan de percepciones que son proyectadas sobre el estímulo externo, como un halo de color o un foco de luz que ilumina el inductor sinestésico. La idiosincrasia y la naturaleza subjetiva del fenómeno dificultan su encaje en la terminología científica. Al mismo tiempo, el término *sinestesia* ha sido aplicado deliberadamente a un amplio rango de fenómenos, desde sinestesia idiopática (adquirida de manera natural en el desarrollo), estados inducidos por drogas, el lenguaje metafórico… hasta creaciones artísticas y teatrales (Cytowic, 2002).

A pesar de esta heterogeneidad fenomenológica, se han ido definiendo una serie de criterios diagnósticos que permiten diferenciar la sinestesia idiopática de otro tipo de condiciones psicológicas (como alucinaciones o estados de conciencia alterados) o de extravagancias artísticas. Siguiendo a Cytowic (2002), la percepción sinestésica es:

1. involuntaria y automática
2. localizable en el espacio
3. consistente y genérica
4. duradera
5. de una importancia emocional

El carácter involuntario de la sinestesia hace referencia a la imposibilidad de manipular o suprimir intencionadamente la experiencia sinestésica. Cuando un sinésteta "grafema-color" ve un carácter escrito, por ejemplo la letra "R", al mismo tiempo observará un halo de color que rodea el grafema. A diferencia de un recuerdo que es traído a la mente a causa de una asociación con algún aspecto del mundo externo, la respuesta sinestésica no puede ser controlada por la fuerza de la voluntad. Mientras que a veces somos capaces de dejar de pensar en un recuerdo desagradable, no es posible dejar de ver, oír u oler un estímulo externo a no ser que uno elimine la entrada de información sensorial. Lo mismo puede aplicarse a la percepción sinestésica.

Cuando los sinéstetas describen su experiencia, a menudo hablan de un color proyectado sobre el carácter escrito (sinéstetas grafema-color) o de formas visuales en "una pantalla" situada a cierta distancia delante de la cara (sinésteta auditivo-visual). Un sinésteta, descrito por Cytowic (1993), que experimentaba sensaciones táctiles en respuesta a la estimulación gustativa, solía cambiar la posición de las manos para "alcanzar" la sensación. De ahí que hablemos de la "localizabilidad" espacial de las sensaciones sinestésicas. No obstante, este rasgo es menos obvio en sinéstetas con percepción sinestésica que se parece más a la imaginería visual. (Véase más adelante, sinéstetas "asociadores".) En esta variante de la sinestesia se mantiene el carácter automático de la respuesta pero la localización espacial es debatible, dado que la percepción no es proyectada externamente. Aún así, lo que caracteriza a todos los casos de sinestesia es su consistencia. Una vez establecidas durante el desarrollo, las asociaciones sinestésicas se mantienen de manera indefinida. Los estudios informan sobre periodos entre pruebas experimentales test-retest con duraciones de semanas, meses o incluso años. Por ejemplo, Baron-Cohen y cols. (1987) estudiaron el caso de un sinésteta, E.P., que experimentaba colores en respuesta al lenguaje hablado. En la sesión inicial le pidieron a E.P. una descripción minuciosa de los colores que "veía" al escuchar 103 estímulos auditivos (palabras, letras y números). Diez semanas más tarde le pasaron la misma prueba y el sujeto fue consistente al cien por cien con respecto de la sesión anterior. Mientras tanto, en sujetos normales (no sinéstetas) sometidos al mismo test con un periodo entre pruebas de tan sólo dos semanas, la consistencia fue significativamente más baja. (La tasa de correspondencia sólo llegó al 17%.) Es decir, el emparejamiento entre estímulos y respuestas sinestésicas es altamente estable en el tiempo y no es comparable con la ejecución memorística de sujetos normales. En la misma línea, la sinestesia es una condición que se adquiere en la infancia (lo sujetos normalmente informan de poseerla "desde siempre" o desde cuando puedan recordar) y que suele perdurar de por vida. Hasta la actualidad no es conocido ningún caso de remisión espontánea de la sinestesia[1].

Además de su consistencia y su durabilidad, hay otro aspecto que diferencia la sinestesia de otros fenómenos como pueden ser las alucinaciones presentes en trastornos psicóticos – el carácter genérico de las percepciones fantasmas. Las respuestas sinestésicas se corresponden con rasgos perceptuales básicos tales como el color, las texturas y formas visuales simples, las sensaciones táctiles, etc. No se trata nunca de composiciones complejas con carácter pictórico o semántico (Cytowic, 2002).

Finalmente hemos de destacar la relación de la sinestesia con el mundo afectivo de quien la posee. A menudo los sinéstetas informan sobre emociones placenteras que acompañan a la experiencia sensorial, parecidas a la “sensación eureka” (Cytowic, 2002). En ocasiones la sinestesia también puede unirse con afectos negativos, en particular cuando la percepción sinestésica es incongruente con la realidad externa. (Por ejemplo, cuando un sinésteta grafema-color observa una letra escrita con tinta de color diferente del fotismo asociado.) Ciertos tipos de sinestesia están conectados directamente con la emocionalidad. Por ejemplo, el sujeto sinésteta R descrito por Milán y cols. (2006, aceptado) experimentaba colores mentales en respuesta a la visión de caras, figuras humanas y escenas visuales con carga emocional. Habitualmente los colores experimentados eran congruentes con la evaluación afectiva que R hacía de la persona o de la escena en cuestión. (De hecho, R a menudo aprovechaba los fotismos para refinar su valoración.) En raras ocasiones el “aura” sinestésico experimentado por R era incongruente con la relación que R mantenía con una persona particular. Por ejemplo, un amigo de R “era” de color verde “lechuga”, asociado a emociones negativas. Este tipo de incongruencias conllevaba intensos sentimientos negativos. En la literatura hay casos parecidos de sinestesia emocional, a destacar el estudio reciente de Jamie Ward (2004) sobre G.W., quien experimentaba colores mentales ante caras y nombres de personas conocidas, así como en respuesta a palabras con carga emocional.

Demostraciones empíricas de la sinestesia

El escepticismo inicial de los psicólogos, neurólogos y otros profesionales con respecto de la sinestesia se debía en gran medida a la falta de métodos experimentales que demostrasen de un modo objetivo la realidad del fenómeno. Desgraciadamente, la ciencia tardó décadas en retomar el tema, considerar la posibilidad de que se tratase de “algo” real y por fin invitar a los sinéstetas a participar en estudios experimentales que pudiesen confirmar o desmentir la autenticidad de su condición.

Como hemos dicho anteriormente, uno de los indicios que apuntan en la realidad del fenómeno es su consistencia a través del tiempo. Para evaluar la consistencia, al sujeto se le presenta un inductor sinestésico (por ejemplo, un grafema en el caso de sinéstetas léxicos o un tono en los sinéstetas musicales) y se le pide un informe verbal sobre la sensación sinestésica asociada (por ejemplo, el color del fotismo). (En diseños más sofisticados suele utilizarse una tabla estandarizada de colores para discernir los fotismos con mayor exactitud.) La prueba se repite pasado un tiempo. Siguiendo este método, prácticamente en todos los estudios publicados la consistencia de los sinéstetas se acerca al 100% (p.ej., Baron-Cohen, 1987; Dixon y cols., 2000; Mattingley y cols., 2001; Milán y cols., aceptado). La estabilidad de asociaciones sinestésicas se mantiene aún cuando es evaluada tras lapsos de tiempo prolongados hasta un año (Baron-Cohen y cols., 1993).

No obstante, la consistencia alta por sí misma no aclara el mecanismo subyacente. Hace relativamente poco, la explicación más común de la sinestesia era en términos de asociaciones aprendidas, posiblemente debido a experiencias de aprendizaje durante la infancia (Ramachandran y Hubbard, 2003a). En teoría un sinésteta léxico podría haber jugado con pegatinas con letras de alfabeto en color y así haber desarrollado una fuerte asociación entre un color y una letra particular. Esta posibilidad estimuló en los años ochenta los primeros estudios que aspiraban a averiguar si se trataba de un fenómeno genuinamente sensorial o no. Los diseños iniciales (y también muchos de los actuales) se apoyaban en modificaciones de la tarea Stroop (Stroop, 1935) y consistían en presentar a un sinésteta grafema-color una cartulina con un carácter impreso en tinta de color congruente o incongruente con el fotismo asociado (p.ej., Wollen y Ruggiero, 1983; Mills y cols., 1999). Dixon, Smilek, Cudahy y Merikle utilizaron la misma lógica en un estudio reciente (Dixon y cols., 2000) con el sinésteta C cuyo inductor sinestésico eran los caracteres numéricos árabes. Los estímulos consistían en un cuadrado de color (línea base) o un número escrito en tinta congruente o incongruente con el fotismo; fueron presentados en orden aleatorio en la pantalla de un ordenador. La tarea del sujeto consistía en nombrar el color de la tinta lo más rápido posible. La respuesta fue registrada con un micrófono, siendo la variable dependiente el tiempo de reacción de C. Como era de esperar, C tardó significativamente más en responder en los ensayos incongruentes (797 ms, 2.8% de errores) con respecto de los congruentes (525 ms, 1.4% de errores) y de la línea base (545 ms, 0.0% de errores).

Este resultado fue replicado en numerosos estudios (p.ej., el estudio de Mattingley y cols., 2001 con un grupo de 15 sinéstetas) y apunta en la automaticidad de la respuesta sinestésica. Sin embargo, otra vez el efecto por sí mismo no demuestra si la sinestesia es el resultado de un proceso perceptual o no. MacLeod y Dunbar en su serie experimental del 1988 entrenaron sujetos no-sinéstetas para asociar formas geométricas acromáticas con etiquetas de colores. Tras miles de ensayos los participantes fueron sometidos a una prueba tipo Stroop en la cual las formas originales fueron presentadas en colores congruentes o incongruentes con la asociación original. Los resultados desvelaron un patrón de interferencia que sólo podía deberse al sobreaprendizaje anterior. Este tipo de evidencia sugiere que un mecanismo de asociación basado en la memoria podría ser suficiente para explicar los tiempos de reacción de los sinéstetas. Sin embargo, los informes subjetivos no concuerdan con esta hipótesis. Los sinéstetas normalmente no hablan en términos de imaginar el fotismo o de acordarse de un color al ser expuestos a un estímulo inductor. Las descripciones suelen referirse a un halo de color específico (Smilek y Dixon, 2003), una sensación táctil concreta (Cytowic, 1993) o un sabor en la lengua. En definitiva, los informes verbales sugieren que la sinestesia es “un fenómeno genuinamente sensorial” (Ramachandran y Hubbard, 2003a). Para poner a prueba esta hipótesis es necesario investigar hasta qué punto los colores “fantasmas” llevan a efectos sensoriales que se dan con colores reales. Ramachandran y Hubbard

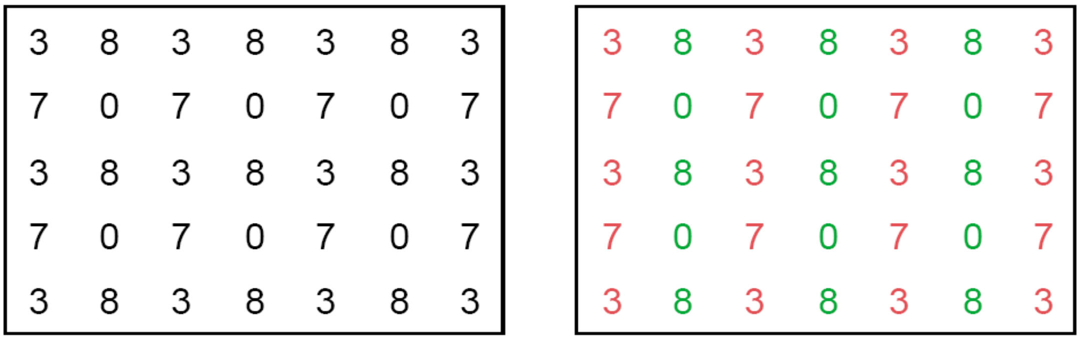


Figura 1: Los normales perciben la matriz de números (izda.) como organizada horizontalmente, debido a la similitud de formas visuales entre el 3 y el 8. Los sinéstetas léxicos observaron una organización vertical, debido al patrón cromático generado por los fotismos. (Ramachandran y Hubbard, 2001a)

(2001a) estudiaron a dos sinéstetas (J.C. y E.R.) que veían fotismos en respuesta a la visión de letras y números. Para ver si se trataba de un procesos sensorial o no, los autores construyeron matrices de números 7x5 que, por su forma visual, podían ser agrupados bien horizontalmente o bien verticalmente. Cuando un rasgo visual lleva a la formación de conjuntos que son percibidos como un todo, se considera que tal rasgo es puramente perceptivo (Beck, 1966; Treisman y Gelade, 1980). Por ejemplo, si una serie de puntos adyacentes en una matriz tienen un color diferente del resto, son reconocidos como grupo cuya forma "destaca" del fondo. El agrupamiento perceptual puede surgir en respuesta a características visuales simples como el color, la forma o la orientación de elementos individuales. En el diseño de Ramachandran y Hubbard, los elementos individuales eran números que, debido a la similitud entre los elementos en filas (3 y 8) podían ser percibidos como organizados horizontalmente (Figura 1, izquierda). No obstante, la distribución de los números fue adaptada de manera que los elementos en columnas alternantes (3 y 7, 8 y 0) estimulaban los mismos colores sinestésicos. Si los fotismos se comportaran de manera parecida a colores reales, deberían superponerse a la organización horizontal inducida por la forma de los números y llevar a una percepción de columnas verticales (Figura 1, derecha). Y efectivamente, ambos sinéstetas informaron de observar agrupaciones verticales en un 90.97% (J.C.) y un 86.75% (E.R.) de los ensayos, mientras que los controles tendían a agrupar los elementos en base a la forma de los caracteres, es decir, horizontalmente.

En otro experimento Ramachandran y Hubbard trabajaron con matrices de grafemas que contenían una figura geométrica (rectángulo, triángulo, paralelepípedo

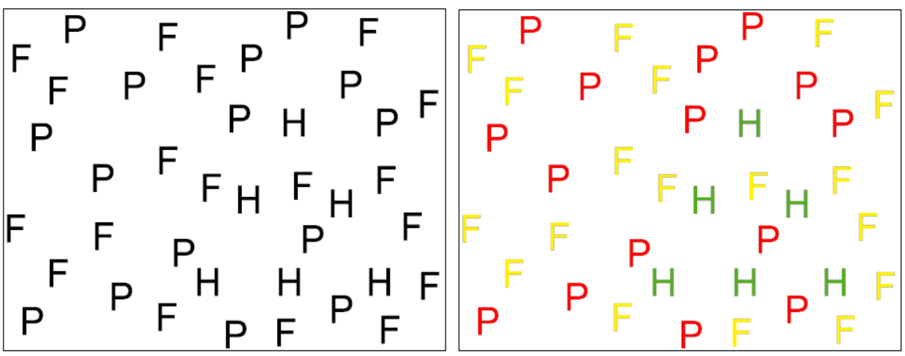


Figura 2: La matriz presentada en la prueba de Ramachandran y Hubbard (2001b) y la imagen en colores "fantasmas", observada por el sinésteta J.C.

o cuadrado) formada por agrupación de caracteres idénticos, entremezclados con otros grafemas (Figura 2, izquierda). La tarea de los sujetos consistía en observar cada matriz durante 1 segundo, intentando discriminar la figura "oculta". Los controles sólo acertaron en un 59.4% de los casos. Mientras tanto, los sinéstetas discernieron la figura geométrica correctamente en un 81.25% de los ensayos. La explicación más parsimoniosa es que en los sinéstetas los fotismos inducidos por los grafemas llevan a un efecto de segregación sensorial ("pop-out") de la forma que componen. (Un resultado parecido se obtendría con normales expuestos a matrices con caracteres en color real, como la de la Figura 2 derecha.)

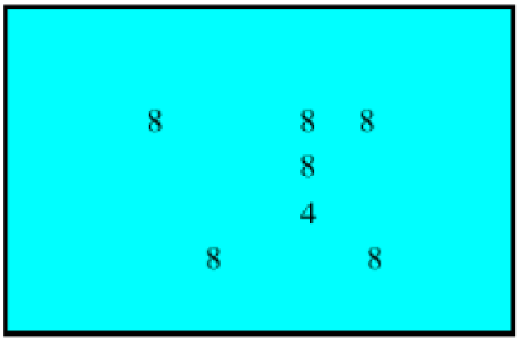


Figura 3: La sinésteta C fue significativamente más lenta en localizar objetivos (números), cuando los caracteres fueron presentados sobre un fondo congruente con el fotismo inducido por el grafema-objetivo (azul, para el número 4). En comparación, en la condición incongruente el aumento del número de distractores prácticamente no afectaba a la ejecución de la sinésteta. (Smilek y cols., 2001)

Los resultados de ambos experimentos de Ramachandran y Hubbard (2001a) sugieren que la sinestesia se debe a un proceso de naturaleza sensorial y no puede ser atribuida a un efecto de la memoria o a un uso excesivo de lenguaje metafórico por parte de los sinéstetas. En consonancia con los resultados anteriores, Smilek y cols. (2001) demostraron que los fotismos realmente pueden influir en la percepción visual. Los investigadores presentaron un carácter numérico acromático (p.ej., 4) sobre un fondo de color, seguido de una máscara en una tarea de identificación. Cuando el número fue presentado sobre un fondo congruente con el fotismo del sujeto sinésteta C, la ejecución fue peor (88% de aciertos) con respecto de la condición incongruente (96%). En otras palabras, cuando el fotismo proyectado sobre el grafema era del mismo color que el fondo, la discriminación era más difícil para C. El mismo resultado fue obtenido en una tarea de búsqueda visual de un grafema entre distractores (Figura 3). Otra vez, la ejecución del sujeto sinésteta (el tiempo de reacción) fue peor para ensayos congruentes en comparación con los incongruentes.

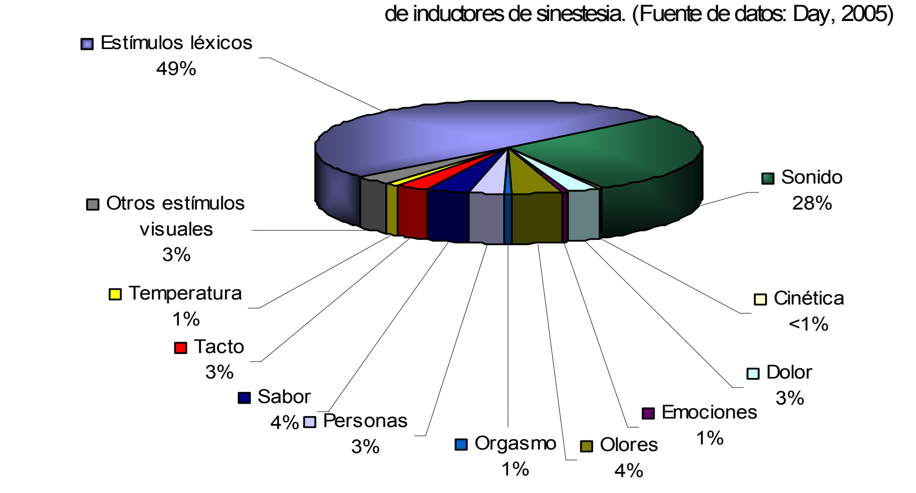
El cuerpo de evidencia disponible indica que las explicaciones en términos de memorias infantiles o de usos excesivos de la metáfora están fuera del lugar. La sinestesia parece ser un proceso de naturaleza perceptual, probablemente debido a una comunicación anómala entre áreas cerebrales, como veremos en la parte final de este texto. En los siguientes apartados vamos a examinar datos sobre la incidencia de la sinestesia en la población general e intentaremos analizar los diferentes subtipos de esta peculiar condición neuropsicológica.

Prevalencia y subtipos de sinestesia

La sinestesia es una condición poco frecuente. Aunque las estimaciones de prevalencia han variado considerablemente en estudios diferentes, el consenso parece apuntar en una frecuencia de 1 de 2000 (0.05%), propuesta en el artículo de Baron-Cohen y cols. (1996). El mismo estudio estima una proporción de 6 mujeres por cada varón con sinestesia. Datos anecdóticos sugieren que los sinéstetas tienden a ser malos en matemáticas, tienen poco sentido de la orientación y son propensos a experiencias "precognitivas" como "déjà vu" o sueños premonitores (Cytowic, 1996). Varios autores informan de una alta frecuencia de profesiones y/o aficiones creativas y artísticas entre sinéstetas (Galton, 1880; Domino y cols., 1989; Dailey y cols., 1997; Ramachandran & Hubbard, 2001b).

El estudio más completo sobre la demografía y la prevalencia de sinestesia (Rich y cols., en prensa) estima la prevalencia en 1 de 1150 (0.087%) en mujeres y 1 en 7150 (0.014%) en hombres, confirmando, además, la mayor probabilidad de esta condición entre parientes genéticos (36%). Hay que anotar que la estimación de prevalencia de Rich y colaboradores es probablemente conservadora, dada la metodología empleada por los autores[2]. El estudio concuerda con los datos anecdóticos en cuanto a las tendencias artísticas de los sinéstetas. Un 24% de los 192 sinéstetas que participaron en el estudio estaban involucrados en profesiones artísticas. (En comparación, datos estadísticos sobre la población de referencia indican que sólo un 2% de personas trabajan en el campo del arte.) Los investigadores también preguntaron a los sinéstetas sobre las posibles ventajas y desventajas de la sinestesia. La mayoría de los sinéstetas encuestados (71%) percibían su condición positivamente, informando que la sinestesia les facilitaba el recuerdo y la organización de datos, era una fuente de placer mental e inspiración creativa. Aproximadamente un tercio de los participantes indicaron algunos aspectos negativos, principalmente una confusión debida a la incongruencia entre la percepción sinestésica y la realidad, como por ejemplo cuando el significado de una palabra no concuerda con el color del fotismo. Los sinéstetas léxicos informaron sobre sentimientos contradictorios debidos a su predisposición negativa hacia personas cuyo nombre era percibido en colores mentales negativos. Una minoría se quejaba de sobrecarga sensorial y de sentirse incómodos por ser "diferente" de otras personas.

Figura 4: La frecuencia relativa de inductores de sinestesia. (Fuente de datos: Day, 2005)



En cuanto a los diferentes subtipos de sinestesia, todos los autores están de acuerdo en que la condición más frecuente es la sinestesia inducida por estímulos léxicos, es decir, números, letras o palabras (Cytowic, 1993; Baron-Cohen y cols., 1996; Rich and Mattingley, 2002; Day, 2005; Rich y cols., en prensa). En el estudio de Rich y cols. exclusivamente un 2% de los sinéstetas encuestados no experimentaban respuestas sinestésicas ante estímulos léxicos (palabras, fonemas o grafemas) y sólo presentaban otras modalidades de sinestesia. Las variantes no-léxicas de la sinestesia son considerablemente menos frecuentes. (Véase la figuras 4.) Aún así, gran parte de los sinéstetas (50% según Day, 2003) experimenta sinestesia a través de más de una modalidad sensorial. (Por ejemplo, los sinéstetas "léxicos" experimentan fotismos al ver, escuchar o pensar en números o letras.) A pesar de que en la mayoría de los sinéstetas la sensación "fantasma" es el color, en la literatura hay casos documentados de olor, tacto, temperatura, sonido, sabor y sensaciones propioceptivas como respuestas sensoriales concurrentes (Figura 5).

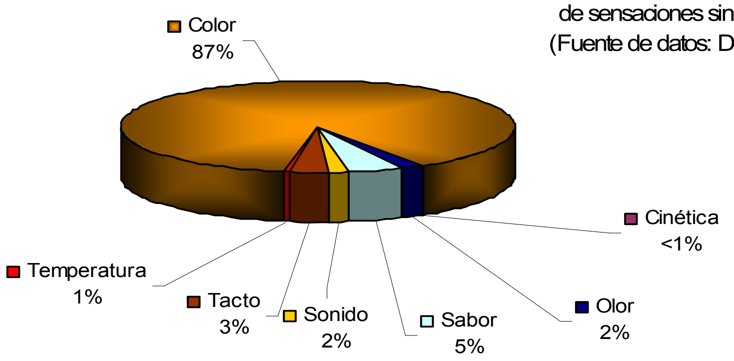


Figura 5: La frecuencia relativa de sensaciones sinestésicas (Fuente de datos: Day, 2005)

De acuerdo con Day (2005) existen dos grandes categorías generales de sinestesia:

a) <u>Sinestesia cognitiva</u>: inducida por estímulos asociados a significados simbólicos aprendidos a través de la cultura (grafemas, fonemas, nombres propios, días de la semana, etc.).
b) <u>Sinestesia básica</u> ("synaesthesia proper" en el original): los estímulos de una modalidad sensorial son percibidos simultánea e involuntariamente a través de otro canal sensorial (p.ej., "ver la música")

Esta distinción se solapa en parte con la propuesta por Marks y Odgaard (2005) quienes hablan de <u>sinestesia intramodal</u> (el inductor y la respuesta sinestésica pertenecen a la misma modalidad sensorial, p.ej. ver grafemas en colores mentales) y de <u>sinestesia intermodal</u> (el estímulo de un sentido es experimentado simultáneamente por otro, p.ej. sensaciones táctiles asociadas a sabores). No obstante, el solapamiento no es total, ya que existen casos de sinestesia cognitiva tanto intramodal como intermodal[3]. Por otro lado, también podemos encontrar variantes intramodales no-léxicas. Hay sinéstetas en los que formas y escenas visuales estimulan la aparición de fotismos. El sinésteta R, descrito por Milán y cols. (2006), experimentaba color rojo al observar el cielo con nubes. Este subtipo de sinestesia es claramente intramodal, sin que se tratase de sinestesia cognitiva (no está asociado a ningún tipo de semántica de índole cultural) pero tampoco de sinestesia básica ("proper") en el sentido de Day. Teniendo en cuenta lo anterior, consideramos más oportuno utilizar la distinción de Marks y Odraard en primer lugar, matizando los aspectos cognitivos de la sinestesia que a veces pueden ser difíciles de discernir. Por ejemplo, en el caso de "música cromática" es posible que la sinestesia esté condicionada culturalmente, por el aprendizaje de la música, pero también podría tratarse de un proceso más directo de "transducción" del input auditivo a la modalidad visual.

Otra matización de la experiencia sinestésica tiene que ver con la forma de experimentar la percepción "fantasma." De acuerdo con Dixon y cols. (2004) existen dos variedades cualitativamente diferentes de la sinestesia léxica. En los sinéstetas "proyectores" el fotismo es percibido en el espacio externo, mientras que los sinéstetas "asociadores" observan el color "fantasma" "en su mente", sin proyección al exterior. Dixon y colaboradores descubrieron que ambos grupos difieren no sólo en las descripciones subjetivas, sino también en la ejecución en la tarea Stroop modificada. El experimento implicaba dos tareas: nombrar el color del grafema presentado o nombrar el color del fotismo asociado al grafema. El color del grafema podía ser congruente o incongruente con el fotismo. Los resultados indican que los sinéstetas "proyectores" son más sensibles a la interferencia del fotismo al nombrar el color de la tinta que viceversa. Es decir, el fotismo interfiere significativamente con la detección del color real pero el color real interfiere poco o nada con la tarea de nombrar el fotismo. Mientras tanto, los sinéstetas "asociadores" eran marginalmente más rápidos en nombrar el color real y la interferencia tipo Stroop tendía a ser igual en ambas tareas. Ramachandran y Hubbard (Ramachandran y Hubbard, 2001b; Ramachandran y Hubbard, 2003b; Hubbard y Ramachandran, 2005) proponen que estas dos clases de sinestesia a su vez difieren en el tipo de estímulos inductores. Mientras que los "proyectores" suelen ser estimulados por el estímulo externo (p.ej., un grafema que representa un número) directamente, los "asociadores" responden sinestéticamente al concepto en sí. De ahí que los "asociadores" presenten fotismos en respuesta a un rango más amplio de estímulos que evocan el concepto inductor (por ejemplo, los días de la semana, los meses, etc., que evocan el concepto numérico). Ramachandran y Hubbard (2001b, 2005) opinan que estos dos tipos de sinestesia podrían estar ligados a mecanismos neurales diferentes y proponen una clasificación alternativa en sinéstetas "inferiores" ("lower synesthetes") y sinéstetas "superiores" ("higher synesthetes"). En los sinéstetas inferiores los fotismos probablemente surgen temprano en la cadena de procesamiento sensorial, respondiendo a rasgos perceptuales del estímulo inductor. Por otro lado, los colores mentales de los sinéstetas superiores surgen en respuesta a aspectos más abstractos que son procesados en áreas cerebrales diferentes. De ahí que la ejecución de ambos grupos en tareas perceptuales no sea igual (Dixon y cols., 2004; Hubbard y Ramachandran, 2005).[4] Por ende, este tipo de diferencias individuales entre sinéstetas podrían explicar gran parte de las inconsistencias observadas entre algunos resultados experimentales (Hubbard y Ramachandran, 2005). Por ejemplo, el estudio de Palmeri y cols. (2002) desvela efectos fuertes de segregación sensorial sinestésica en una tarea de búsqueda visual de grafemas. En un experimento similar con 14 sujetos (Edquist y cols., 2005), sólo 2 de los sinéstetas mostraron facilitación en la búsqueda con respecto de los controles, y ninguno de ellos presentó un patrón de "pop-out" sensorial. Posiblemente, en el estudio de Palmeri todos o casi todos los sujetos fueran de tipo "proyector" o "inferior" mientras que no lo fueran en este segundo estudio[5]. Dada la heterogeneidad del fenómeno, hay que ser particularmente cauto en el diseño y el manejo de los datos, ya que al promediar las puntuaciones individuales fácilmente podría llegarse a una desinterpretación de la realidad. De ahí que en muchos casos la estrategia experimental más recomendable pueda ser la de un diseño de caso único o de comparación individual entre sinéstetas (Smilek y Dixon, 2002).

Preconsciente y sensorial o consciente y conceptual

Si usted fijase su mirada en el punto central de la Figura 6 A, sería capaz de discernir el número 5 situado lateralmente. No obstante, si el mismo número está rodeado por distractores (Figura 6 B), resulta casi imposible discriminarlo (Bouma, 1970). En contraste con los sujetos normales, dos sinéstetas estudiados por Ramachandran y Hubbard (2001b), sometidos a esta prueba de *crowding* perceptual, sí eran capaces de descifrar el número "invisible", deduciéndolo por el color del fotismo asociado[6]. Este resultado sugiere que el color "fantasma" surge a un nivel preconsciente, antes de que se dé el efecto de *crowding* resultante de la sobrecarga de recursos atencionales por los distractores. Los resultados de Smilek y cols. (2001) apuntan en la misma dirección. El sinésteta C realizó una tarea de identificación visual de números que eran presentados brevemente en la pantalla. Cuando los grafemas fueron presentados sobre un fondo de color incongruente con el fotismo, C era significativamente más rápido en identificarlos que en la condición congruente. Parece poco plausible que el fotismo influya la identificación si surgiese después del reconocimiento consciente del carácter.

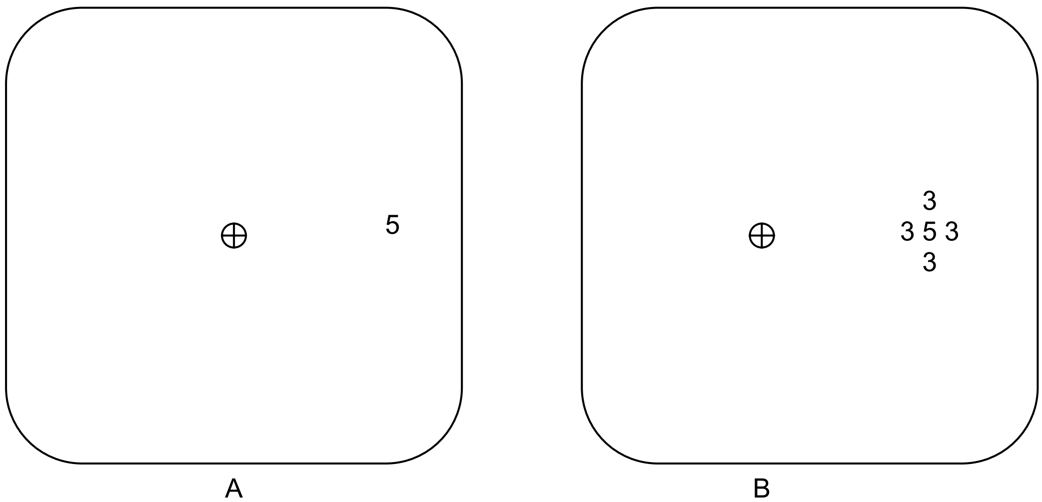


Figura 6.: La prueba de crowding aplicada a sinéstetas por Ramachandran y Hubbard (2001b), indica que la formación de fotismos precede a la identificación consciente del grafema.

Sin embargo, no toda la evidencia es consistente con la hipótesis preconsciente. En el estudio de Mattingley y cols. (2001), los autores sometieron quince sinéstetas a una tarea de *priming* con grafemas inductores de sinestesia, presentados durante un tiempo muy corto (28 o 56 ms) y seguidos de una máscara, para eliminar el reconocimiento consciente del carácter. La tarea de los sujetos consistía en nombrar el color de un cuadrado presentado en la pantalla después del "prime". Sorprendentemente, no se observó influencia alguna de fotismos (asociados al grafema enmascarado) sobre el tiempo de reacción en la identificación del color, aún cuando los sujetos sí mostraron un patrón de *priming* clásico en la tarea de reconocimiento de grafemas. (Es decir, cuando en lugar de un cuadrado en color los sujetos tenían que identificar un grafema presentado después del carácter enmascarado, las respuestas eran más rápidas cuando ambos caracteres – el "prime" y el objetivo – eran iguales. Aunque la identidad del "prime" fue reconocida a un nivel no consciente, no llevó a la inducción de fotismos correspondientes.)

La discusión sobre si la consciencia del estímulo es necesaria o no para que se dé la respuesta sinestésica (el fotismo) va en paralelo con el debate sobre el carácter conceptual o perceptual del estímulo inductor. Mientras que los resultados de Mattingley y cols. (2001) sugieren que la identificación del estímulo léxico es una condición para que surja el fotismo, otros estudios apuntan en que los colores mentales son una respuesta directa a los aspectos perceptuales del inductor. Ramachandran y Hubbard (2001a, 2001b) mencionan una serie de efectos que ilustran la dependencia de los fotismos de las características físicas del estímulo, como el contraste, la excentricidad del estímulo o la frecuencia de presentación alternada de dos grafemas inductores. Por otro lado, el hecho de que los sinéstetas grafema-color presenten fotismos ante fuentes tipográficas extrañas o incluso ante textos escritos a mano, apunta en la importancia de la interpretación cognitiva más que de los rasgos visuales por sí.

¿Estamos entonces tratando con un fenómeno sensorial o no? En nuestra opinión, para superar las inconsistencias es necesario, antes del todo, avanzar en la distinción entre sinéstetas superiores e inferiores y, a ser posible, controlar la presencia de ambos grupos en el diseño experimental. La evidencia sugiere que el grado de dependencia de los aspectos perceptuales o conceptuales no es el mismo en todos los sinéstetas. Como hemos dicho anteriormente, en esta fase de la investigación de la sinestesia el diseño de grupo puede no ser el más apropiado, dada la gran variabilidad interindividual. En segundo lugar, quizás la distinción dicotómica entre procesos pre- y post-atencionales (o preconscientes y conscientes o sensoriales y conceptuales) sea demasiado simple para dar cuenta de la ejecución de sinéstetas en tareas conductuales (Ramachandran y Hubbard, 2005). Incluso en los pocos casos de sinéstetas grafema-color inferiores que muestran patrones de ejecución propiamente sensoriales, es lógico esperar al menos alguna influencia de procesos conceptuales. Sería difícil creer que la sinestesia grafema-color, cuyo arranque está íntimamente relacionado con el aprendizaje de la lectura, fuera un proceso puramente sensorial, independiente del conocimiento léxico que está en su origen. De hecho, en el caso de estímulos ambiguos (por ejemplo, 9O89 y SOL), el color sinestésico suele cambiar en función de la interpretación dependiente del contexto. La cuestión que queda por aclarar es si éste y otros efectos son el resultado de una modulación de arriba-abajo, como creen Ramachandran y Hubbards (2001b), o si el fotismo surge una vez interpretada la identidad del grafema, la postura defendida por Mattingley y cols. (2001).

El encéfalo sinestésico

Pese a la evidencia conductual acumulada, algunos teóricos seguían dudando sobre la realidad del fenómeno y manteniendo que la sinestesia podía ser el resultado de asociaciones particularmente fuertes, desarrolladas durante el periodo infantil. Al parecer, la ciencia moderna tiene poca fe en el individuo y siempre pide pruebas "hechas a máquina" para confirmar cualquier dato tachado de subjetivo.

Para convencer a los escépticos y dar un tiro de gracia a las explicaciones asociacionistas, los investigadores no tardaron mucho en someter a los sinéstetas a las tecnologías más modernas de neuroimagen.

La primera investigación del cerebro sinestésico, realizada por Cytowic y Wood (1982), confirmó la sospecha de que el funcionamiento neuronal de los sinéstetas difería del de una persona normal. Desgraciadamente, el sujeto estudiado (MW) mostraba una actividad cerebral anómala incluso cuando no experimentaba sinestesia, lo cual dificultó la interpretación de los datos. En el 1995 Paulesu y cols. sentaron a seis mujeres con sinestesia auditiva léxico-cromática en un escáner de tomografía por emisión de positrones (PET). Los resultados confirmaron las hipótesis, desvelando actividad en áreas visuales (corteza temporal posterior-inferior y cisura parieto-occipital) de las sinéstetas, expuestas a palabras presentadas auditivamente. Sorprendentemente, la actividad del área responsable del procesamiento del color en humanos (V4/V8) no alcanzaba niveles de significación. Aún así, el funcionamiento cerebral de los sujetos sinéstetas difería claramente de los controles cuyas áreas visuales se mantenían inactivas ante la misma estimulación sensorial.

Las investigaciones posteriores han empleado tecnologías más finas para avanzar en la comprensión de la neuroanatomía funcional de la sinestesia. Weiss y cols. (2001) trabajaron con RS, un sinésteta léxico-cromático que presentaba fotismos en respuesta a nombres de personas familiares. La resonancia magnética funcional (fMRI) reveló activación bilateral del área V4, activación de la corteza visual extraestriada, así como de la corteza retro-splenial que suele asociarse con la detección de familiaridad personal. El estudio de Nunn y cols. (2002), realizado con fMRI, también desveló activación en áreas del color (V4/V8) en el hemisferio izquierdo de sinéstetas léxico-cromáticos expuestos a palabras presentadas auditivamente, pero no ante no-palabras y tonos. Los sujetos controles entrenados en asociar colores específicos con palabras no mostraron este patrón de activación. Otro dato de importancia que concuerda con los resultados anteriores es la ausencia de activación en áreas de procesamiento visual temprano (V1, V2), lo cual sugiere que estas regiones no son necesarias para experimentar colores sinestésicos. El único estudio cuyos resultados no concuerdan con esta hipótesis fue publicado por Aleman y cols. (2001), quienes detectaron actividad en la región V1 en un sinésteta léxico-cromático al presentar palabras auditivamente. No obstante, como la activación observada sólo alcanzó niveles marginales de significación y al tratarse de un caso aislado, es poco probable que este dato sea generalizable.

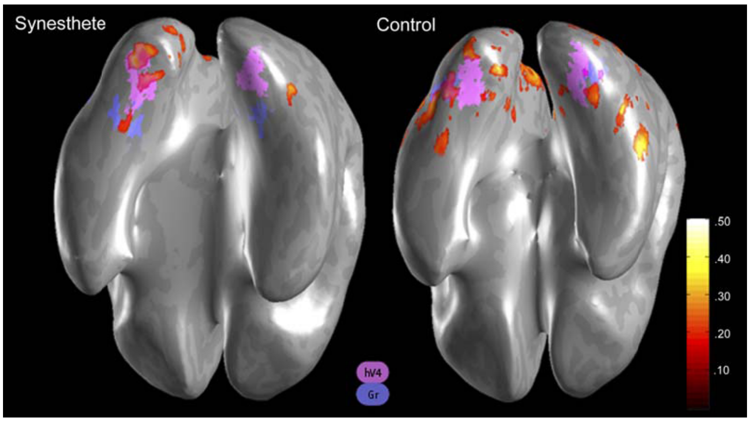


Figura 7: Imagen fMRI de la cara ventral de dos cerebros inflados. El área V4 está marcada en color púrpura y la región de procesamiento de grafemas marcada en azul. En ambos sujetos puede apreciarse activación en el área de grafemas pero sólo el sujeto sinésteta presenta actividad en el área del color V4. (Hubbard y Ramachandran, 2005)

Prácticamente todos los estudios apuntan en la importancia del área de procesamiento del color (V4/V8) en la generación y/o experimentación de fotismos. Para explorar el grado de implicación de este y otros áreas visuales, Hubbard y cols. (2005) combinaron la fMRI con medidas conductuales (la prueba de crowding y la prueba de pop-out sinestésico) en un diseño con 6 sinéstetas grafema-color y 6 sujetos controles. Al comparar los datos conductuales con los de la fMRI, observaron una correlación significativa entre el nivel de activación de áreas visuales (particularmente el V4) y la ejecución en las pruebas perceptuales. En otras palabras, los sinéstetas que alcanzaron mejores puntuaciones conductuales, también presentaban una actividad neuronal más alta en el área del color (V4) al ser expuestos a grafemas acromáticos. Este dato va a favor de la idea de que los sinéstetas, incluso los que presentan la misma variedad de sinestesia, constituyen un grupo heterogéneo con importantes diferencias interindividuales. Posiblemente la activación de las áreas visuales sea mayor en los sinéstetas que perciben sus fotismos como proyectados externamente (Figura 7). De todos modos, la consecuencia lógica de casi todos los estudios de neuroimagen es que por lo menos en algunos sinéstetas, los fotismos se parecen bastante a la experiencia del color real no sólo a nivel subjetivo sino también a nivel neuronal.

El origen de la sinestesia y teorías explicativas

Antes de presentar los principales modelos neuronales de sinestesia, es conveniente mencionar algunos datos sobre su hipotético origen genético. A pesar de que los estudios centrados en la incidencia y la heredabilidad de sinestesia son más bien escasos, la inmensa mayoría de los autores indica que la sinestesia idiopática tiende a aparecer más a menudo entre parientes (p.ej., Galton, 1880) y es aproximadamente 6 veces más frecuente en mujeres (Baron-Cohen y cols., 1996; Rich y cols., en prensa). Este dato de por sí apunta en un probable origen genético de la condición sinestésica. Las investigaciones de incidencia familiar sugieren que se trata de un rasgo dominante ligado al cromosoma X (Bailey y Johnson, 1997). Por otro lado, el estudio de Smilek y cols. (2001) indica que la heredabilidad de la sinestesia podría ser más compleja. Los investigadores descubrieron un caso de gemelas monozigóticas de las que solamente una presenta sinestesia léxico-cromática. (Su sinestesia fue comprobada experimentalmente utilizando la variante modificada de la tarea Stroop.) Los autores proponen que la ausencia de la condición en una de las hermanas podría deberse bien a la inactivación del cromosoma X o a la presencia de una mutación del gen responsable de la sinestesia.

Con todo, teniendo en cuenta la evidencia acumulada, la probabilidad de que la genética contribuye al desarrollo de la sinestesia es muy alta. Las cuestiones a responder son, en primer lugar, cuál es el mecanismo específico de transmisión genética y, en segundo lugar, cómo afecta el supuesto gen (o genes) la neuroanatomía, dando lugar a la alteración sensorial de la sinestesia. Con respecto a la segunda pregunta, existen al menos tres teorías sobre el mecanismo neuronal a través del cual la estimulación sensorial normal lleva a la experiencia de fotismos. Dada la gran prevalencia de la variante grafema-color en la población sinésteta, en un principio los tres modelos que vamos exponer a continuación, han sido propuestos para explicar esta modalidad del fenómeno.

Sinestesia: ¿un "cruce de cables"?

El núcleo de todas las teorías neurocognitivas de la sinestesia es la postulación de algún tipo de comunicación neuronal anómala. Si zonas corticales específicas, cuya comunicación es limitada en un cerebro normal, establecen conexiones activas, esto puede llevar a la generación de sensaciones "fantasmas", como en el caso de pacientes amputados que experimentan sensaciones táctiles en su miembro inexistente (Ramachandran y cols., 1992). Este fenómeno inspiró a Ramachandran y Hubbard para desarrollar su modelo de interconexión local que puede dar cuenta de la aparición de fotismos en los sinéstetas léxicos-cromáticos (Ramachandran y Hubbard, 2001b, Ramachandran y Hubbard, 2003b, Hubbard y Ramachandran 2005). Al estudiar la sinestesia grafema-color, los autores cayeron en la cuenta de que tanto el área cerebral del color (V4) como el área visual responsable del procesamiento de grafemas están situadas en la misma zona cortical - el giro fusiforme. Si en un cerebro humano ambas áreas establecieran comunicación neuronal, lo esperable sería que el sujeto experimentase colores en respuesta a la visión de grafemas[7]. La cuestión es, ¿por qué y cómo se desarrollarían estas conexiones entre zonas que procesan aspectos diferentes de la entrada visual?

En el transcurso de la maduración cerebral el encéfalo pasa por una etapa de estabilización de conexiones, cuando un gran número de sinapsis redundantes es eliminado en el proceso llamado *poda axónica*. Si una mutación genética causara un fallo en este proceso madurativo en zonas específicas, el cerebro conservaría conexiones neuronales que podrían llevar a la experimentación de sensaciones inusuales como las de la sinestesia. El hecho de que dos regiones corticales como el V4 y la zona de procesamiento de grafemas sean próximas físicamente, incrementa la probabilidad de comunicación neuronal entre ambas. Además de la evidencia de estudios de neuroimagen que implican el V4 en la experiencia de sinestesia léxico-cromática, los autores anotan que las conexiones anatómicas entre áreas infero-temporales y el V4 han sido descubiertas en fetos de macacos (Kennedy y cols., 1997). Gracias a la poda axónica, la proporción de aferencias al V4 procedentes de áreas superiores se reduce radicalmente en animales adultos. Los autores postulan que, en humanos, una mutación genética podría llevar a una poda axónica deficiente en el giro fusiforme y, en consecuencia, a la perduración de la conectividad anómala en el cerebro adulto. La inducción de fotismos sería, por lo tanto, una consecuencia de la activación del área del color a través de conexiones procedentes de la región del procesamiento visual de grafemas.

El modelo de desinhibición de conexiones de arriba-abajo

No todos los autores están de acuerdo con la necesidad de postular conexiones anómalas en la sinestesia. Grossenbacher y Lovelace (2001) defienden que para explicar la percepción sinestésica es suficiente considerar el funcionamiento de la maquinaria cerebral normal. El procesamiento de la entrada sensorial, por ejemplo la visual, progresa a través de módulos cerebrales organizados jerárquicamente. La información es descompuesta en rasgos particulares (el color, el movimiento, la forma, etc.) que son analizados por áreas especializadas. Después de pasar por varias etapas de procesamiento a lo largo de vías especializadas, las señales convergerán en un área multimodal. (De acuerdo con los autores, en la sinestesia tanto la señal del inductor sinestésico (p.ej., el grafema) como la información de la sensación concurrente (p.ej., el color) dispondrían de sus propias vías de procesamiento que confluirían en el área multimodal.) No obstante, además de la conexiones "hacia delante", el cerebro normal también presenta conexiones donde la información puede fluir hacia atrás en la cadena de procesamiento. En el procesamiento sensorial normal, la mayoría de las conexiones "hacia atrás" son inhibidas por el sistema para evitar la generación de ruidos y anomalías en la comunicación. Grossenbacher y Lovelace proponen que un fallo en la inhibición podría llevar a la generación de sensaciones sensoriales propias de la sinestesia. Concretamente, en cuanto la señal del inductor pase por las etapas de procesamiento unimodal y alcance la zona de convergencia (multimodal), podría viajar hacia atrás por la vía de la sensación inducida hasta llegar al nivel donde tiene lugar la generación de la percepción sinestésica. (Véase la Figura 8.) En otras palabras, la teoría de Grossenbacher defiende que la sinestesia es el resultado de un feedback desinhibido, originado en una región cortical multimodal como podría ser el surco temporal superior. (Esta estructura presenta conexiones con áreas unimodales de procesamiento y a su vez es sensible a rasgos perceptuales específicos de varias modalidades sensoriales.)

La idea de que la sinestesia ocurre en una etapa relativamente tardía del procesamiento sensorial ha recibido cierto apoyo empírico desde investigaciones con potenciales evocados. Los autores destacan el hecho de que las diferencias en la actividad cerebral entre sinéstetas y normales no se observan hasta 200 milisegundos después del onset del estímulo inductor (Schiltz y cols., 1999). Además, la posibilidad de inducción sinestésica por sustancias psicotrópicas sugiere que la existencia de conexiones neuronales anómalas no es una condición necesaria para la sinestesia[8].

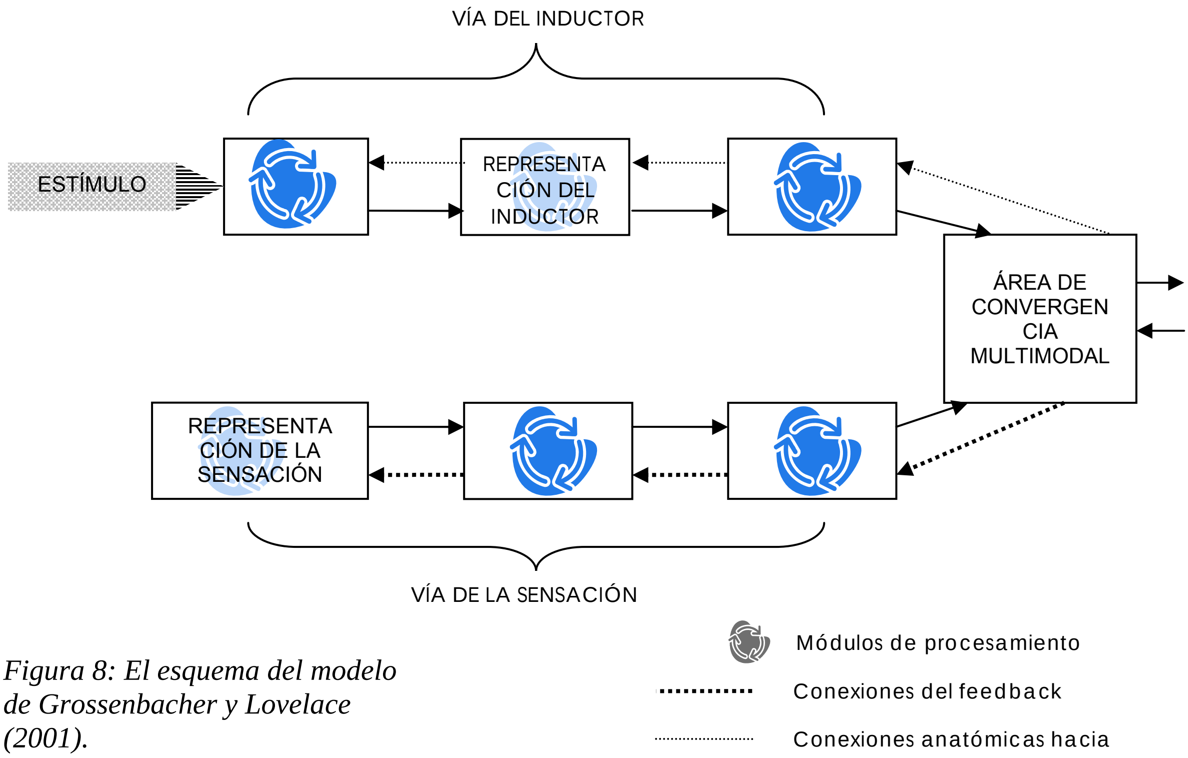


Figura 8: El esquema del modelo de Grossenbacher y Lovelace (2001).

El modelo de retroalimentación en bucle [9]

El modelo de retroalimentación en bucle (Myles y cols, 2003; Smilek y cols., 2001) constituye un esquema híbrido que combina algunos aspectos de las propuestas anteriores. Los autores se apoyan en el hecho de que la información visual fluye a través del sistema de procesamiento tanto en dirección hacia delante como en el sentido contrario, hacia atrás (o de arriba abajo). Cuando un sinésteta observa un grafema acromático, las señales progresan desde áreas visuales inferiores, pasando por el área de reconocimiento de la forma (giro fusiforme posterior), hasta llegar a la región donde se analiza el significado del símbolo (giro fusiforme anterior). De acuerdo con Smilek y cols., la activación de un fotismo en sinéstetas "proyectores" es el resultado de una retroalimentación cíclica desde áreas de procesamiento de la forma y del significado hacia la región del color V4. Pongamos un ejemplo, considerando el caso hipotético de un fotismo rojo inducido por la letra "B". Cuando las líneas y las curvaturas que componen la letra están siendo procesadas en la corteza estriada y el giro fusiforme posterior, simultáneamente las señales desde esta zona llegan a la zona anterior del giro fusiforme donde tiene lugar el análisis del significado. Al principio, cuando el análisis de la forma todavía no está completo, la señal puede no ser suficiente para dar lugar a un reconocimiento consciente de la letra. Sin embargo, los autores proponen que incluso una activación parcial del significado de la letra puede activar el percepto rojo en el área del color (V4). Más concretamente, antes de que se complete el análisis de la forma y del significado, el área anterior del giro fusiforme a través de conexiones de arriba-abajo comunicará con el área del color, activando la representación del rojo. A su vez, esta activación del rojo en V4, por medio de conexiones hacia delante, reforzará la activación del significado "B" en el fusiforme anterior. (Véase el esquema del modelo en la Figura 9.) Las señales neuronales viajarán cíclicamente hasta generar el percepto consciente completo – él de una B roja. De esta manera los autores explican el hecho de que el contexto que afecta la interpretación del significado afecta también al color sinestésico. (Recuerden los efectos de estímulos ambiguos como 9O89 y SOL.)

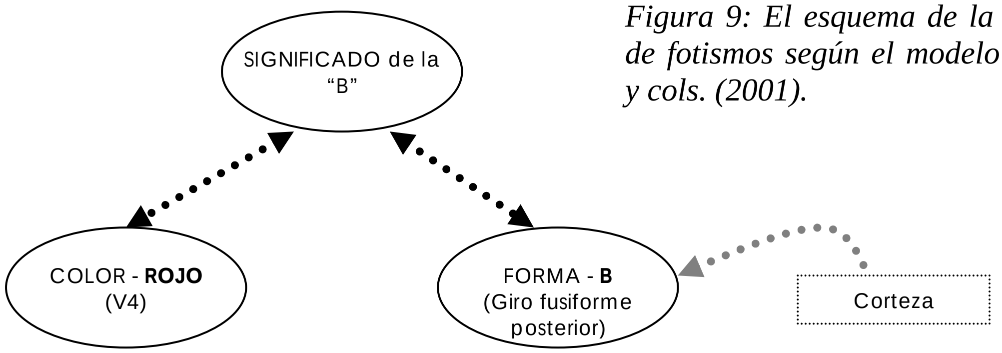


Figura 9: El esquema de la activación de fotismos según el modelo de Smilek y cols. (2001).

Dado que la modulación de arriba-abajo constituye una característica del funcionamiento del cerebro humano en general, en la actualidad resulta imposible disociar experimentalmente los procesos propuestos por el modelo de interconexión local (Hubbard y Ramachandran, 2005) del modelo de retroalimentación en bucle. Para dar cuenta de los efectos contextuales en los fotismos, Ramachandran y Hubbard proponen que los mismos mecanismos *top-down* que están presentes en personas normales explican la influencia del contexto en el color del fotismo. El mecanismo de retroalimentación en bucle propuesto por Smilek y cols. llevaría, en un principio, a los mismos efectos conductuales. En el futuro será necesario avanzar en la especificidad de ambos modelos para poder verificar o refutar las propuestas respectivas. Asimismo, como apuntan Hubbard y Ramachandran (2005), los modelos pueden no ser mutuamente excluyentes. Es perfectamente plausible que una combinación de ambos mecanismos (la interconexión local y la retroalimentación desinhibida desde áreas del significado) esté presentes en algunos sinéstetas. También hay que considerar la posibilidad de que formas diferentes de experimentar la sinestesia en sinéstetas proyectores y asociadores conlleven mecanismos neurocognitivos dispares.

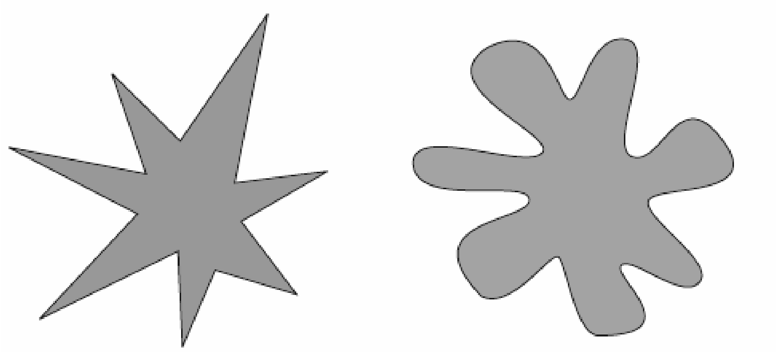
Anotaciones finales

A lo largo de esta breve revisión del conocimiento científico sobre el fenómeno llamado sinestesia, hemos visto que esta peculiar condición no es un fruto de memorias infantiles, que su origen se debe probablemente a una alteración genética y que las sensaciones "fantasmas" pueden llevar a efectos típicamente sensoriales como el *pop-out* de grafemas por fotismos. Hemos analizado la evidencia conductual y la de los estudios de neuroimagen para concluir que la sinestesia comparte muchos aspectos con la percepción normal tanto a nivel conductual como a nivel neurológico. Tras revisar los principales modelos explicativos, podemos conjeturar que la causa de la sinestesia está en una comunicación anómala entre áreas cerebrales, débase esta a una interconexión anormal en la corteza sensorial o a la desinhibición de vías neuronales de arriba abajo. ¿Cuáles son, entonces, las limitaciones de nuestro conocimiento actual y hasta dónde puede llevarnos el camino de la investigación de la sinestesia? Antes del todo hemos de decir que la etapa de la verificación de la realidad del fenómeno parece estar, por fin, superada. En nuestra opinión, los investigadores implicados en el estudio de la sinestesia han demostrado con éxito y fuera de dudas la autenticidad de la sinestesia, confirmando en la gran mayoría de los casos la veracidad de los informes subjetivos. Ahora bien, para avanzar en nuestra comprensión de la sinestesia y desvelar sus bases neuroanatómicas será necesario ampliar los límites de la investigación actual en varias direcciones.

En primer lugar, hemos de anotar que la gran parte de las hipótesis disponibles están construidas sobre la base de datos procedentes del estudio de sinéstetas léxicos (Grossenbacher y Lovelace, 2001; Hubbard y Ramachandran, 2005). Aún cuando esto es comprensible dada la alta frecuencia relativa de esta modalidad de la sinestesia, sería conveniente ampliar los paradigmas experimentales actuales para ver hasta qué punto se parecen otras variantes de sinestesia a la sinestesia léxico-cromática a nivel conductual y también a nivel neurológico.

En segundo lugar, como hemos resaltado anteriormente, es imprescindible tener en cuenta las diferencias individuales en la intensidad y la cualidad fenomenológica de la experiencia sinestésica. Si se confirma la conveniencia de la división teórica en sinéstetas "inferiores" (proyectores) y "superiores" (asociadores), esto va a tener importantes implicaciones para el diseño experimental, la interpretación de datos y, posiblemente, para el refinamiento de los modelos neurocognitivos.

Figura 10: ¿Quién es Bouba y quién es Kiki? Esta imagen demuestra que los humanos no asocian formas con sonidos de manera arbitraria. Casi el 100% de los sujetos encuestados relacionan el sonido "kiki" con la forma de la izquierda y "bouba" con la de la derecha. (Köhler, 1929)



Como hemos visto en la introducción de este texto, el término sinestesia ha sido aplicado a una gran variedad de fenómenos: la sinestesia idiopática, los estados inducidos por drogas, las maniobras del arte…. Quizás este uso excesivo de la palabra refleje, al menos en parte, la verdad. No es una casualidad que varios autores consideren que la investigación de la sinestesia puede abrir puertas hacia la explicación de las bases neurológicas de la metáfora en particular y del lenguaje en general (Ramachandran y Hubbard, 2001b). La sinestesia podría abarcar una gran variedad de condiciones, desde la sinestesia "inferior", pasando por sinestesias más asociativas, sinestesias inducidas conceptualmente, sinestesias emocionales…hasta quizás el talento para utilizar la expresión artística multimodal. La investigaciń futura tendrá que responder dónde están las fronteras entre estos fenómenos y si se trata de condiciones cualitativamente distintas o es una cuestión de grado. Una parte de la respuesta puede estar en la investigación neuroanatómica al considerar si realmente los sinéstetas (¿y qué "clases" de sinéstetas?) presentan una conectividad neuronal anómala o, por lo contrario, los "fantasmas" de su cerebro surgen a causa de una desinhibición de la maquinaria cerebral normal. Los informes subjetivos desvelan paralelismos llamativos entre la sinestesia y la percepción normal. Por ejemplo, Ward y cols. (2006) demostraron que las asociaciones entre sonidos y colores en sinestesia presentan el mismo patrón de correspondencia entre la luminancia y el tono, como la asociación intermodal sonido-color de personas normales. Ramachandran y Hubbard (2003b) sugieren que en varios dominios los seres humanos tienden a establecer las mismas asociaciones sinestésicas, como por ejemplo, en el caso de asociación de ciertas formas visuales con el sonido. (Véase la Figura 10.) La cuestión a responder es si el parecido de estos efectos con la sinestesia idiopática va más allá de los aspectos superficiales.

Para cerrar nuestra reflexión, consideramos oportuno mencionar la importancia de la sinestesia para el avance de nuestra comprensión de la experiencia subjetiva. El fenómeno sinésteta ha constituido un curioso rompecabezas para la ciencia cognitiva por la sencilla razón de tratarse de una experiencia fenomenológica cuya incidencia es muy baja. A diferencia de patologías psiquiátricas y trastornos resultantes de lesiones cerebrales, la sinestesia es una condición innata, no perturbadora y altamente estable, que se da en individuos por lo demás normales. Lo que llama la atención de laicos y profesionales es el hecho de que los sinéstetas informan de ver "cosas" que las personas "normales" no pueden percibir. Si usted al encontrarse en un cruce de peatones dice que ve "un semáforo en rojo", ningún científico cognitivo va a empeñarse en aplicarle una tarea Stroop para verificar que usted realmente ve lo que dice ver. Curiosamente, desde el punto de los sinéstetas, los comienzos de la investigación sobre la sinestesia eran precisamente eso – responder a la pregunta: ¿es verdad lo que usted afirma y realmente ve la B acromática en rojo? En otras palabras, la investigación cognitiva invirtió tiempo y esfuerzo para comprobar la autenticidad de una experiencia subjetiva, demostrando lo mismo que los sinéstetas ya nos habían comunicado con sus propias palabras. Si aceptamos por completo los informes verbales de los sinéstetas, aparentemente la ciencia ha hecho un trabajo en vano. No obstante, además de demostrar empíricamente la veracidad de la introspección, en nuestra opinión este esfuerzo ha constituido una lección de aprendizaje para la psicología, en relación con la comprensión científica de la experiencia subjetiva. Posiblemente por primera vez la investigación empírica se ha enfrentado directamente con la cuestión de los *cualia*, tratando de responder a una cuestión parecida a la célebre pregunta de Nagel (1974) de "¿cómo es ser un murciélago?". El desarrollo de nuestra comprensión de la sinestesia, acompañado de un perfeccionamiento de la metodología, significa en nuestra opinión también un importante progreso para el estudio de las experiencias "en primera persona". Para seguir avanzando en esta dirección será imprescindible compaginar los datos conductuales y neurológicos con los informes subjetivos (Smilek y Dixon, 2002) y convertir el punto de vista del sujeto en una parte integral de la investigación neuropsicológica.

Notas finales:

1. Sólo se conocen casos de pérdida de la sinestesia después de un trauma cerebral. (Véase Spalding y Zangwill, 1950; y Sacks, Waserman, Zeki, y Siegel, 1988.)

2. Los autores utilizaron un anuncio en el periódico The Australian para contactar con los sinéstetas. Es posible que no todos lo individuos con sinestesia que leyeron el periódico respondieron al anuncio.

3. Por ejemplo, cuando la escucha de fonemas, pero no de sonidos sin significado, lleva a la percepción de fotismos, se trataría de un subtipo cognitivo intermodal.

4. No está claro si la división propuesta refleja una dimensión dicotómica que corresponde a una distinción cualitativa entre sinéstetas o si puede haber un continuo, con casos de sinéstetas “a medio camino” entre sinéstesia inferior y superior.

5. Esto es perfectamente plausible teniendo en cuenta que sólo aproximadamente 10% de los sinéstetas son de tipo “proyector” (Dixon y cols., 2004) y, por lo tanto, no es posible esperar que los efectos sensoriales se den por igual en todos.

6. Este efecto no se da en todos los sinéstetas. Probablemente sólo los sinéstetas inferiores respondan sinestéticamente ante grafemas presentados a un nivel no consciente. (Hubbard y cols., 2005)

7. En teoría, también podría ocurrir lo contrario – experimentar grafemas en respuesta a la visión de colores. Véase la discusión de Hubbard y Ramachandran (2005) de por qué tal posibilidad es poco plausible.

8. No obstante, como argumentan Ramachandran y Hubbard (Hubbard y Ramachandran, 2005), la fenomenología de la sinestesia congénita difiere significativamente de los estados inducidos por drogas, con lo cual es probable que su mecanismo cerebral subyacente también sea diferente.

9. “Re-Entrant Processing” en el original (Smilek y cols., 2001).

Referencias

Aleman, A., Rutten, G-J.M., Sitskoorn, M.M., Dautzenberg, G. and Ramsey, N.F. (2001). Activation of striate cortex in the absence of visual stimulation: an fMRI study of synesthesia. *NeuroReport, 12*, 2827-30.

Bailey, M.E.S., Johnson, K.J. (1997). Synaesthesia: Is a genetic analysis feasible? En S. Baron-Cohen y J.E. Harrison (Eds.), *Synaesthesia: Classic and Contemporary Readings.* Oxford: Blackwell.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: Prevalence and familiality. *Perception, 25,* 1073-1079.

Baron-Cohen, S., Harrison, J., Goldstein, L.H., Wyke, M. (1993). Coloured speech perception: Is synaesthesia what happens when modularity breaks down?. *Perception, 22* (4), 419–26.

Baron-Cohen, S., Wyke, M.A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception, 16,* 761-767.

Beck, J. (1966). Effect of orientation and shape similarity on perceptual grouping. *Percept. Psychophys., 1*, 300-302.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature, 226*, 177–178.

Cytowic, R.E. (1993). *The man who tasted shapes.* New York: Putnam.

Cytowic, R. E. (1996). Synesthesia: Phenomenology and neuropsychology. *Psyche, 2*(10). http://psyche.cs.monash.edu.au/v2/psyche-2-10-cytowic.html

Cytowic, R. E. (2002). Touching tastes, seeing smells—and shaking up brain science. *Cerebrum, 4*(3), 7–26.

Cytowic, R. E. (2003). Synesthesia: Anomalous binding of qualia and categories. En G. Adelman & B. H. Smith (Eds.), *Encyclopedia of Neuroscience (3rd Edition)*. New York: Elsevier.

Cytowic, R.E. and Wood, F.B. (1982). Synesthesia I: A review of theories and their brain basis. *Brain and Cognition, 1*, 23-35.

Dailey, A., Martindale, C., Borkum, J. (1997). Creativity, synaesthesia and physiognomic perception. *Creativity Research Journal, 10* (1), 1–8.

Day, S. (2005). Some Demographic and Socio-cultural Aspects of Synesthesia. En Robertson, L.C. y Sagiv, N. (Eds.), *SYNESTHESIA: Perspectives from Cognitive Neuroscience* (pp. 11-33). Oxford University Press, New York.

Day, S.A. (2005). Types of synaesthesia. Extraído el 20 de julio de 2006 desde http://home.comcast.net/%7Esean.day/Types.htm

Dixon, M.J., Smilek, D., Cudahy, C. y Merikle, P.M. (2000). Five plus two equals yellow. *Nature, 406* (6794), p. 365.

Domino, G. (1989). Synaesthesia and creativity in fine arts students: An empirical look. *Creativity Research Journal, 2* (1–2), 17–29.

Edquist, J., Rich, A.N., Brinkman, C., and Mattingley, J.B. (2005). Do synaesthetic colours act as unique features in visual search? *Cortex, 42*(2), 222-31.

Galton, F. (1880/1997). Colour associations. En S. Baron-Cohen & J. E. Harrison (Eds.), *Synesthesia: Classic and contemporary readings* (pp. 43-48). Oxford: Blackwell.

Grossenbacher, P.G., and Lovelace, C.T. (2001). Mechanisms of synesthesia: cognitive and physiological constraints. *Trends In Cognitive Science, 5,* 36–41.

Hubbard, E.M. y Ramachandran, V.S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron, Vol. 48*, 509–520.

Hubbard, E.M., Arman, A.C., Ramachandran, V.S., and Boynton, G.M. (2005). Individual differences among grapheme-color synesthetes: brain-behavior correlations. *Neuron, 45*, 975–985.

Kennedy, H., Batardiere, A., Dehay, C., and Barone, P. (1997). Synaesthesia: implications for developmental neurobiology. En Synaesthesia: Classic and Contemporary Readings, S. Baron-Cohen, y J.E. Harrison (Eds.), pp. 243–256. Malden, MA: Blackwell Publishers, Inc.

Köhler, W. (1929). *Gestalt Psychology,* New York: Liveright.

Luria, AR. (1968). *The Mind of a Mnemonist.* New York: Basic Books.

MacLeod, C. M., & Dunbar K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 14,* 126-135.

Marks, LE. (1978). *The Unity of The Senses: Interrelations Among the Modalities.* New York: Academic Press.

Marks, L.E. & Odgaard, E.C. (2005). Developmental Constraints on Theories of Synesthesia. En In Robertson, L.C. y Sagiv, N. (Eds.), *SYNESTHESIA: Perspectives from Cognitive Neuroscience* (pp. 214-236). Oxford University Press, New York.

Mattingley, J.B., Rich, A.N., Yelland, G. and Bradshaw, J.L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. *Nature, 410,* 580–2.

Mills, C.B., Boteler, E.H., & Oliver, G.K. (1999). Digit synaesthesia: An ease using a Strooplike test. *Cognitive Neuropsychology, 16,* 181-191.

Myles, K.M., Dixon, M.J., Smilek, D., and Merikle, P.M. (2003). Seeing double: the role of meaning in alphanumeric-colour synaesthesia. *Brain Cogn., 53*, 342–345.

Nagel, Th. (1974). What is it like to be a bat? *Philosophical Review, 83*, 435-50.

Nunn, J.A., Gregory, L.J., Brammer, M., Wiliams, S.C.R., Parslow, D.M., Morgan, M.J., Morris, R.G., Bullmore, E.T., Baron-Cohen, S., and Gray, J.A. (2002). Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. *Nature Neuroscience, 5* (4), 371-75.

Palmeri, T.J., Blake, R., Marois, R., Flanery, M.A., & Whetsell, Jr. W. (2002). The perceptual reality of synesthetic colors. *Proceedings of the National Academy of Science, 99,* 4127-4131.

Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J.D.G., Goldstein, L., Heather, J., Frackowiak, R.S.J. and Frith, C.D. (1995). The physiology of coloured hearing: A PET activation study of colour word synaesthesia, *Brain, 118*, 661-676.

Ramachandran, V.S. and Hubbard, E.M. (2001a). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London, B, 268*, 979–83.

Ramachandran, V.S. and Hubbard, E.M. (2001b). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8* (12), 3–34.

Ramachandran, V.S. and Hubbard, E.M. (2002). Synesthetic colors support symmetry perception, apparent motion and ambiguous crowding. *Abstracts of the Psychonomic Society, 7,* 79.

Ramachandran, V.S. y Hubbard, E.M. (2003a). The Phenomenology of Synaesthesia. *Journal of Consciousness Studies, 10* (8), 49-57.

Ramachandran, V. & Hubbard, E.M. (2003b). Hearing Colors, Tasting Shapes. *Scientific American, 288* (5), 52-59.

Ramachandran, V.S., Rogers-Ramachandran, D., and Stewart, M. (1992). Perceptual correlates of massive cortical reorganization. *Science, 258*, 1159–1160.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2006). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition,* en prensa.

Rich, A.N. and Mattingley, J.B. (2002). Anomalous perception in synaesthesia: A cognitive neuroscience perspective. *Nature Reviews Neuroscience, 3*, 43-52.

Sacks, 0., Wasserman, R.L., Zeki, S., & Siegel, R.M. (1988). Sudden color blindness of cerebral origin. *Society for Neuroscience Abstracts, 14,* 1251.

Schiltz, K., Trocha, K., Wieringa, B.M., Emrich, H.M., Johannes, S y Münte, T.F. (1999). Neurophysiological aspects of synesthetic experience. *J. Neuropsychiatr. Clin. Neurosci., 11*, 58–65.

Smilek D., Moffatt B.A., Pasternak J., White B.N., Dixon M.J., Merikle P.M. (2002). Synaesthesia: A case study of discordant monozygotic twins. *Neurocase, 8*, 338 – 342.

Smilek, D. y Dixon, M.J. (2002). Towards a Synergetic Understanding of Synaesthesia: Combining Current Experimental Findings Withs Synaesthetes' Subjective Description. *PSYCHE, 8* (1). http://psyche.cs.monash.edu.au/v8/psyche-9-01-smilek.html

Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2001). Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience, 13,* 930-936.

Spalding, J.M.K., & Zangwill, 0. (1950). Disturbance of number-form in a case of brain injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 12,* 24-29.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Treisman, A.M. & Gelade, G.A. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Walker, P., & Smith, S. (1984). Stroop interference based on the synaesthetic qualities of auditory pitch. *Perception, 13,* 75-81.

Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21* (7), 761-772.

Ward, J., Huckstep, B., Tsakanikos, E. (2006). Sound-colour synaesthesia: to what extent does it use cross-modal mechanisms common to us all? *Cortex, 42(2)*, 264-80.

Weiss, P.H., Shah, N.J., Toni, I., Zilles, K. and Fink, G.R. (2001). Associating colours with people: A case of chromatic-lexical synaesthesia. *Cortex, 37*, 750-53.

Wollen, K. A., & Ruggiero, F. T. (1983). Coloured-letter synaesthesia. *Journal of Mental Imagery, 7,* 83-86.

Chapter 2

*Synaesthesia: the Existing State of Affairs**

***** *Paper in press (Cognitive Neuropsychology)*

Abstract

In synaesthesia one type of stimulation evokes the sensation of another, such as when hearing a sound produces photisms, i.e. mental percepts of colors. In the past, the idiosyncrasy of this phenomenon, as well as the natural mistrust of scientists towards the subjective, consigned synaesthesia to the periphery of scientific interest. However, the landscape has changed radically in the last two decades. The labor of many researchers, inside as well as outside of cognitive neuroscience, has transformed synaesthesia into a scientific reality whose existence can be demonstrated and studied empirically. The present paper summarizes and reflects on our current knowledge concerning synaesthesia in all its aspects (cognition, behavior, neurology, genetics and demographics).

Introduction

When R listens to music, his mind generates colors which do not exist in the "real" world as perceived by "normal" people. He perceives classical music as "dark brown", electronic music as mostly "purple" and symphonic compositions as "red" (Milán et al., 2007). Undoubtedly, in a more distant past this kind of perception would have been considered witchcraft and not so long ago R's extraordinary ability to "see music" could have led him to an imposed stay in a mental institution (Day, 2005; Cytowic, 1993). Even today many people with synaesthesia prefer not to talk about their condition, trying to act "normal" in order to avoid the common hostility towards the unusual and the unknown, (Day, 2005). The term synaesthesia comes from Greek, meaning "joined perception" (aesthesis translates perception, and syn = joined, together). In synaesthetes one type of stimulation evokes the sensation of another, such as when hearing a sound produces photisms, i.e. mental percepts of colors. Quite frequently this condition involves a "transduction" of a learnt semantic category (e.g., letters, numbers, human faces or days of the week) into a sensory experience (e.g., perception of synaesthetic color).

The first legitimate report on synaesthesia is attributed to Sachs in 1812 (cited in Krohn, 1982; also in Dann, 1998), who described the condition in himself and his sister as a part of a PhD dissertation on his albinism. In the nineteenth century there might have been a dozen of reported cases of possible synaesthetes but these early studies seem to have aroused very little interest. (For a review, see Wheeler, 1920.) Within the scientific community synaesthesia was "brought into existence" by Francis Galton (1880), who observed that a small number of people had the peculiar capacity of experiencing the stimulation of one sense in a multimodal way, i.e. in two or even more sensory modalities (Ramachandran & Hubbard, 2001b). Following Galton, a number of studies were published until the gradual onset of behaviorism in the 1930s. The idiosyncrasy of the phenomenon, as well as the natural mistrust of scientists towards the subjective, consigned synaesthesia to the periphery of scientific interest; many decades would have to pass for synaesthesia to be brought back into the realms of empirical science. Consequently, the lack of medical and psychological information led to numerous personal misfortunes when synaesthetes who "came out of the closet" were diagnosed as schizophrenics and drug addicts or even confined to mental hospitals (Day, 2005). In the most fortunate cases, medical professionals were skeptical, considering that the synaesthete who was speaking about a "yellow melody" or a food that "tastes pointy" (Cytowic, 1993), was just being excessively metaphorical.

Most of the first modern investigations into synaesthesia either passed unnoticed or were seen as mere curiosity. For instance, Luria (1968) described a case of eidetic memory in a multimodal synaesthete who showed peculiar interconnections between virtually all the senses. Ten years later, Lawrence Marks in his book The Unity of the Senses pointed out the scientific importance of synaesthesia, emphasizing its potential for studying the neurological bases of metaphor (Marks, 1978). However, due to the predominant influence of behaviorism and its absolute distrust in subjective experience, psychology did not find it important to study a phenomenon which was only revealed through first person verbal reports.

Apparently, “scientists in the 20th century […] consistently strove to eliminate the subjective role of a human observer in gathering empirical data.” (Cytowic, 2002)

However, the landscape has changed in the last two decades. A number of contemporary researchers have transformed synaesthesia into a scientific reality whose existence can be demonstrated and studied empirically. The application of psychometric methods to synaesthesia has provided an experimental “certificate of authenticity” that has finally convinced the scientific community. Since the turn of the century, a substantial number of papers have been published in top-tier scientific forums. In addition to abundant psychometric studies, scientists eagerly take advantage of modern neuroimaging techniques in order to study the brains of synaesthetes. (See the review by Hubbard & Ramachandran, 2005.) In summary, synaesthesia is fully recognized as a phenomenon that can open new doors in our understanding of scientific and philosophic enigmas, such as the nature of perceptual qualia or the neural bases of metaphor and language.

What is it like to be a synaesthete?

When N, a synaesthete, reads the Spanish first name “Noelia”, each letter makes her see a specific color. Coincidentally, the colors of “Noelia” make up a rainbow color sequence. When it comes to color-to-letter matching in grapheme-chromatic synaesthesia, no two people’s synaesthetic associations are identical. If another grapheme-color synaesthete saw the same letters, the pattern of color-letter correspondence would change. In the same way, a synaesthete whose photisms are elicited by musical sounds presents unique tone-to-color matching, different from that of any other musical synaesthete. However, even though cross-modal matches vary from synaesthete to synaesthete in all the known varieties of synaesthesia, a few trends have been observed such as almost two thirds of grapheme-color synaesthetes perceiving the letter “O” as white (Day, 2005).

Besides the idiosyncratic nature of synaesthetic mappings, subjective reports also point to other kinds of discrepancies in synaesthetic experience. Some synaesthetes describe their photisms as spots of color “floating in their mind’s eye”, in a way similar to normal mental imagery. Meanwhile, other synaesthetes speak about perceptions that are projected externally onto the eliciting stimulus, appearing as a colored “aura” surrounding the synaesthetic inducer.

The idiosyncrasy and the subjective nature of the phenomenon make synaesthesia difficult to fit into common scientific taxonomy. Furthermore, confusion arises from the imprecise use of the term synaesthesia which has been applied to a wide array of phenomena, ranging from idiopathic synaesthesia (a naturally occurring cross-modal perception), to altered states of consciousness caused by psychotropic substances, to metaphorical language and even to visual arts and theatre performances (Cytowic, 1996, 2002).

Despite this phenomenological heterogeneity, Cytowic (1996, 2002) tried to establish a series of “diagnostic criteria” in order to distinguish idiopathic synaesthesia from different psychological conditions (e.g., hallucinations and drug-induced experiences) and artistic extravagancies. Following Cytowic (2002), synaesthetic perception is:

1. involuntary and automatic
2. consistent and generic
3. spatially extended
4. memorable
5. affect-laden

Before providing a more detailed description of these features, it should be noted that the first two (i.e., synaesthesia being involuntary and automatic, consistent and generic) are probably the least problematic and the most agreed upon in the scientific community. The rest of Cytowic's criteria are more controversial and, rather than being "diagnostic" in the strict sense of the word, they represent features which are likely (but not necessarily) to be observed, to a higher or lesser degree, in the majority of synaesthetes.

The involuntary character of synaesthesia refers to the impossibility to manipulate synaesthetic perception or to suppress it by will (e.g., Dixon, Smilek, Cudahy & Merikle, 2000; Mattingley, Rich, Yelland & Bradshow, 2001, Wollen & Ruggiero, 1983). When a grapheme-color synaesthete sees a printed character, e.g. the letter "R", simultaneously he will perceive a color halo surrounding the grapheme. The feeling is much different from that of a memory brought to one's mind due to some kind of association with certain sensory aspects of the outer world. While usually we are able to stop thinking about unpleasant memories, it is not possible to stop seeing, hearing or smelling external stimuli unless you eliminate sensory input. The same applies to synaesthesia in the sense that it is virtually immune to any voluntary control.

Synaesthetes' reports suggest that synaesthesia is acquired very early during development and it lasts for a lifetime.[1] Once established, synaesthetic associations remain unchanged; when a synaesthete is presented with a series of inducers across multiple time points, he/she will experience the same synaesthetic *concurrents* in response to the triggering stimuli. Studies report on consistency measures with test-retest periods of weeks, months or even years. For instance, Baron-Cohen et al. (1987) studied a case of a synaesthete who experienced photisms in response to spoken language. In a preliminary interview they asked E.P. to describe in detail the colors she saw when listening to 103 different auditory stimuli (words, letters and numbers). Ten weeks later they did a retest. The subject's answers were 100% consistent with respect to the previous experimental session. In contrast, a non-synaesthete participant who was asked to associate colors with the same inducers, was far less accurate in her responses. (With a test-retest period of two weeks only, the measure of consistency was less than 17%.) In brief, the connection between inducing stimuli and synaesthetic responses is extremely stable over time and, as will be shown later, it cannot be explained by memory performance.

In addition to its consistency and durability, there is another aspect of synaesthesia that makes it different from other phenomena such as hallucinations present in psychotic disorders. Synaesthetic responses are typically generic; they correspond to basic perceptual qualities such as color, texture and fundamental visual forms, tactile sensations, etc. Moreover, quiet often the synaesthetic percepts, through their association to the inducing stimulus, may enhance the synaesthete's memory by serving as additional memory cues. (For instance, number-color synaesthesia may help to remember telephone numbers.) Even though Cytowic (2002) argues that synaesthetic experience is never pictorial or laden with semantic content, it should be noted that there have been cases of letter-color synaesthetes who, when they hear a word (e.g., “table”), may actually see the letters (T-A-B-L-E) spelled out in color.

When synaesthetes describe their subjective experience, they often speak about colors being projected onto a written character (grapheme-color synaesthesia) or about visual entities on a “screen” situated a few inches in front of one’s face (audio-visual synaesthesia). Cytowic (1993) reports the case of a synaesthete who experienced tactile sensations in response to gustatory stimulation. The subject used to alter the position of his hands in order to better “reach” for the feeling. All these aspects illustrate the “spatial quality” of synaesthetic sensations. However, this feature is less obvious if we consider those people whose synaesthesia is more similar to visual imagery. (See “associator synaesthetes” further on in this paper.) This variety of synaesthesia is also completely automatic but the ability to spatially localize is uncertain, given that percepts are not projected externally.

Finally, a series of authors (Milán et al. 2007, Ward, 2004, Cytowic, 2002, Ramachandran & Hubbard, 2001b) have emphasized the relationship of synaesthesia with emotion. Frequently synaesthetes claim experiencing pleasant sensations that accompany synaesthetic perception and are sometimes similar to a “Eureka!” feeling (Cytowic, 2002). Occasionally, synaesthesias can also be related to negative feelings, particularly when the synaesthetic perception is incongruent with the outer reality. (For example, when a grapheme-color synaesthete sees a letter printed in a different color than that of the associated photism.) Certain types of synaesthesia are directly related to the emotion. For instance, R, a synaesthete reported by Milán et al. (2007), experienced mental colors in response to faces, human figures and visual scenes with emotional content. Normally the colors experienced were congruent with R’s emotional assessment of the person or the visual stimulus in question. (R often used the photisms to refine his opinions about people.) Very rarely, the synaesthetic “aura” experienced by R was not congruent with respect to the personal relationship that R maintained with a person, e.g. when a good friend of his “had a very unpleasant green color”. This kind of incoherency was extremely uncomfortable to R and accompanied by negative emotions. A few similar cases have been reported in literature, one that is particularly interesting is a report by Ward (2004) about G.W., a synaesthete who experienced mental colors in response to human faces, known person’s names and affect-laden words.

Empirical demonstrations of synaesthesia

Initial skepticism around synaesthesia among psychologists, neurologists and other professionals was, at least in part, due to the lack of experimental methods that would allow for an objective demonstration of the phenomenon. A few early experimental studies actually examined the hypothesis that synaesthesia was a consequence of a classical conditioning mechanism (Kelly, 1934; Howels, 1944). With the intent to corroborate this proposal, they trained non-synaesthete subjects to associate arbitrary pairs of tones and colors. Even though some participants were quite successful in this memory task, there was no evidence of any type of accompanying color perception (Rich & Mattingley, 2002), such as reported by synaesthetes. Behind these early attempts to empirically approach synaesthesia, it took decades for scientists to return to the subject matter and finally invite synaesthetes to participate in experimental studies that could confirm or refute the genuineness of their condition.

As we mentioned before, one of the indicators that strongly supports the reality of synaesthesia, is its constancy over time. In order to assess the consistency of a synaesthete, the subject is normally shown a series of synaesthetic inducers (e.g., a grapheme for a grapheme-color synaesthete). His/her task is to simply report on the elicited synaesthetic perception (for example, the color of the photism). (In more sophisticated designs, a standardized color set or a software color palette can be used to match the colors of the photisms more precisely; e.g. Witthoft & Winawer, 2006; Milán et al., 2007) The experimental session is replicated days, weeks or even months later. Following this methodology, virtually all studies report consistency levels that are very close to 100% (e.g., Baron-Cohen, 1987; Dixon et al., 2000; Mattingley et al., 2001). The stability of synaesthetic associations is maintained over time, even when assessed after a time gap of several months (Baron-Cohen et al., 1993).

However, the high consistency by itself does not reveal the nature of the underlying neurocognitive mechanisms. Not so long ago, the most common explanation of synaesthesia was in terms of memory associations, possibly due to a learning experience in early childhood (Ramachandran & Hubbard, 2001b, 2003a). In theory, a lexical synaesthete could have played with refrigerator magnets with colored letters and consequently developed powerful associations between printed characters and specific color hues. A better understanding of the nature of synaesthesia required converging evidence from a number of sources: experiments designed to demonstrate that the experience of photisms is not under voluntary control; perceptual experiments to demonstrate that synaesthetes do indeed experience synaesthetic percepts when exposed to inducing stimuli; subjective reports to supplement and inform these objective inquiries.

In the 1980s, a series of studies sought to uncover whether synaesthesia was a perceptual or a memory phenomenon. Most of these studies (as well as much of the current research) worked with the most common grapheme-color synaesthetes, employing modifications of the Stroop task (Stroop, 1935). Standard design consisted in presenting a printed character which was either of the same color (congruent) or of a different color than the synaesthete’s photism (incongruent), and then asking the synaesthete to name the print color (e.g., Wollen & Ruggiero, 1983; Mills et al., 1999). Dixon, Smilek, Cudahy & Merikle applied this same logic in a more recent study (Dixon et al., 2000) with C, a synaesthete who reacted synaesthetically to Arabic numerals. Stimuli consisted of a color square (base line) or a colored number whose hue was congruent or incongruent with respect to C’s photism. The stimuli were presented on a computer screen in random order. C’s task was to identify and say the color of the stimulus as fast as possible. As expected, C was significantly slower when responding to incongruent colors (797 ms, 2.8% error rate) with respect to the congruent ones (525 ms, 1.4% errors) and the base line (545 ms, 0.0% errors).

This result has been replicated in several studies (e.g., a study with 15 synaesthetes by Mattingley et al., 2001), revealing clearly the automaticity of synaesthetic perception. However, this kind of result does not demonstrate if synaesthesia is a genuinely perceptual process or not. MacLeod and Dunbar (1988) trained non-synaesthete subjects to associate black & white geometric shapes with the names of different colors. After thousands of trials, the participants were tested on a Stroop task where the original shapes were presented either in the same or in different colors with respect to the original matching. The results showed a clear interference pattern that could only be explained as an effect of the previous excess of learning. This data suggest that a simple associative mechanism, based on a memory performance, could be sufficient to explain the reaction times of synaesthetes. Nevertheless, subjective reports do not fit within this hypothesis. Synaesthetes normally do not speak in terms of “remembering or imagining a color hue”, when exposed to an inducer stimulus. In their verbal descriptions they typically mention a halo of specific color tone (Smilek & Dixon, 2003), concrete tactile sensations (Cytowic, 1993) or tastes on the tongue (Ward & Simner, 2003). In other words, these reports suggest that synaesthesia is much better described as a sensory phenomenon and it certainly cannot be seen as a high-level memory association (Ramachandran & Hubbard, 2001a, 2001b, 2003a).

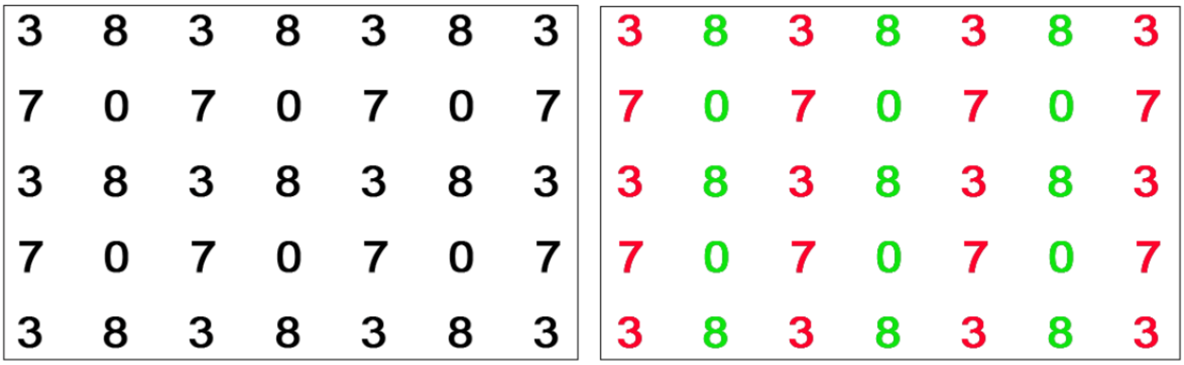


Figure 1: Normal subjects usually perceive this number matrix as horizontally organized (left figure), due to the shape similarity between the numbers 3 and 8. Lexical synaesthetes studied by Ramachandran and Hubbard observed a vertical set-up, induced by a chromatic pattern of the photisms (right). (Ramachandran & Hubbard, 2001a)

In order to test this hypothesis it was necessary to explore to what degree the synaesthetic colors lead to sensory effects observed with real colors. Ramachandran & Hubbard (2001a) studied two synaesthetes (J.C. and E.R.) who experienced photisms upon observing letters and numbers. To see if this was a sensory process or not, the authors set up number matrixes that, due to its visual characteristics, could be perceived as either a vertical arrangement (a series of columns) or a horizontal one (i.e., numbers grouped in rows). When a visual feature leads to formation of clusters which are perceived as wholes, it is assumed that such a feature is genuinely perceptual (Beck, 1966; Treisman & Gelade, 1980). For instance, if a series of neighboring elements in a matrix is of a different color than the rest, it will be recognized as a distinctive group, standing out in the background. This phenomenon, termed *perceptual grouping*, occurs in response to basic visual features such as color, shape and orientation. In Ramachandran and Hubbard’s design, the matrix elements were numbers that due to the similarity in shape between the number elements (e.g., the 3s and 8s), could be perceived as organized in a specific manner (for example, as rows in Figure 1, left). However, the authors chose the matrix numbers for each synaesthetic subject in such a way that the grouping by synaesthetic color would lead to a different visual organization than the grouping by shape. In the stimulus represented in Figure 1, the elements in alternating columns (3s and 7s, 8s and 0s) induced the same synaesthetic colors for the synaesthete E.R. If the photisms behaved much like real colors, they should overcome the horizontal organization induced by the number shapes, leading to a perception of colored vertical columns (Figure 1, right). This is what actually happened. While the control subjects tended to group the elements solely on the basis of grapheme shape, the synaesthetes reported perceiving groupings based on their induced colors in 90.97% (J.C.) and 86.75% (E.R.) of the trials.

In another experiment with the same synaesthetes, Ramachandran and Hubbard (2001a) used arrangements of randomly scattered graphemes, containing an embedded shape (square, rectangle, parallelogram or triangle) that consisted of a grouping of identical characters (Figure 2, left). The subject's task was to observe the figure for 1 second and then try to identify the "hidden" shape. Non-synaesthete controls found the shape in 59.4% of trials. In contrast, synaesthetes got it right in 81.25% of trials. The most frugal explanation is that photisms induced by the graphemes led to a sensory segregation ("pop-out") of the embedded shapes. When this experiment was replicated later by Hubbard et al. (2005) with 6 synaesthetes, the results confirmed that the synaesthetes' performance was significantly better than in the controls. However, the synaesthetes were inferior to a second group of control participants who were exposed to arrangements of actually colored graphemes, such as in Figure 2, right. This suggests that photisms are not as effective as real colors in so far as reaction-time performance is concerned.

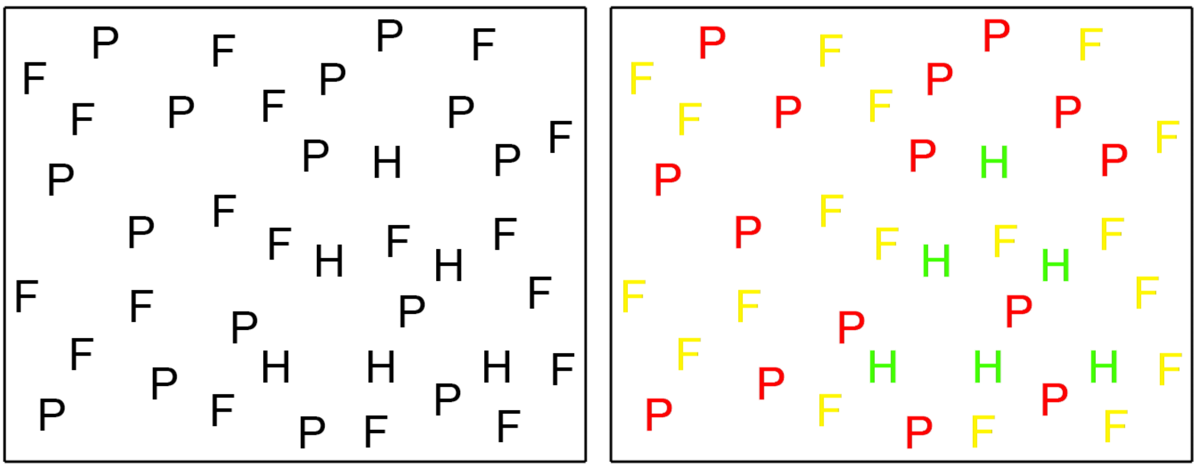


Figure 2: The "letter soup" used in a visual search experiment by Ramachandran and Hubbard (2001b). Right figure represents the image as "seen" in synaesthetic colors.

Overall, the results of both experiments by Ramachandran & Hubbard (2001a; See also Hubbard et al., 2005.) suggest that the nature of the mechanism underlying synaesthesia is sensory and cannot be accounted for by simple memory associations or attributed to an excessive use of metaphoric language. In line with these data, Smilek et al. (2001) demonstrated that photisms could actually influence visual perception. The researchers presented an achromatic number character on a plain color background, followed by a mask. When the number was presented on a background of the same hue (a congruent condition), the performance was significantly worse (88% correct) with respect to the incongruent condition (96% correct). In other words, the discrimination seemed to be more difficult for the synaesthete when the photism projected on the grapheme stimulus was of the same color as the background. The same result was obtained in a visual search task where the subject had to look for a specific grapheme among distractors (Figure 3.). Again, her performance was impaired (longer RT) for color congruent trials compared to the incongruent ones.

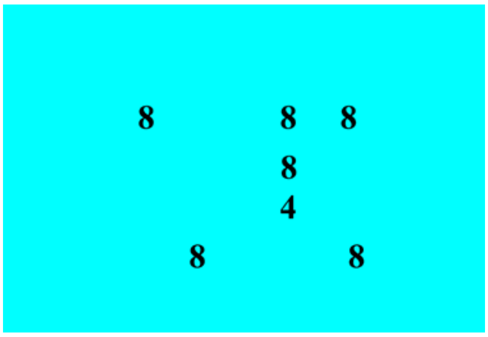


Figure 3: The synaesthete C was significantly slower when looking for a number grapheme that was presented on a background of the same color as the associated photism (e.g., a "blue" 4 on a blue background). When the background was incongruent (i.e., of a different color than the photism of the target), the number of distractors did not influence C's performance. (Smilek et al., 2001)

The amount of available evidence suggests that theories of synaesthesia in terms of childhood memories or metaphorical language are definitively out of place. Synaesthesia seems to be a sensory-like process that can be accounted for by an anomalous communication between specific brain regions, as we will see later on. In the following sections we will examine the evidence concerning the incidence of synaesthesia in the population and explore the different modalities of this peculiar neuropsychological condition.

Synaesthesia prevalence and subtypes

Synaesthesia is not a widespread condition. Even though estimations of prevalence have been changing widely across different studies, until recently the consensus seemed to lie somewhere around 1 in 2000 (0.05%), as proposed by Baron-Cohen et al. (1996). The same study estimated a proportion of 6 female synaesthetes for every male with the condition. Even though the latter estimation is in accordance with quite a few other papers (e.g., Rich et al., 2005), it should be noted that the majority (if not all) of these studies probably suffered from a sampling bias caused by a higher willingness in women to inform about their synaesthesia (Ward & Simner, 2005; Simner et al., 2006). In a more recent study, using opportunistic samples (participants recruited from the communities of Glasgow and Edinburgh Universities), Simner et al. (2006) did not find any significant gender asymmetry. Besides challenging previous reports on this account, the result could possibly, but not necessarily, undermine purported X-linked inheritance of synaesthesia. (The subject of synaesthesia genetics will be discussed later on in this paper.) Moreover, Simner et al's assessment of synaesthesia prevalence yielded a considerably higher value (4.4%) than previously assumed. Given the scope and the type of sampling employed, Simner et al's data are likely to be the best estimates to date.[2]

Besides the prevalence and the likely absence of sex bias, there are additional demographic aspects of synaesthesia that ought to be mentioned. A series of authors have reported high incidences of synaesthesia among people dedicated to artistic and/or creative professions and hobbies (Galton, 1880; Domino, 1989; Dailey et al., 1997; Ramachandran & Hubbard, 2001b). This idea has been confirmed in a large-scale study by Rich et al. (2005): 24% out of the 192 synaesthetes who participated in the research, were professional artists or had a career linked to the arts. (In comparison, in the normal population of reference only 2% of people worked in the field of arts.) Interestingly, some authors believe that there are specific neurophysiological mechanisms which lead to above-average creative abilities in synaesthets. As we will discuss later, virtually all current neurocognitive models suggest an existence of some kind of neural hyperconnectivity between specific regions of a synaesthete's brain. Ramachandran and Hubbard (2001a) proposed that if such hyperconnectivity was more diffusely expressed, it could lead to "a greater propensity and opportunity for creatively mapping from one concept to another." However, up to date there have been only a few empirical studies focused on creativity in synaesthesia (e.g., Domino, 1989; Sitton & Pierce, 2004) and more research will be necessary in order to confirm (or refute) this proposal.

A large number of authors agree that synaesthesia is a familial condition (e.g., Galton, 1880; Baron-Cohen et al., 1996; Rich et al., 2005). Rich et al. reported that 36% of synaesthetes participating in this large-scale study reported having at least one biological relative with synaesthesia. The authors also interviewed the participants about potential advantages and disadvantages of synaesthesia. The majority of synaesthetes (71%) perceived their condition positively, claiming that synaesthesia enhances their memory skills, eases data organization and provides a source of mental pleasure and creative inspiration. Approximately one third of those interviewed mentioned some negative aspects, mainly synaesthesia being a source of confusion due to incongruence between synaesthetic perception and physical reality (e.g. when the meaning of a word does not fit with the elicited photism). Lexical synaesthetes reported contradictory feelings caused by a negative disposition towards persons whose names were perceived in negative mental colors. A small number of synaesthetes complained about sensory overload and feelings of discomfort because of "being different".

On account of anecdotal reports it has often been assumed that synaesthetes tend to be bad in arithmetic, have a poor sense of direction and frequently have "precognitive" experiences such as "déjà vu" or premonitory dreams (Cytowic, 1989). The data collected by Rich et al. (2005) supports the suggestion concerning synaesthetes poor sense of direction. Conversely, synaesthetes do not seem to be more likely to report precognitive phenomena than the general population.

As far as different subtypes of synaesthesia are concerned, all the authors agree that the most frequent modality of synaesthesia is the one induced by lexical stimuli, such as numbers, letters and words (Cytowic, 1993; Baron-Cohen et al., 1996; Rich and Mattingley, 2002; Day, 2005; Rich et al., 2005; Simner et al., 2006). For instance, in the study by Rich et al. less than 2% of the interviewed synaesthetes did not experience synaesthesia in response to lexical stimuli (words, phonemes or graphemes) and only presented other kinds of synaesthesia. If lexical stimuli are further subdivided into more specific categories, the days of the week turn out to be the most frequent synaesthetic inducers (Simner et al., 2006). On the other hand, non-lexical modalities of synaesthesia are much less frequent. Up to 50% of synaesthetes (estimate based on the data by Day, 2007) experience synaesthesia in more than one sensory modality. (For example, "lexical" synaesthete can "see colors" when seeing, hearing or merely thinking of numbers and letters.) Even though for the majority of synaesthetes the synaesthetic sensation is color (Day, 2005, 2007; Simner et al., 2006), there are reported cases of smell, tactile sensations, sound, taste and proprioception as concurrent percepts. (See Figure 4.)

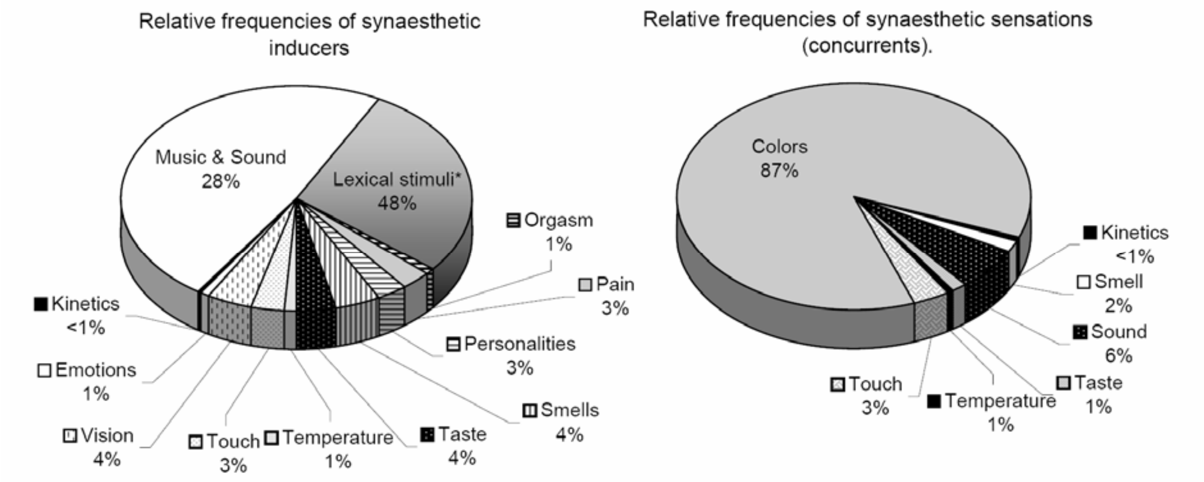


*Figure 4: Relative frequency of synaesthetic inducers and concurrents. (Source of data: Day, 2007) *Note: Lexical stimuli include graphemes, digits, time units and written and spoken words.*

According to Day (2005), there are two major categories of synaesthesia:

a) *Cognitive synaesthesia*: Photisms or other synaesthetic perceptions are induced by stimuli associated to symbolic meanings, transmitted within specific culture (graphemes, phonemes, people's names, week days, etc.)

b) *Synaesthesia "proper"*: Stimuli of one sensory modality are perceived simultaneously and involuntarily through an additional sensory channel (e.g., seeing music).

This classification partially overlaps with the distinction put forward by Marks and Odgaard (2005) who distinguish between an *intramodal synaesthesia* (the inducer and the synaesthetic response belong to the same sensory modality, e.g. when graphemes are perceived as colored) and an *intermodal synaesthesia* (the stimulus induces a concurrent in a different modality, e.g. tactile sensations elicited by taste). However, the overlap is only partial given that there have been cases of both intramodal and intermodal cognitive synaesthesia[3]. There are also synaesthetes with intramodal non-lexical synaesthesia for whom when observing shapes and visual scenes photisms are induced. For instance, the synaesthete R, described by Milán et al. (2007) experienced the color red when watching the sky with clouds. This kind of synaesthesia would be clearly intramodal. It does not seem to be related to any kind of culturally acquired semantics, i.e., it is not the cognitive subtype, but neither is it a case of synaesthesia “proper”, as defined by Day. Taking into account these nuances, we prefer to use Marks and Odgaard’s taxonomy, along with additional clarification of the cognitive aspects which are sometimes difficult to determine. For instance, in the case of “colored music” we might be dealing with a culturally conditioned synaesthesia, triggered by musical education, or it could be the result of a more straightforward “transduction” of auditory input into visual percepts of color.

Another important aspect of synaesthesia has to do with the mode of experiencing synaesthetic sensations. According to Dixon et al. (2004), there are at least two qualitatively different varieties of visual synaesthesia. *Projector synaesthe*tes perceive their photisms as located in external space, usually being projected onto the eliciting stimulus (e.g., a grapheme in lexical synaesthesia). On the contrary, *associator synaesthetes* observe synaesthetic colors in their mind’s eye; there is no external projection of the photisms. Dixon and colleagues discovered that these two groups differed not only in their subjective reports but also in their performance on a modified Stroop task. The experiment included two tasks: to name the color of a grapheme presented on a computer screen or to name the color of the photism triggered by the grapheme. The color of the grapheme could be congruent or incongruent with respect to the photism. The results show that “projector” synaesthetes are more sensitive to interference of the photisms when naming the grapheme color than vice versa. That is, the photisms somehow disrupt the ability to name the grapheme color, while the real color interferes little or not at all with the ability to name the photism. On the other hand, the “associator” synaesthetes were faster at naming the grapheme color and they showed the same interference pattern in both tasks. This double dissociation in Stroop interference pattern has also been reported in a more recent study by Ward, Li, Salih & Sagiv (in press).

Ramachandran and Hubbard (Ramachandran & Hubbard, 2001b, 2003b; Hubbard & Ramachandran, 2005) proposed an alternative higher vs. lower distinction, motivated by differences in the level of representation of the inducing stimulus. In synaesthetes termed as *lower*, the photisms are elicited by specific perceptual features of the inducer (e.g., the form of a digit) and they most probably occur in early stages of perceptual processing. On the contrary, photisms of *higher* synaesthetes arise in response to more abstract, conceptual aspects of the inducer (e.g., the meaning of a number), which are processed by different brain areas. The matter of the level of representation of synaesthetic triggers is indeed critical to the debate about the underlying neurocognitive mechanisms[4]. On the other hand, the distinction put forward by Ramachandran and Hubbard seems to be more problematic than Dixon et al’s, because it is founded on theoretical, yet-to-be-proved, assumptions rather then phenomenological reports of synaesthetes (Ward et al., in press). Some authors (Dixon & Smilek, 2005; Hubbard & Ramachandran, 2005) speculated that the projector-associator distinction actually mapped on to the lower-higher dimension. However, a recent study by Ward et al. (in press) demonstrates that the two distinctions are most probably orthogonal. According to previous accounts on this issue, certain behavioral characteristics are expected of higher/associator or lower/projector synaesthetes respectively. For instance, the higher level synaesthesia may be particularly associated with ordinal sequences (a conceptual level property); digits, roman numerals, spelled out numbers or dice patterns should elicit the same synaesthetic colors in higher synaesthetes (but not lower synaesthetes) because they represent the same number concept. On the other hand, in lower/projector synaesthetes the colors of words should be more frequently derived from graphemic constituents, provided that it is true that they are sensitive to the external stimulus per se (i.e., the graphemes) and not the underlying concept. Firstly, Ward et al's findings indicate that the presence or absence of the lower or higher characteristics is independent of the projector/associator classification (assessed by first-person reports). Some of their associator participants presented "lower" features, as well as "higher" features were observed in many projector synaesthetes. Moreover, the only reliable difference (beyond phenomenological reports) between the associators and the projectors was found in their respective patterns of Stroop-type interference, first reported in the study by Dixon et al. (2004). (Remember that projector synaesthetes were faster in naming photism colors rather than real colors of graphemes; the opposite was observed in the associators.) According to Ward and colleagues, this behavioral discrepancy results from diverse spatial frames of reference evoked during synaesthesia. While the projectors employ an externalized frame of reference defined relative to the location of graphemic stimuli, the associators use an internalized frame ("their mind's eye") or perhaps do not have any specific frame of reference with respect to their photisms[5]. Following this proposition, the slower reaction times of the associators in a photism naming task actually reflect an attentional effect. They need to shift their attention from one spatial location to a new one; the projectors' attentional resources remain in the same location during the task.

In summary, the study by Ward et al. brings in important new data, a novel approach to the problem of phenomenological and behavioral differences, and may have important implications for present neurocognitive models of synaesthesia. Even though the consensus regarding this issue is still to be sought, it is clear that inter-individual variability could account for a number of inconsistencies observed across various experimental studies (Hubbard & Ramachandran, 2005; Ward et al., in press). For example, Palmeri et al. (2002) demonstrated a strong sensory segregation effect with a synaesthete W.O. in a visual search task (the subject's task was to detect a grapheme target among distractors.) In a similar experiment with 14 synaesthetes (Edquist et al., 2005), only 2 subjects showed facilitation in visual searches in comparison to the control group of non-synaesthetes, and they did not present a sensory "pop-out" pattern that had appeared in Palmeri's results. In theory, it is possible that the subject in the Palmeri et al. study was of a "projector" or "lower" type, while there were no such synaesthetes in the latter experiment. Given the heterogeneity of the phenomenon of synaesthesia, particular caution is necessary when designing and analyzing data. If individual data are averaged indiscriminately, the obtained results and their interpretation are likely to be distorted. Frequently, single-case designs and/or interindividual comparisons between synaesthetes are highly recommended research strategies (Smilek & Dixon, 2002).

Preconscious and sensory or conscious and conceptual?

If you fix your gaze at the central cross in figure 5A, you can discern the number 5 located at your visual periphery. However, if the same number is surrounded by distractors (Figure 5B), it is virtually impossible to identify (Bouma, 1970). This effect, termed as “crowding”, is a result of attention overload due to the distractors. Quite contrary to the data obtained with normal subjects, two synaesthetes studied by Ramachandran and Hubbard (2001b) who were tested on the same perceptual “crowding” task easily identified the “invisible” number. As reflected in their verbal reports, they were able to deduce the number identity through the photism color, elicited by the grapheme. This result is analogous to that observed in non-synaesthetic subjects when the target is actually colored (Kooi et al., 1994), and suggests that the synaesthetic color percept occurs on a preconscious level, before the crowding effect takes place.

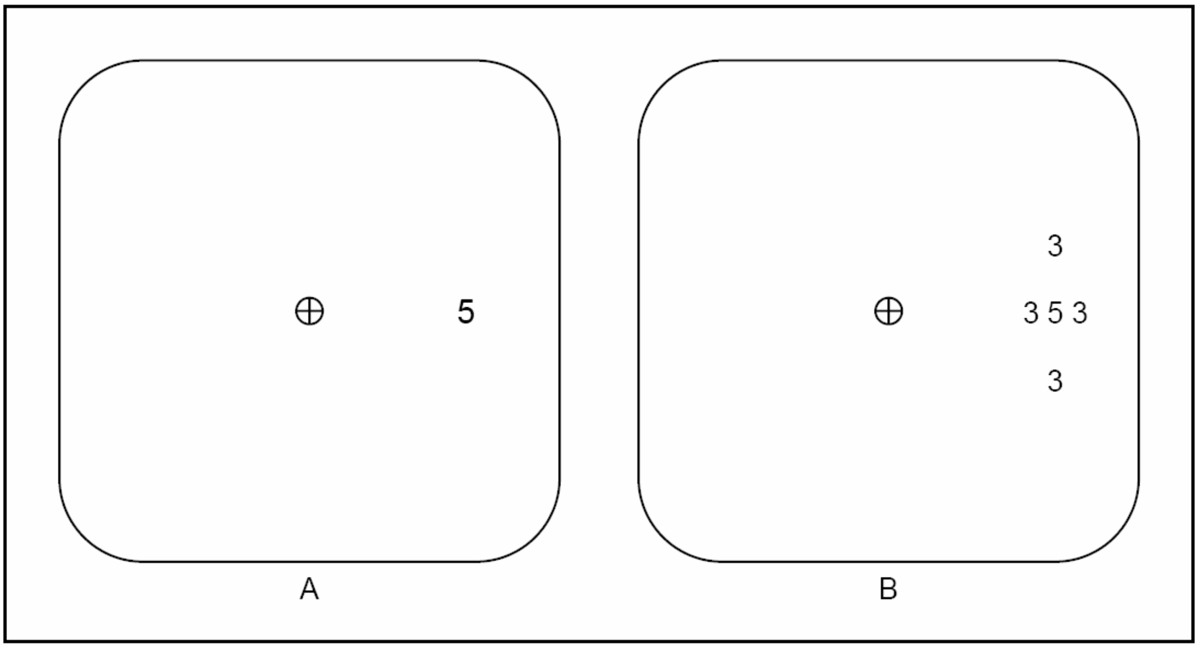


Figure 5: The crowding task, applied to synaesthetes by Ramachandran and Hubbard (2001b), suggests that the induction of photisms precedes the conscious identification of graphemes.

Evidence provided by Smilek et al. (2001) goes in the same direction. The synaesthete C carried out a number identification task that consisted in naming a number briefly presented on a computer screen. When the graphemes were placed on a background of a different color than the associated photism (i.e., incongruent condition), C’s responses were significantly faster than in a color congruent condition. It is hard to think that the photism would influence the number identification in such a way, if it occurred after the conscious recognition of the grapheme.

However, not all the evidence is consistent with the preconscious hypothesis. Mattingley et al. (2001) subjected 15 lexical synaesthetes to two priming tasks. In the first one, they presented a grapheme during 28 or 56 ms and immediately followed by a mask, in order to eliminate conscious identification of the character. Participants' task was to name the color of a square patch that appeared on the screen right after the masked stimulus (the prime). If photisms had occurred before conscious recognition of the masked character, they would have influenced the color naming task, facilitating color identification when the grapheme photism and the color patch were of the same hue. Nevertheless, none of the subjects showed any synaesthetic priming effect, but they did present "classical" priming in a letter identification task. (In a second task they had to identify another grapheme presented after the masked character.) As expected, synaesthetes' reaction times were faster when the target grapheme and the prime were identical. This demonstrates that even though the grapheme presentation time of 28 or 56 ms was sufficient to produce unconscious "classical" priming, most likely it did not lead to photism induction. On the basis of these findings, the authors suggested that "synaesthetic colors typically arise only for inducers that are represented at conscious levels of visual processing" (Rich & Mattingley, 2002). Furthermore, in a more recent experimental series Mattingley et al. (2006) also demonstrated that when the primes are presented long enough so as to produce conscious percepts of color, reducing the amount of attention available to process the synaesthetic inducer considerably reduces the priming effects. Again, this seems to indicate that conscious, selective attention to the stimulus might play an important role in synaesthesia.

The controversy of whether or not conscious identification of synaesthetic inducers is necessary for synaesthesia to occur is closely related to a debate concerning the perceptual vs. conceptual nature of synaesthetic triggers. While some suggest that the recognition of the lexical stimulus as such is a necessary condition for photisms to occur, other studies seem to go in the opposite direction, defending that synaesthetic colors are a direct response to perceptual features of the inducer. At least in some synaesthetes, photisms produce effects typically observed with real colors: they can provide an input to apparent motion perception (Ramachandran & Azoulai, 2006; Ramachandran & Hubbard, 2002), produce McCollough color after-effect (Blake, Palmeri, Marois et al., 2005) or be influenced by changes in physical attributes of the inducer, such as contrast, eccentricity (with respect to central vision), and frequency rate of alternately presented graphemes (Ramachandran and Hubbard, 2001a, 2001b). On the other hand, the fact that grapheme-color synaesthetes experience photisms with rare typographic fonts or even with handwriting, points to the importance of cognitive interpretation of the graphemes more than just their visual features per se.

So then are we dealing with a sensory phenomenon or not? Firstly, we propose that it is necessary to make further progress in differentiating between lower and higher as well as projector and associator synaesthetes (Ward et al., in press). In order to overcome the inconsistencies it is essential to take into account and to control the presence of different varieties of synaesthesia in experimental designs. Available data suggest that the degree of dependence upon either perceptual or conceptual aspects is not the same for all synaesthetes and it may also vary across different stimulus modes (e.g., spoken words vs. written words) in the same synaesthete. Secondly, it is necessary to take into consideration the different spatial frames of reference evoked by synaesthetes, as suggested by Ward et al. Finally, it should be noted that dichotomic categorizations of cognitive processes (as unconscious vs. conscious, perceptual vs. conceptual or pre- vs. post-attentional) are possibly too simplistic to account for synaesthetes' behavioral data (Ramachandran & Hubbard, 2005). Even in those rare cases of grapheme-color synaesthetes who show typical sensory patterns in their behavioral performance, it is logical to expect at least some influence of conceptual processes. It is hard to believe that grapheme-color synaesthesia whose origin is intimately related to the acquisition of reading-skills, is a purely sensory process, independent of lexical knowledge. In fact, the synaesthetic color of ambiguous stimuli (e.g., the "O" in 9O89 and LOVE) typically changes in accordance with the surrounding lexical context (Dixon et al., 2006; Ramachandran & Hubbard, 2003a). The matter to be solved is whether this and other similar effects are the consequence of a top-down modulation, as proposed by Ramachandran & Hubbard (2001b), or whether the photisms only arise once the grapheme has been identified, as put forward by Mattingley et al. (2001).

Synaesthetic brain

The first study of the synaesthetic brain, carried out by Cytowic and Wood (1982), supported the suspicion that neuronal functioning of synaesthetes was different from that of a normal person. Unfortunately, unexpected complications arouse due to the fact that the only subject of this investigation (MW) showed additional anomalous cerebral activity even when he did not experience synaesthesia. This fact made data interpretation quite problematic; the scientific community would have to wait more than a decade for new and finer neuroimaging data.

In 1995 Paulesu et al. seated 6 female with auditory lexical-chromatic synaesthesia in a positron emission tomography (PET) scanner. During the exposition of the synaesthetes to spoken words, neural activity was observed in visual areas (posterior-inferior temporal cortex and parieto-occipital junction). This was to be expected if, as hypothesized, synaesthesia was a perceptual phenomenon rather than a result of high level associations. Surprisingly, activity in the area responsible for color processing in humans (V4/V8) did not reach statistical significance. In any case, Paulesu et al's study provided a first clear-cut demonstration showing that the cerebral functioning of the synaesthete subjects was different from that of normal, control subjects. The non-synaesthetes' visual areas gave no response to the same auditory stimulation.

Posterior studies used finer technology which allowed making further progress in the understanding of functional neuroanatomy of synaesthesia possible. Weiss et al. (2001) worked with RS, a lexical-chromatic synaesthete who experienced photisms in response to the names of people he knew. When RS was being exposed to such stimuli, functional magnetic resonance (fMRI) revealed a bilateral activity in the area V4, an activation of the extra-striate visual cortex, as well as the retro-splenial cortex (the region usually associated to person familiarity). Nunn et al. (2002) subjected lexical-chromatic synaesthetes to an experiment where they presented spoken words, pseudo-words (i.e. nonsense syllables) and single pure tones. An fMRI scan showed increased activity in the left hemisphere color area (V4/V8) when listening to words, but not when listening to pseudo-words or tones.

Nunn's design included a control group of non-synaesthetes who received extensive training in associating specific words with color hues. In contrast to the synaesthetes, these participants did not present any activity in color regions when imagining colors in response to the words. The results agree with previous research, showing no activity in visual areas V1 or V2, and suggest that processing in earlier visual areas is not necessary to experience visual synaesthesia. The only study not in line with the aforementioned hypothesis was published by Aleman et al. (2001), who detected activity in the V1 area of a lexical-chromatic synaesthete exposed to auditorily presented words. However, this seems to be an isolated result that only reached marginal levels of significance.

Virtually all research points to the importance of the color processing area (V4/V8) for the generation and/or experiencing of photisms (Sperling et al., 2006). In order to explore the degree of involvement of this as well as other brain regions, Hubbard et al. (2005) combined an fMRI scan with behavioral measures (a crowding task and a synaesthetic pop-out task, described earlier in this paper) in a study with 6 grapheme-color synaesthetes and 6 control subjects. When they compared the behavioral data and the fMRI data, they found a significant correlation between the degree of activation in visual areas (particularly the hV4) and the performance in the crowding task. The results were correlated between the two behavioral tasks, too. In other words, those synaesthetes who reached the best scores in the crowding and the pop-out tests also presented higher neuronal activity in the color area (V4) when exposed to synaesthetic inducers (Figure 6).

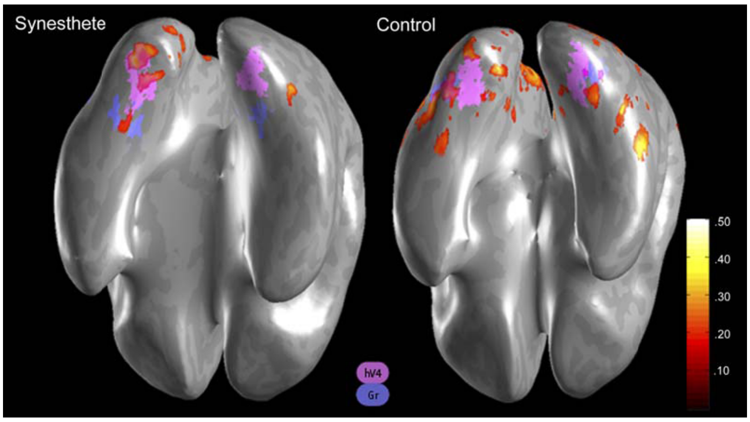


Figure 6: The subjects of this neuroimaging experiment were exposed to achromatic grapheme stimuli. An fMRI output shows ventral views of two inflated brains. The V4 area, responsible for color processing, is indicated in purple and the grapheme area indicated in blue. In both subjects there is activation in the grapheme area but only the synaesthete shows activity in the V4. (Reprinted from Hubbard et al. (2005).)

This result is in line with the idea that synaesthetes, including those who have the same kind of synaesthesia, are a heterogeneous group with important inter-individual differences. It is possible that the activation of visual areas is stronger in those synaesthetes who perceive their photisms as externally projected. Interestingly, in a recent study Rouw & Scholte (2007) report on structural differences in neural connectivity between "associator" and "projector" synaesthetes. First, by means of diffusion tensor imaging (DTI) technology the authors have shown that synaesthesia is associated with increased (or more coherent) connectivity in white matter structure at various locations in the brain (inferior temporal cortex, parietal and frontal cortex). In addition, they observed that grapheme-color synaesthetes with the strongest increased DTI signal in the inferior temporal cortex (adjacent to the fusiform gyrus) were "projectors" rather than "associator" synaesthetes.

In summary, the bulk of neuroimaging evidence indicates that at least in some synaesthetes, the experience of photisms resembles the perception of real colors, both on the subjective and the neurological levels. Yet, as more recent studies suggest (Rouw & Scholte, 2007; Rich et al., 2006; Hubbard et al., 2005), the implication of visual areas in synaesthesia is not equally strong across different individuals. Moreover, according to the aforementioned study by Rouw & Scholte (2007), white matter hyperconnectivity is present not only in inferior temporal visual areas but also in parietal and frontal cortices. More research would be needed to uncover the relationship between these structural abnormalities and the brain activation which leads to synaesthetic perception.

Origins of synaesthesia and current neurocognitive models

Before presenting the principal neurocognitive models, it is imperative to mention a series of data regarding the purported genetic background of synaesthesia. Despite the relative rarity of studies exploring the incidence and the heritability of synaesthesia, most researchers agree that idiopathic synaesthesia tends to run in families (e.g., Galton, 1880; Baron-Cohen et al., 1996; Rich et al., 2005). This fact alone points to a possible genetic cause of the synaesthetic condition. Earlier investigations about incidence of synaesthesia suggested an X-chromosome-linked dominant trait (Bailey & Johnson, 1997), with a possible increase in male mortality that would explain the higher frequency of this condition in females (Baron-Cohen et al., 1996; Rich et al., 2005; Ward & Simner, 2005). However, the latter proposition, based on the skewed female-to-male ratio, has been called into question by a recent study by Simner et al. (2006), who report an almost perfectly equal proportion of female-to-male synaesthetes (1.1:1). (In fact, Ward & Simner's study (2005) with 85 synaesthetic families did not find any evidence of the purported male mortality.) Yet, even if the absence of sex bias is confirmed, the higher incidence of synaesthesia among relatives provides a strong argument in favor of the genetic influence. The heritability of synaesthesia just might be more complex than previously thought. For instance, Smilek et al. (2002, 2005) have already reported two cases of monozygotic twins (two twin sisters and two twin brothers) who are discordant for synaesthesia[6]. These findings seriously question previous suggestions that synaesthesia is simply an X-linked dominant trait. If the genetic case for synaesthesia is correct, it means that the penetrance of the genotype for synaesthesia is probably incomplete (Smilek et al., 2005) and not sufficient by itself as a cause of the synaesthetic condition. (The discovery of male identical twins discordant for synaesthesia also contradicts a previous speculation in Smilek et al. (2002), based on a study of female monozygotic twins, that discordance of synaesthesia in identical twins is due to X-inactivation.)

In view of the evidence gathered thus far, the involvement of genetics in the development of synaesthesia still remains an open issue. First, what is the mechanism of genetic transmission of synaesthesia and, second, how does the hypothesized gene (or genes) affect the neuroanatomy, giving rise to this sensory alteration. In relation to the second question, there are at least three modern theories regarding the neuronal mechanism through which a normal sensory stimulation leads to the experience of photisms. Because of the relatively higher prevalence (and availability) of grapheme-chromatic synaesthetes, all three models presented here have been, in principle, suggested to take account for this modality of the phenomenon.

Synaesthesia and "crossed wires"

The core idea of all current neurocognitive models of synaesthesia is a postulation of some kind of anomalous communication in the brain. If specific cortical areas, whose connectivity is limited in a normal brain, established active connections, this could produce "phantom" sensations typical for synaesthesia (Baron-Cohen et al., 1993). The underlying mechanism might be similar to the one present in amputee patients. The reorganization of the cortex following amputation frequently gives rise to tactile sensations on a nonexistent limb (Ramachandran et al., 1992). This phenomenon inspired Ramachandran and Hubbard, leading them to develop a *local crossactivation* model that accounts for the emergence of photisms in lexical-chromatic synaesthetes (Ramachandran & Hubbard, 2001b, 2003b; Hubbard & Ramachandran, 2005). When studying grapheme-color synaesthesia, the authors realized that the color area (V4) and the visual area responsible for grapheme identification were located in the same brain region – the fusiform gyrus. If neurons from these areas started to communicate, the expected subjective output would be an experience of colors upon seeing graphemes[7]. The question is: why and how would these interconnections emerge between cortical areas that process completely different aspects of visual input?

In the course of cerebral maturation, the human brain goes through a phase of refinement in the formation of functional neural circuits, where a number of redundant and/or unnecessary pathways are eliminated through a process termed axonal pruning. If a genetic mutation caused a failure of pruning in specific cortical regions, these prenatal connections would persist in the adult brain, eventually leading to unusual sensory alterations, i.e. synaesthesia. For instance, in the case of grapheme-color synaesthesia the neuronal connections between the V4 and the grapheme area would be more numerous (less completely pruned) than in non-synaesthetes. The fact that these two brain areas are close to each other, increases the likelihood of reciprocal neuronal communication. In addition to the evidence demonstrating the implication of V4 in lexical-chromatic synaesthesia, the authors make reference to the discovery of the aforementioned connections in fetal monkeys. Kennedy et al. (1997) found neuronal pathways between inferior temporal regions and the V4 area in prenatal macaque brain. Thanks to the process of axonal pruning, in adult animals the proportion of neural afferences from higher areas to V4 is reduced radically. Ramachandran and Hubbard propose that in humans a genetic mutation could lead to defective axonal pruning in the fusiform gyrus and consequently to anomalous connectivity in the adult brain. Thus, synaesthetic photisms would be the result of the color area being activated through connections originating in the area responsible for grapheme processing.

It should be noted that there are alternative theoretical models that fall within the "cross-wiring scheme" as well. Rich and Mattingley (2002) proposed that in grapheme-color synaesthetes unique functional connections were present at later levels of the processing hierarchy; concretely between the module of letter recognition and the modules of color categorization and color imagery. Even though the lack of anatomical specificity makes this hypothesis difficult to test using neuroimaging techniques, recent data by Rich et al. (2006) give some support to the latter proposal. In their experimental series involving color imagery tasks as well as exposition to synaesthetic inducers, the authors observed that synaesthetic colors were associated with fMRI activity of the left medial lingual gyrus in grapheme-color synaesthetes. This area is known to be involved in tasks requiring the retrieval of color knowledge, such as naming the color of an object (e.g., Martin et al., 1995). On the other hand, no significant activity in the V4 area was registered during photism experiences. Apparently the results contradict earlier neuroimaging investigations (Hubbard et al., 2005; Nunn et al., 2002; Sperling et al., 2006) which emphasized the role of the V4/V8 area for the generation of synaesthetic colors. On the other hand, it is likely that inter-individual differences observed in synaesthetes on behavioral and phenomenological levels may also account for the differences in brain-behavior correlates (Hubbard et al., 2005). Indeed, it would have been interesting if Rich et al. (2006) had reported on whether their experimental subjects were projector or associator synaesthetes. It is possible that for the associators the cross-activation involves higher visual areas related to more abstract attributes of colors, while the projectors' synaesthetic experience relies on areas activated earlier during visual processing.

Disinhibition of top-down connections

Not all of the authors agree with the necessity of assuming anomalous neural pathways in synaesthesia. Grossenbacher and Lovelace (2001) affirm that to account for synaesthetic perception it is sufficient to consider the functioning of a (structurally) normal brain. As the authors correctly point out, synaesthetic experiences have been reported by otherwise non-synaesthetic individuals who were under the influence of hallucinogens. The processing of sensory input progresses through a series of hierarchically organized modules. After going through various processing stages along dedicated pathways, the signals progressively converge until reaching a multimodal area. According to the authors, in synaesthesia neural signals of the synaesthetic inducer (e.g., a sound) travel along a separate processing pathway before reaching a multimodal "crossroad" where they "meet" signals of other sensory modalities. However, in addition to these afferent (feedforward) connections, the human brain also presents connections where information can travel backwards in the "processing chain". Normally the feedback from the multimodal convergence zone is "restricted to the pathway in which afferent (feedforward) information has arisen" (Rich & Mattingley, 2002). For instance, top-down visual signals should only influence processing in the corresponding (lower-level) visual areas, while other directions of information flow are inhibited in order to avoid neuronal "noise" and processing anomalies. What Grossenbacher and Lovelace propose is that a failure of such inhibition could lead to the activation of an otherwise independent neural pathway, generating synaesthetic perception.[8] More specifically, when the signal of a synaesthetic inducer reaches the zone of multimodal convergence (after going through all of the unimodal processing modules), it can travel backwards along the pathway of the synaesthetic modality and arrive at the level where the concurrent percept is generated. (See Figure 7.) In summary, Grossenbacher's model defends the view that synaesthesia is the result of a disinhibited feedback originating in a multimodal cortical area such as the superior temporal sulcus. (The aforementioned structure shows connections with unimodal areas and, at the same time, it is responsive to specific perceptual features of several sensory modalities.)

The idea that synaesthesia occurs in a relatively late stage of sensory processing, has received some empiric support from event-related potentials research. The authors emphasize the fact that differences in brain activity in synaesthetes and non-synaesthetes are not observed until 200 milliseconds after the inducing stimulus onset (Schiltz et al., 1999). Moreover, synaesthetic perception is sometimes experienced during psychotropic "highs" in normal subjects (Ramachandran & Hubbard, 2001b; Cytowic, 1993) and it can also be induced by post-hypnotic suggestions in highly susceptible non-synaesthetes (Fuentes, Cohen-Kadosh & Catena, 2007). While it is true that these facts seem to show that the existence of anomalous anatomical connections is not a necessary condition for synaesthesia to occur,[9] it should also be pointed out that the recent study by Rouw & Scholte (2007) actually reports on increased white matter connectivity in grapheme-color synaesthetes, favoring the hyperconnectivity accounts of synaesthesia.

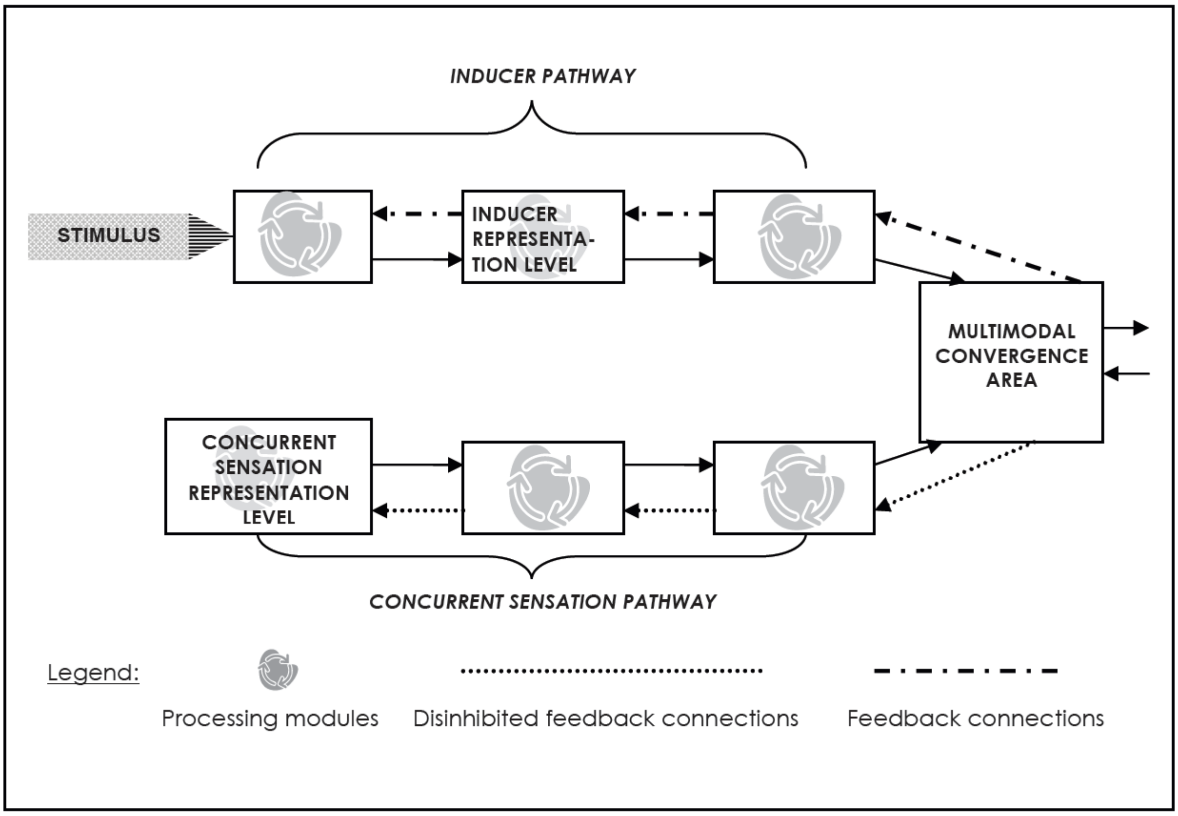


Figure 7: Scheme of Grossenbacher's & Lovelace's model. Adapted from Grossenbacher & Lovelace (2001).

Re-Entrant processing model

The re-entrant processing model (Myles et al., 2003; Smilek et al., 2001) is, in some ways, a hybrid scheme that combines certain aspects of the aforementioned proposals. The authors base their model on the fact that visual information flows both forwards (bottom-up) and backwards (top-down) along the visual processing pathways. When a lexical-color synaesthete observes an achromatic grapheme, the corresponding neural signals from the retina first arrive at lower visual areas.

Subsequently they are processed by a shape processing area (the posterior fusiform gyrus) before finally reaching the area in charge of the analysis of the meaning (the anterior fusiform gyrus). According to Smilek et al., the activation of photisms in "projector" synaesthetes is a result of cyclic feedback communication from the shape and the meaning processing areas to the color region V4. As an illustration, let's consider a case of red photism induced by an achromatic letter "B". When the curves and the lines making up the letter are being processed by the striate cortex and the posterior fusiform gyrus, simultaneously signals originating from these areas travel to the anterior fusiform gyrus, where the meaning of the grapheme is analyzed. In the beginning, before completion of the shape analysis, these signals are not sufficient to give way to conscious recognition of the letter. However, the authors propose that even a partial activation of the meaning can activate a red percept in the color area (V4). More specifically, prior to the conclusion of the form and the meaning analyses, the anterior region of the fusiform gyrus will communicate with the color area through top-down connections, activating the representation of the color red. At the same time, this activation of red in the V4 will strengthen the activation of the meaning of "B" in the anterior fusiform, through bottom-up connections. (See the scheme of the model depicted in Figure 8.)

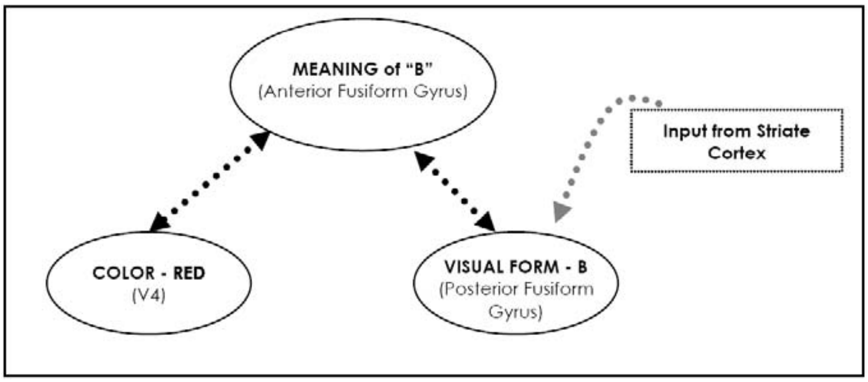


Figure 8: Schematic depiction of a photism activation mechanism, following the model by Smilek et al. (2001). The "meaning of B" denotes a more abstract representation of the letter that is independent of font or case.

In this way, the neural signals will travel in a cyclical manner until they give rise to a complete conscious perception of a red "B". This mechanism also accounts for the fact that the context affecting the interpretation of a grapheme (e.g., the O in 9O89 and SOUL), also determines the synaesthetic color of the stimulus (Dixon et al., 2006).

Given the fact that the top-down modulation is a general feature of human brain functioning, at the moment it is not possible to experimentally dissociate the processes proposed by the local crossactivation model (Hubbard & Ramachandran, 2005) and the re-entrant processing model. In order to account for the contextual effects in photisms, Ramachandran and Hubbard suggest that the same top-down mechanisms that are present in normal people, can explain the influence of semantic context on the photism color. Specifically, if the context is able to skew the perception of the grapheme shape by a top-down influence from higher regions to the grapheme area, it makes sense to assume that, in synaesthetes, the latter region will consequently alter the activation of synaesthetic colors in the V4. In principle, the re-entrant processing mechanism proposed by Smilek et al. would lead to the same behavioral output. In the future it will be necessary to reach a deeper level of specificity in both models, so that it will be possible to either corroborate or to refute the respective proposals. At the same time, as Hubbard and Ramachandran (2005) have pointed out, the two models may not be mutually exclusive. It is perfectly plausible that a combination of both mechanisms (the local crossactivation and the disinhibited feedback from the meaning analysis areas) is present in some synaesthetes. In addition, we should also consider the possibility that different ways of experiencing synaesthesia in "projector" and "associator" synaesthetes imply diverse neurocognitive mechanisms. In fact, the aforementioned study by Rouw & Shoulte (2007) demonstrates that "projectors" showed stronger structural connectivity in the inferior temporal cortex than "associators".

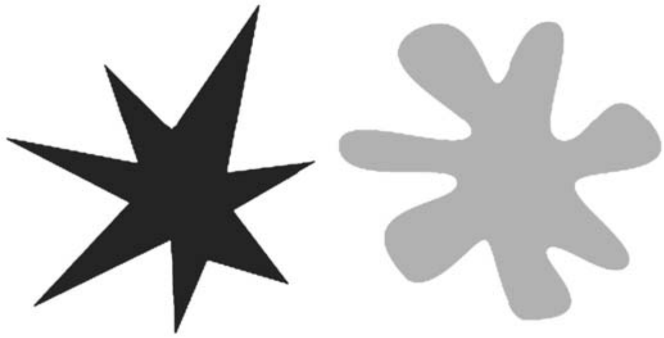
Final notes

Along this review of current scientific knowledge relating to the phenomenon termed synaesthesia, we have tried to analyze a few central points which have marked the development of synaesthesia research. First, we have seen that this peculiar condition is not the result of childhood memories and its origin is probably due to a genetic alteration. Second, we have observed that the synaesthetic sensations can lead to sensory effects where photisms can increase the efficiency with which graphemes can be detected in perceptual crowding tasks, visual search and perceptual grouping tasks. Third, we have analyzed behavioral and neuroimaging evidence, concluding that synaesthesia shares many aspects with normal perception on both behavioral and neurological levels. And finally, after revising the most influential neurocognitive models, we may conjecture that the root of synaesthesia is in some sort of anomalous communication between specific brain areas, which could be caused by abnormal "cross-wiring" in the sensory cortex, by top-down pathways disinhibition or both. What then are the limitations of our present knowledge and where is synaesthesia research heading? First of all, it is worth saying that the stage of verifying the reality of synaesthesia seems to be finally over. In our opinion, the scientists involved in the study of synaesthesia successfully demonstrated beyond any reasonable doubt that synaesthesia is authentic and that the subjective reports of synaesthetes are to be taken seriously. Even so, the investigation into the neurophysiological background of this condition is still in its beginnings. In order to make further progress in our understanding of synaesthesia, it will be necessary to expand the limits of existing research in several directions.

To begin with, it should be pointed out that a greater part of the hypotheses and models are built upon the basis of data proceeding from studies with lexical synaesthetes (Grossenbacher & Lovelace, 2001; Hubbard & Ramachandran, 2005). Even though this is understandable given the relatively high frequency of this subtype of synaesthesia, it would be imperative to broaden current experimental paradigms with the aim of exploring to what degree other varieties of this condition are similar to the lexical-chromatic synaesthesia on behavioral as well as neurological levels.

Furthermore, as we emphasized before in this text, it is vital to take into account individual discrepancies in the intensity and the phenomenological quality of the synaesthetic experience. If the theoretical division of synaesthetes into "lower/higher" and "projector/associator" subtypes is further confirmed, it will have important implications for the experimental designs, the interpretation of the data and, possibly, for the refinement of the neurocognitive models.

Figure 9: Who is Kiki and who is Bouba? These figures demonstrate that the humans do not associated shapes to images in an arbitrarily. Almost 100% of the interviewed subjects related "kiki" sound with the left figure and the "bouba" sound with the right figure. (Köhler, 1929)



On the other hand, the term synaesthesia has been applied to a broad range of phenomena: idiopathic synaesthesia, drug induced anomalous perception, artistic expositions involving the coupling of sound and light, etc. Perhaps the imprecision with which the word synaesthesia is used actually reflects certain aspects of the truth. It is not an accident that various authors defend that synaesthesia research can bring new insights into our understanding of the neurological bases of metaphor and language (Marks, 1978; Cytowic, 2002; Ramachandran & Hubbard, 2001b, Maurer, 2006). Subjective reports reveal striking parallels between the synaesthesia and cross-modal associations reported by non-synaesthetes. For instance, Ward et al. (2006) demonstrated that the associations of sounds to colors in synaesthesia showed the same pattern of correspondence between luminosity and tone pitch as in cross-modal associations of normal persons. Ramachandran and Hubbard (2003b) note that people frequently tend to form the same synaesthetic associations; e.g. in the case of associating particular visual shapes to sounds (Köhler, 1929). (See Figure 9.) The authors believe that specific regions of the human brain have an innate capacity to extract common, abstract properties from otherwise unrelated domains (Ramachandran & Hubbard, 2005), such as the concept of “jaggedness” present in both the “kiki” sound and the shape depicted in Figure 9 on the left. If an elementary aptitude for cross-modal abstraction was in fact hard-wired in our nervous systems, the synaesthetic phenomenon could be understood as a more enhanced (and “more perceptual”) version of this natural property of the human mind. In any case, hypotheses concerning the relationship between synaesthesia and the cross-modal language and metaphor still remain on highly speculative grounds. Does the similarity of these phenomena to the congenital synaesthesia extend beyond superficial aspects? In theory, synaesthesia, in a broader sense, could encompass a great variety of conditions ranging from “lower” synaesthesia to more “associative” synaesthesias, to conceptually triggered synaesthesias, to emotional synaesthesias, eventually up to the level of multimodal artistic expression and, possibly, cross-modal metaphor. Future research should respond to the question of where the frontiers lie between these phenomena as well as to whether we are dealing with qualitatively different conditions or if it is only a matter of degree. Part of the answer may arise from the neuroanatomical research which should elucidate whether the synaesthetes (and what types of synaesthetes) really present unusual neuronal connectivity or, on the opposite side, whether the “phantoms” in their brains show up due to the disinhibition of normal cerebral machinery.

As a final point of reflection, we believe it is worth mentioning the importance of synaesthesia for the progress of our understanding of subjective experience. The synaesthetic phenomenon constitutes a peculiar puzzle for cognitive science for one simple reason – it is a phenomenological experience which has a very low occurrence. Unlike disorders caused by brain injuries, it is a heritable and highly stable, life-long “condition”. Moreover, synaesthesia is unlike schizophrenia (which is as likely as heritable as synaesthesia) in that it is not bothersome to the person who experiences it; it occurs in otherwise normal individuals. What attracts the attention of both the general public and the experts is the fact that the synaesthetes claim to see things that “normal” people cannot perceive. If, upon waiting for a pedestrian crossing you declare “observing a red light on a semaphore”, there will be no cognitive scientist running to subject you to a Stroop task in order to corroborate that you really see what you claim to see. Oddly enough, from the synaesthetes’ point of view the beginning of synaesthesia research was identical to the aforementioned situation. Numerous professionals tried to answer questions like: is it true what you state and do you actually perceive an achromatic “B” in red? In other words, cognitive science invested time and efforts in confirming the genuineness of subjective experience, achieving the same data which the synaesthetes had already provided through their own words. If we were to completely believe synaesthetes’ verbal reports, then apparently science has done much work in vain. However, in our opinion, this effort in addition to empirically demonstrating the veracity of the introspection comprises a lesson for psychology in relation to the scientific understanding of subjective experience. Possibly for the first time empiric research has had to cope directly with the matter of qualia, trying to answer a question analogous to the renowned riddle proposed by Nagel (1974): “What is it like to be a bat?” (What is it like to be a synaesthete?) The development of our understanding of synaesthesia, accompanied by significant improvements in methodology, also amounts to an important advancement in the study of the “first person experience” per se. In order to make further progress in this direction, it will be essential to combine behavioral and neurological evidence with subjective reports (Smilek & Dixon, 2002) and to convert the first-person viewpoint into an integral part of neuropsychological research.

Endnotes:

1. Typically synaesthetes claim they have been synaesthetic from as early as they can remember. No cases of spontaneous remission of synaesthesia have been reported so far even though synaesthetic capacity can sometimes be lost as a consequence of cerebral trauma. (See Spalding & Zangwill, 1950; and Sacks, Waserman, Zeki & Siegel, 1988.)

2. It must be noted that even in this study (Simner et al., 2006), testing of certain subtypes of synaesthesia was excluded for ethical and/or technical reasons; namely the variants triggered by, or inducing, pain and emotional states.

3. For instance, when hearing phonemes leads to the perception of photisms, we are dealing with a cognitive intermodal subtype of synaesthesia.

4. It is not clear if this classification reflects a dichotomic dimension which corresponds to qualitative differences between the synaesthetes, or if there is a continuum with cases laying “halfway” between the “lower” and the “higher” synaesthesia.

5. Ward et al. (in press) suggest that the projector-associator dichotomy needs to be further subdivided, in order to include all types of frames of reference reported by synaesthetes. See the original paper for a full account on this topic.

6. It must be noted that in both studies the authors did not check for (or do not report on) the presence of subtypes of synaesthesia other than the grapheme-color variety.

7. In theory, the opposite result is also conceivable; i.e. the subject could experience graphemes in response to colors. See the discussion by Hubbard & Ramachandran (2005), where they argue why such a possibility is much less plausible.

8. Similar mechanism was proposed earlier by Armel & Ramachandran (1999) to explain acquired synaesthesia, observed in a patient who became blind as a consequence of suffering retinitis pigmentosa.

9. Nonetheless, Ramachandran & Hubbard (2005) argue that the phenomenon of congenital synaesthesia can differ from the drug-induced experiences. Superficial similarity of the phenomena should not be straightforwardly interpreted in terms of identical neuronal mechanisms.

References

Aleman, A., Rutten, G-J.M., Sitskoorn, M.M., Dautzenberg, G. & Ramsey, N.F. (2001). Activation of striate cortex in the absence of visual stimulation: an fMRI study of synesthesia. *NeuroReport, 12*, 2827-30.

Armel, K.C. & Ramachandran, V.S. (1999). Acquired synesthesia in retinitis pigmentosa. *Neurocase, 5*, 293-296.

Bailey, M.E.S., Johnson, K.J. (1997). Synaesthesia: Is a genetic analysis feasible? In S. Baron-Cohen & J.E. Harrison (Eds.), *Synaesthesia: Classic and Contemporary Readings.* Oxford: Blackwell.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: Prevalence and familiality. *Perception, 25*, 1073-1079.

Baron-Cohen, S., Harrison, J., Goldstein, L.H., & Wyke, M. (1993). Coloured speech perception: Is synaesthesia what happens when modularity breaks down? *Perception, 22*(4), 419–26.

Baron-Cohen, S., Wyke, M.A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception, 16,* 761-767.

Beck, J. (1966). Effect of orientation and shape similarity on perceptual grouping. *Percept. Psychophys., 1*, 300-302.

Blake, R., Palmeri, T. J., Marois, R., & Chai-Youn, K. (2005). On the Perceptual Reality of Synesthetic Color. In L. C. Robertson & N. Sagiv (Eds.), *Synesthesia: Perspectives from Cognitive Neuroscience* (pp. 47-73). New York: Oxford University Press.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature, 226*, 177–178.

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses.* New York: Springer.

Cytowic, R.E. (1993). *The man who tasted shapes.* New York: Putnam.

Cytowic, R. E. (1996). Synesthesia: Phenomenology and neuropsychology. *Psyche, 2*(10). http://psyche.cs.monash.edu.au/v2/psyche-2-10-cytowic.html

Cytowic, R. E. (2002). Touching tastes, seeing smells—and shaking up brain science. *Cerebrum, 4*(3), 7–26.

Cytowic, R. E. (2003). Synesthesia: Anomalous binding of qualia and categories. In G. Adelman & B. H. Smith (Eds.), *Encyclopedia of Neuroscience (3rd Edition)*. New York: Elsevier.

Cytowic, R.E. & Wood, F.B. (1982). Synesthesia I: A review of theories and their brain basis. *Brain and Cognition, 1*, 23-35.

Dailey, A., Martindale, C., & Borkum, J. (1997). Creativity, synaesthesia and physiognomic perception. *Creativity Research Journal, 10* (1), 1–8.

Dann, K. T. (1998). *Bright Colors Falsely Seen: Synaesthesia and the Search for Transcendental Knowledge*. New Haven and London: Yale University Press.

Day, S. (2005). Some Demographic and Socio-cultural Aspects of Synesthesia. In Robertson, L.C. & Sagiv, N. (Eds.), *SYNESTHESIA: Perspectives from Cognitive Neuroscience* (pp. 11-33). Oxford University Press, New York.

Day, S. (2007). Types of synaesthesia. Retrieved January 20, 2007 from http://home.comcast.net/%7Esean.day/Types.htm

Dixon, M. J., & Smilek, D. (2005). The importance of individual differences in grapheme-color synesthesia. *Neuron, 45*, 821–823.

Dixon, M.J., Smilek, D., Cudahy, C. & Merikle, P.M. (2000). Five plus two equals yellow. *Nature, 406* (6794), p. 365.

Dixon, M.J., Smilek, D., Duffy, P.L., Zanna, M.P. & Merikle, P.M. (2006). The role of meaning in grapheme-colour synaesthesia. *Cortex, 42*, 243-252.

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4*(3), 335-343.

Domino, G. (1989). Synaesthesia and creativity in fine arts students: An empirical look. *Creativity Research Journal, 2*(1–2), 17–29.

Edquist, J., Rich, A.N., Brinkman, C., & Mattingley, J.B. (2005). Do synaesthetic colours act as unique features in visual search? *Cortex, 42*, 222-31.

Galton, F. (1880/1997). Colour associations. In S. Baron-Cohen & J. E. Harrison (Eds.), *Synesthesia: Classic and contemporary readings* (pp. 43-48). Oxford: Blackwell.

Grossenbacher, P.G., & Lovelace, C.T. (2001). Mechanisms of synesthesia: cognitive and physiological constraints. *Trends In Cognitive Science, 5,* 36–41.

Howells, T. H. (1944). The experimental development of color–tone synesthesia. *Journal of Experimental Psychology, 34*, 87–103.
Hubbard, E.M. & Ramachandran, V.S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron, Vol. 48*, 509–520.
Hubbard, E.M., Arman, A.C., Ramachandran, V.S., & Boynton, G.M. (2005). Individual differences among grapheme-color synaesthetes: brain-behavior correlations. *Neuron, 45*, 975–985.
Fuentes, L., Cohen-Kadosh, R., & Catena, A. (2007). *Synesthesia experience under post-hypnotic suggestion: Evidence in favour of the deshinibition hypothesis*. Paper presented at the Synaesthesia, Science & Art: Second International Congress, Granada (Spain).
Kelly, E. L. (1934). An experimental attempt to produce artificial chromaesthesia by the technique of the conditioned response. *Journal of Experimental Psychology, 17*, 315–341.
Kennedy, H., Batardiere, A., Dehay, C., and Barone, P. (1997). Synaesthesia: implications for developmental neurobiology. In Synaesthesia: Classic and Contemporary Readings, S. Baron-Cohen & J.E. Harrison (Eds.), pp. 243–256. Malden, MA: Blackwell Publishers, Inc.
Kooi, F.L., Toet, A., Tripathy, S.P., and Levi, D.M. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spat. Vis., 8*, 255–279.
Köhler, W. (1929). *Gestalt Psychology,* New York: Liveright.
Krohn, W. O. (1892). Pseudo-chromaesthesia, or The Association of Color with Words, Letters, and Sounds. *American Journal of Psychology, 5*, 20-41.
Luria, AR. (1968). *The Mind of a Mnemonist.* New York: Basic Books.
MacLeod, C. M., & Dunbar K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 14,* 126-135.
Marks, L.E. (1978). *The Unity of The Senses: Interrelations Among the Modalities.* New York: Academic Press.
Marks, L.E. & Odgaard, E.C. (2005). Developmental Constraints on Theories of Synesthesia. In Robertson, L.C. & Sagiv, N. (Eds.), *SYNESTHESIA: Perspectives from Cognitive Neuroscience* (pp. 214-236). Oxford University Press, New York.
Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science, 270*, 102–105.
Mattingley, J.B., Rich, A.N., Yelland, G. and Bradshaw, J.L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. *Nature, 410,* 580–2.
Mattingley, J.B., Payne, J.M., & Rich, A.N. (2006). Attentional load attenuates synaesthetic priming effects in grapheme-colour synaesthesia. *Cortex, 42*, 213-221.
Maurer, D., Pathman, T. & Mondloch, C.J. (2006). The shape of boubas: sound–shape correspondences in toddlers and adults. *Developmental Science, 9*(3), 316-22.
Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., Mata Martín, J. L., Rodríguez Artacho, MA., Domínguez García, E. & Vila, J. (2007) Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies*. *14*(4), 75-95.
Mills, C.B., Boteler, E.H., & Oliver, G.K. (1999). Digit synaesthesia: An ease using a Strooplike test. *Cognitive Neuropsychology, 16,* 181-191.
Myles, K.M., Dixon, M.J., Smilek, D., & Merikle, P.M. (2003). Seeing double: the role of meaning in alphanumeric-colour synaesthesia. *Brain Cogn., 53*, 342–345.
Nagel, Th. (1974). What is it like to be a bat? *Philosophical Review, 83*, 435-50.
Nunn, J.A., Gregory, L.J., Brammer, M., Wiliams, S.C.R., Parslow, D.M., Morgan, M.J., Morris, R.G., Bullmore, E.T., Baron-Cohen, S., & Gray, J.A. (2002). Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. *Nature Neuroscience, 5*(4), 371-75.
Palmeri, T.J., Blake, R., Marois, R., Flanery, M.A., & Whetsell, Jr. W. (2002). The perceptual reality of synesthetic colors. *Proceedings of the National Academy of Science, 99,* 4127-4131.

Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J.D.G., Goldstein, L., Heather, J., Frackowiak, R.S.J. & Frith, C.D. (1995). The physiology of coloured hearing: A PET activation study of colour word synaesthesia, *Brain, 118*, 661-676.

Ramachandran, V. S., & Azoulai, S. (2006). Synesthetically induced colors evoke apparent motion. *Perception, 35*(11), 1557-1560.

Ramachandran, V.S. & Hubbard, E.M. (2001a). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London, B, 268*, 979–83.

Ramachandran, V.S. & Hubbard, E.M. (2001b). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.

Ramachandran, V.S. & Hubbard, E.M. (2002). Synesthetic colors support symmetry perception, apparent motion and ambiguous crowding. *Abstracts of the Psychonomic Society, 7,* 79.

Ramachandran, V.S. & Hubbard, E.M. (2003a). The Phenomenology of Synaesthesia. *Journal of Consciousness Studies, 10*(8), 49-57.

Ramachandran, V. & Hubbard, E.M. (2003b). Hearing Colors, Tasting Shapes. *Scientific American, 288*(5), 52-59.

Ramachandran, V. S., & Hubbard, E. M. (2005). The emergence of the human mind: Some clues from synesthesia. In L. C. Robertson & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 147-190). New York: Oxford University Press.

Ramachandran, V.S., Rogers-Ramachandran, D., & Stewart, M. (1992). Perceptual correlates of massive cortical reorganization. *Science, 258*, 1159–1160.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2005). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition, 98*(1), 53-84.

Rich, A. N., Williams, M. A., Puce, A., Syngeniotis, A., Howard, M. A., McGlone, F., et al. (2006). Neural correlates of imagined and synaesthetic colours. *Neuropsychologia, 44*(14), 2918-2925.

Rich, A.N. & Mattingley, J.B. (2002). Anomalous perception in synaesthesia: A cognitive neuroscience perspective. *Nature Reviews Neuroscience, 3*, 43-52.

Rouw, R. & Scholte, S. (2007). Increased structural connectivity in grapheme-color synesthesia. *Nature Neuroscience, 10*(6), 792-797.

Sacks, 0., Wasserman, R.L., Zeki, S., & Siegel, R.M. (1988). Sudden color blindness of cerebral origin. *Society for Neuroscience Abstracts, 14,* 1251.

Schiltz, K., Trocha, K., Wieringa, B.M., Emrich, H.M., Johannes, S & Münte, T.F. (1999). Neurophysiological aspects of synesthetic experience. *J. Neuropsychiatr. Clin. Neurosci., 11*, 58–65.

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., et al. (2006). Synaesthesia: the prevalence of atypical cross-modal experiences. *Perception, 35*(8), 1024-1033.

Sitton, S. C., & Pierce, E. R. (2004). Synesthesia, creativity and puns. *Psychological reports, 95*(2), 577-580.

Smilek D., Moffatt B.A., Pasternak J., White B.N., Dixon M.J., Merikle P.M. (2002). Synaesthesia: A case study of discordant monozygotic twins. *Neurocase, 8*, 338 – 342.

Smilek, D. & Dixon, M.J. (2002). Towards a Synergetic Understanding of Synaesthesia: Combining Current Experimental Findings Withs Synaesthetes' Subjective Description. *PSYCHE, 8* (1). http://psyche.cs.monash.edu.au/v8/psyche-9-01-smilek.html

Smilek, D., Dixon, M. J., & Merikle, P. M. (2005). Synaesthesia: Discordant male monozygotic twins. *Neurocase, 11*(5), 363 - 370.

Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2001). Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience, 13,* 930-936.

Spalding, J.M.K., & Zangwill, O. (1950). Disturbance of number-form in a case of brain injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 12,* 24-29.

Sperling, J.M., Prvulovic, D., Linden, D.E.J., Singer, W. & Stirn, A.(2006). Neuronal Correlates of color-graphemic synaesthesia: a fMRI study. *Cortex, 42*, 295-303.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Treisman, A.M. & Gelade, G.A. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Walker, P., & Smith, S. (1984). Stroop interference based on the synaesthetic qualities of auditory pitch. *Perception, 13,* 75-81.
Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.
Ward, J., Huckstep, B. & Tsakanikos, E. (2006). Sound-colour synaesthesia: to what extent does it use cross-modal mechanisms common to us all? *Cortex, 42*, 264-80.
Ward, J., Li, R., Salih, S. & Sagiv, N. (in press). Varieties of grapheme-colour synaesthesia: A new theory of phenomenological and behavioral differences. *Consciousness and Cognition*.
Ward, J., & Simner, J. (2003). Lexical-gustatory synaesthesia: Linguistic and conceptual factors. *Cognition, 89*, 237–261.
Ward, J. & Simner, J. (2005). Is synaesthesia an X-linked dominant trait with lethality in males? *Perception, 34*(5), 611-23.
Weiss, P.H., Shah, N.J., Toni, I., Zilles, K. & Fink, G.R. (2001). Associating colours with people: A case of chromatic-lexical synaesthesia. *Cortex, 37*, 750-53.
Wheeler, R. H. (1920). The synaesthesia of a blind subject. *University of Oregon Publications, 5*, 1-61.
Witthoft, N. & Winawer, J. (2006) Synesthetic colors determined by having colored refrigerator magnets in childhood. *Cortex, 42*, 175-183.
Wollen, K. A., & Ruggiero, F. T. (1983). Coloured-letter synaesthesia. *Journal of Mental Imagery, 7,* 83-86.

Part II

Synaesthesia and Emotion

Chapter 2

Experimental Study of Phantom Colors in a Color Blind Synaesthete

***** *Published paper (Journal of Consciousness Studies)*

Abstract

Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound produces *photisms*, i.e. mental percepts of colors. R is a 20 year old color blind subject who, in addition to the relatively common grapheme-color synaesthesia, presents a rarely reported cross modal perception in which a variety of visual stimuli elicit aura-like percepts of color. In R, photisms seem to be closely related to the affective valence of stimuli and typically bring out a consistent pattern of emotional responses. The present case study suggests that colors might be an intrinsic category of the human brain. We developed an empirical methodology that allowed us to study the subject's otherwise inaccessible phenomenological experience. First, we found that R shows a Stroop effect (delayed response due to interference) elicited by photisms despite the fact that he does not show a regular Stroop with real colors. Secondly, by manipulating the color context we confirmed that colors can alter R's emotional evaluation of the stimuli. Furthermore, we demonstrated that R's auras may actually lead to a partially inverted emotional spectrum where certain stimuli bring out emotional reactions opposite to the normal ones. These findings can only be accounted for by considering R's subjective color experience or qualia. Therefore the present paper defends the view that qualia are a useful scientific concept that can be approached and studied by experimental methods.

Introduction

R is a 20 year old male who belongs to the rare group of people who have synaesthetic perception. Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound produces *photisms*, i.e. mental percepts of colors. In addition to the relatively common grapheme-color synaesthesia, R presents a variety of synaesthetic associations. Not only numbers and letters but also first names, surnames, persons, town and city names, abstract concepts, natural sounds and music elicit percepts of color in his mind's eye. For example, the town of Granada is "red", hope is "white", intelligence is "yellow", classical music is "dark brown" while electronic music is "purple" and symphonic compositions are "red", both pain and joy are "yellow", love is "red", etc.[1]

Surprisingly, R also suffers from a mild form of color blindness (dichromatic daltonism), thus having difficulty in discriminating between certain shades of red, brown and green. The frequency of color blindness in the general population is 1 to 8%. Even though the proportion of synaesthetes used to be underestimated in the past (e.g., 1 in 20 000; Cytowic, 1989), according to more recent studies, the prevalence numbers are likely to lie somewhere between 1 in 200 (Ramachandran & Hubbard, 2001b) and 1 in 2,000 (Baron-Cohen et al., 1996). Despite the fact that both color blindness and synaesthesia are relatively rare, the combination of the two could actually be more frequent than predicted by chance alone. (For instance, Ramachandran & Hubbard [2001a; 2001b] also report a case of color-weakness and synaesthesia.) If, as hypothesized elsewhere, synaesthesia is linked to the X-chromosome (Bailey & Johnson, 1997), then both conditions might not be independent and we could actually expect synaesthesia to be relatively common among the color-blind.

Seemingly, the sensation of color is a quale (Chalmers, 1996), which in R's case has very distinctive characteristics. The word quale refers to our subjective, introspectively accessible experience, showing aspects that cannot be found in the world external to our minds (Jackson 1982; Searle, 1992; Chalmers, 1996). The question is whether these mental phenomena (qualia) can or cannot be studied within the framework of empirical science. Is it possible to make science of subjective experience and establish correlations between the quale and external objects? Can we explore "what it is like to experience something?" Nagel (1974) believes that there are certain qualities that exist only within one particular point of view, defining an experience for one particular experiencer. Therefore Nagel asks: "What is it like to be a bat?" Although bats cannot tell us about their inner life, R **can** speak, allowing us to access his mental states through introspection. Some authors believe that introspection is not reliable at all. Daniel C. Dennett (1988) tries to demonstrate this by means of thought experiment that involves two coffee experts discussing the flavor of a coffee brand. One of them says that the taste of the coffee is not the same as it used to be (alteration of qualia) but he still likes it. The other thinks that the coffee is the same (qualia has not changed) but he does not like it anymore. According to Dennett there is no way to judge who is right and who is wrong. However, our approach to introspection was a different one. We started the research with a "naïve" attitude of trusting R's verbal reports to see how far we could go looking for behavioral evidence that would support R's subjective descriptions. The goal was not to simply demonstrate R's daltonic-synaesthetic condition, but to combine subjective first-person point of view with empirical evidence in order to find out whether the concept of qualia could be useful in scientific psychology, similar to the way the "magical" notion of power is useful in Newtonian physics to describe empirical phenomena.

Usually thought experiments such as Nagel's Bat or Dennett's Coffee Masters belong to a kind of parallel universe, apart from the realms of empirical science. In our study we try to merge both points of view seeking scientific answers to the enigma of qualia: "What is it like to be R?" The present paper is focused on an aspect of R's synaesthesia that we termed *aura*. Traditionally *aura* is an esoteric concept that refers to a supposed psychic energy field surrounding the bodies of all creatures, being associated with physical and psychological health. We have decided to use this term in relation to R's synaesthesia because of the superficial similarity to his *photisms*. However, we would like to emphasize that R is not an enthusiast of esoteric wisdom and personally prefers to describe his experience in different terms.

When R meets a person, he usually perceives a translucent spot of color in his mind's eye. This aura-like experience is best described as mental imagery and is never projected externally onto the person being perceived. Following Dixon et al. (2004), R could be categorized as an "associator" synaesthete in contrast with "projector synaesthetes" who perceive their photisms as located "out there".

R claims that this experience is highly consistent over time and cannot be suppressed by will. Even though aura-like photisms do not seem to be a frequent variety of synaesthesia, a small number of similar cases have been reported in the literature (Cytowic, 1989; Ward, 2004). Besides humans activating photisms, R also claims that images or scenes that are either emotionally or esthetically exciting also lead to synaesthetic responses even when no humans are present. Pleasing pictures are typically red while repulsive scenarios elicit a pale green color in his mind's eye. According to R, people's *auras* present a specific pattern: attractive people tend to be red; people that look dirty or sick are green; those who give an impression of optimism and happiness are purple while aggressive and envious people are yellow; old people and people that are uninteresting to R are brown. There are no blue or white people. R often uses his aura photisms to make intuitive judgments about anyone he meets[2], although, as he mentioned during the interview, not all the people necessarily trigger synaesthetic perception.

In summary, R's most distinctive photisms can be categorized in line with their emotional valence: positive emotions seem to be associated with red or purple auras; green indicates something usually repulsive; brown is neutral and yellow shows certain ambivalence, with both joy and aggressiveness associated. As you will see later on, colors can vary in tone and luminosity depending on the triggering stimuli but they always follow the aforementioned pattern.

Our ambition in studying R's color experience can be summarized in the following questions: How does R see "real" colors? (Experiment 1) What is the subjective importance of colors to R? (Experiment 2) Is there any relationship between photisms and real-world objects? (Experiments 2 and 3) What are the main attributes of R's "mental colors"? (Experiment 3) How do they influence R's emotional responses? (Experiments 4 and 5) Can we provide behavioral evidence of R's auras? (Experiment 6) In brief, does R really see the world in a different way? If so, what is it like?

Assessment of R's color identification skills and Color Stroop in R (Experiment 1)

In a pilot study we provided R with 100 randomly selected color samples (out of a color palette consisting of more than 500 hues) and asked him to identify the colors presented. Color patches were presented on a computer screen, using RGB codes to generate appropriate hues. We would like to emphasize that we only asked R to roughly classify the shades in general color categories such as green, red, blue, etc. For example, we considered an answer as "correct" when a "dark olive green" (RGB value: 85;107;47) hue was identified as green or a "firebrick red" (RGB: 178;34;34) was identified as red. Concerning R's typical color identification errors, he usually places variations of orange into green and brown categories. Colors such as "lemon chiffon 2" (238;233;191) and similar colors are "pale green". Hues such as "dark orange 4" (RGB: 139;69;0), "carrot" (237;145;33) and "melon" (227;168;105) are all "lettuce green"; "chocolate" (210;105;30) is also green; and "dark-sea green" (143;188;143) is dark brown. R also confuses variations of grey: "grey 10" (26;26;26) is seen as dark brown, "grey 20" (51;51;51) as burgundy red, "grey 40" (102;102;102) as pale brown, "grey 80" (204;204;204) as green and, finally, "grey 70" (179;179;179) as grey. "Salmon" (198;113;113) and "teal" (56;142;142) are both called "bottle green". "Indian red" (245;204;176) is seen as brown, while "red" (255;0;0) and "red 2" (238;0;0) are identified correctly as red. R does not show major problems with blue hues. However, only specific shades of green, e.g. "cobalt green" (61, 145, 64), are correctly identified.

Additionally, we were interested in testing R for Stroop effect (Stroop, 1935). To do this we used traditional color naming design by presenting words "red", "green" and "blue" on a computer in the center of the screen for 2000 ms or until a response was emitted. The words could be written in a red, green or blue font color. R's task was to identify the color (not the name written) by striking the corresponding key on a keyboard: B for red, N for green and M for blue. The keys were covered with a patch of corresponding color to facilitate the response. In a person with normal color vision you expect longer RT for incongruent trials (e.g. "red" written in the color green) because of the influence of reading automatism that interferes with color identification. However, R has red-green discrimination problems because of his daltonic condition.[3] The experiment design consisted of 10 series of 21 trials, presented on a computer screen using MEL software (Schneider, 1988). The instructions put emphasis on precision over speed.

Surprisingly, we did not find significant Stroop effect ($t=-0.33$, $p<0.79$). Mean RT was 660 ms for congruent trials and 677 ms for incongruent trials. Stroop effect was not found for accuracy data ($t=-0.76$, $p<0.52$). R reached a 13% error for congruent trials and 14% for incongruent trials. Ten control participants (non-synaesthetes with normal color vision) presented significant Stroop effect in RT, $F(1, 9)=10.13$, $p<0.011$. Mean RTs were 538 ms and 635 ms for congruent and incongruent trials respectively. Accuracy reached a 2 % error for congruent trials and a 4.5 % error for incongruent trials. Summarizing experiment 1, R does not show significant Stroop effect and his color identification skills are far from perfect.

Consistency of aura photisms. Is R's red truly red? (Experiments 2 and 3)

Because R's auras seemed to be strongly associated with emotions, we used the International Affective Picture System (IAPS) (Lang et al., 1999) to select appropriate stimuli for bringing out R's synaesthetic response. The current version of the IAPS consists of 832 color images, available in digital format, belonging to various semantic categories: portraits, nudes and erotica, animals, household objects, dead and mutilated bodies, sport and fitness, etc. In order to evaluate the consistency or the photisms, R went through sets 1 through 8, 13 and 14 of the IAPS (approximately 500 images altogether) naming a color of an aura photism for each picture. His responses were 98% consistent over time when he did a re-test 30 days later. The inconsistencies observed (only 2%) were related to "pale brown" and "white" photisms and "green" and "yellow" photisms. However, R reports that this happens occasionally when an image triggers more than one synaesthetic color. For example, the image of an old man with a long white beard (IASP # 0072) is both pale brown and white; the image showing a drug addict taking a shot (IASP # 0197) is "green" and "yellow"; the photography of a black kid (IASP # 0113) is at the same time red and purple; the image of an elderly man smiling while hugging two youngsters (IASP # 0133) is brown with some areas that are yellow. In these cases R's response depends on which part of the image is attended and/or what elements of the scene are more dominant. Finally, it must be said that not all the images elicit synaesthetic response (e.g., an image of a cow, # 0020; a closeup of violet flowers, # 0042; an image of mushrooms, # 0048; an image of a fighter plane # 0056; a still life with fruits and food, # 0167).

Before proceeding with our exploration of R's subjective experience, we considered it necessary to obtain a thorough classification of R's photisms. During our experimental sessions with R and other synaesthetes we have often encountered a problem related to the subjectivity of color perception (remember that because of his color blindness R had difficulties with discrimination of certain shades of green, brown and red). It is known that even people with normal color vision can present subtle differences in color matching which can be accounted for by genetic differences at the level of the photoreceptors (Winderickx *et al.*, 1992a; Winderickx *et al.*, 1992b). Therefore, how could we possibly know which color R was "seeing" when he reported an orange photism? If you try to imagine a default "orange", it is very probable that your "orange" is not the same shade as the one that another person sees in his/her mind's eye (It is even possible that somebody might call "red" or "brown" what you would still consider as "orange").

To eliminate the problem of subjective color perception, we designed a special computer program developed in the C# language, using the Microsoft Visual Studio 2005 framework, that would display a synaesthetic stimulus (i.e., a photograph) on the left side of the screen and a palette of color shades on the other side. Samples of color were vertically arranged rectangles; both the picture and the color samples were presented on a black background. There was a scroll button next to the color samples that allowed the subject to scroll up and down to see all the shades of a given color.

When designing the program, our primary concern was how to get the appropriate color shades, i.e. what color palette to use. Today's computer screens can display up to 16 million color shades and obviously we did not want R to go through this amount of samples. We decided to use MIT's Xconsortum RGB color specifications (Walsh, 2005) that had the advantage of being roughly classified into color categories (shades of Black and Grey, Blue, Brown, Grey, Green, Orange, Red, Violet, White and Yellow), while offering a large variety of options for each color shade. We generated specific color shades using standard hexadecimal encoding. To ensure constancy of color perception we used the same monitor (LCD Acer AL1714, 17", color temperature settings on neutral) during all experimental sessions, as well as maintained constant illumination conditions (fluorescent light).

Information gathered from R during interview sessions allowed us to reduce the number of color shades presented for each stimulus, using shades of the color that R reported as his synaesthetic response (e.g., shades of red for photographs with erotic content). This was a starting point to determine specific colors of R's photisms.

R's task was to observe a stimulus on the left side of the screen and then to choose a color sample that was closest to his synaesthetic experience. When clicking on a color sample on the right, a rectangle of the same color appeared a few inches below the stimulus, allowing the subject to see the shade better and reducing possible interference of color contrasts to a minimum. Once R found a color corresponding to his synaesthesia, he clicked on a "next" button, located at the bottom right of the screen, to proceed to the following item. His responses were recorded in a data file, including color name and its hexadecimal encoding.

Following this procedure, R went through a series of pictures selected out of the sets 1 through 8, 13 and 14 of the IAPS (we used images that R had previously marked as the most intense in terms of photism vividness.) In Table 1 you can see the correspondence between aura color categories and specific color shades as chosen by R. Table 2 offers verbal descriptions of the IAPS images that we used, classified by their corresponding aura color shade. This image-color relation was reliable and consistent over time (2 repetitions). In a few words, from then on we would be able to know exactly what color R was speaking about when describing his photisms.

Table 1: Correspondence between R's photisms and real colors

Category	*Selected color shades within each category*	*RGB code*	*R's verbal description*
Red photism	Shade 1: Red3	205,0,0	Intense red - sexual and esthetic
	Shade 2: OrangeRed3	205,55,0	Power red
Green photism	Shade 1: OliveDrab3	154,205,50	Sick green
	Shade 2: OliveDrab1	192,255,62	
	Shade 3: Grey11	28,28,28	Disgusting green or brown-fear
	Shade 4: Chartreuse4	69,139,0	Lettuce green
Yellow photism	Shade 1: Yellow	255,255,0	Pointy/sharp yellow – pain, joy and shine
	Shade 2: Light Yellow	255,255,224	Pale yellow
Brown photism	Shade 1: Tan4	139,90,43	Pale brown

Table 2: IAPS images used in Experiments 4 through 6

Category:	***Images (IAPS code and verbal description):***
Red photism	**Shade 1**: 0090 – hand holding a handgun, 0131 – closeup of a male face, 0157 – planet Earth, 0193 – young woman in a colorful sari, 0222 – close-up of a cello, 0321 – spacecraft in space, 0327 – hand holding a handgun, 0332 – man with a pistol pointing to his head, 0379 – young muscular mulatto, 0438 – nude of a young black woman, 0478 – set of military automatic knives, 2005 – portrait of a young man smiling, 2025 – portrait of a good-looking young woman, 2375 – portrait of a good-looking mulatto woman, 4537 – young man with a tattoo on his back
	Shade 2 : 0086 – landscape with rocky mountains covered with snow, 0156 – sky with plenty of white clouds, 0158 – desert landscape, intense blue skies, 0265 – sky with plenty of white clouds, 0325 – sky with plenty of white clouds, 0380 – muscular young man working out, 0393 – man walking on the top of a mountain, blue skies, 0434 – close-up of a white man kissing a smiling black woman on her cheek, 0446 – naked young couple resting on a white bed, 0455 – climber on the top of a mountain, snowed rocky hills in the background, 1731 – African landscape with two lions next to a pond, white clouds, 2278 – Indian American woman and a kid, 4503 – portrait of a muscular black man, 4676 – naked young couple embracing, 5551 – sky with plenty of white clouds, 5661 – aesthetic picture of a cavern wall, 6311 – young good-looking woman with a junkie look, smoking, 8186 – sky surfer above mountains, in action
Green photism	**Shade 1 and 2**: 0021 – young man smiling, 0026 – young man with an aggressive facial expression, 0029 – young man with neutral expression, 0080 – erotic take of a naked young woman with her genitals exposed, 0096 – blue umbrella (opened), on the floor, 0135 – mid-aged couple riding on bicycles, smiling, 0137 – sweaty fat older man holding a mug of beer, 0145 – young woman in a wet elastic t-shirt coming out of the sea, 0148 – naked sporty man standing, with his genitals exposed, 0149 – naked man sitting on a balcony, 0166 – close-up of an antique watch, 0168 – mid-aged man in a library, working on a computer, 0190 – portrait of a mid-aged man with neutral expression, wearing a beret, 0192 – trio of smiling elderly man dressed in black tuxedos, 0194 – portrait of a man with neutral expression
	Shade 3 : 0005 – tarantula spider, 0033 – mutilated human head, 0035 – mutilated dead body 0075 – half naked man with badly burnt body, 0076 – mutilated corps, 0077 – mutilated bloody hand, 0117 – burnt dead animal, 1205 – close-up of a tarantula spider, 2981 – man carrying a head of a deer, covered with blood, 3068 – corps mutilated beyond recognition, 9301 – toilet splattered with feces, 9471 – Dunkin' Donuts building destroyed by fire
	Shade 4 : 0121 – close-up of a snake with a wide-open jaw, 0138 – mutilated human head, 0139 – close-up of human eyes suffering from some serious ophthalmologic illness, 0140 – infant head with a malformation syndrome, 0179 – two Asian health workers carrying an unconscious blood-coverer woman, 0197 - drug addict taking a shot, 0198 – detail of a man urinating, 0199 – extremely skinny, naked black man rubbing his face against the rear of an animal, 0202 – mutilated human head, 0203 – close-up of a female face with bruises, 0204 – naked female torso with a long operation scar on the abdomen, 0233 – randomly scattered trash, 0234 - toilet splattered with feces, 0292 – toilet full of vomit, 0360 – dead animal decomposing, 0361 – nuclear cloud
Yellow photism	**Shade 1 :** 0049 – close-up of coniferous needles, 0201 – a kid with a yelling expression 0240 – fishermen cutting fish, 0251 – kid being treated by a dentist, 0266 – city landscape with fireworks, 0315 – a mid-aged man in a white shirt covered with blood, yelling, 0319 – explicit photography of a sexual intercourse of a young couple, 0331 – close-up of a woman with a knife on her throat, threatened by a man, 0322 – fireworks, 0362 – men standing around a burning cross, dressed in a Ku-Klux-Clan outfits, 0427 – close-up of a canine head with wide-open jaws, 0476 – stylized photo of a male with syringes tied to his head, 1419 – bird next to a nest with two baby-birds, 1525 - close-up of a canine head with wide-open jaws, 8485 – man running away from a burning F1 car
	Shade 2 : 0009 – white water bird, 0092 – facility with white rockets pointing to the sky, 0103 – modern urban architecture, 0180 – man working, dressed in an protective clothing and a gasmask, 0340 – fork with spaghetti above a steaming pot full of Italian food, 0400 – cloth placed on an ironing board, 0422 – exploding fighter airplane in the air
Brown photism	**Shade 1:** 0057 – empty woven basket, 0059 – book on the floor, 0071 – bearded mid-aged man, 0072 – very old man with white beard and a hat, 0093 – rolling pin, 0212 – massive wooden armchair with leather straps for fixating one's arms and legs, 0220 – pushcart, cartons and piles of paper in an office, 0274 – dustpan, 0294 – dirty kitchenware, 0309 – kid sitting behind a chessboard, 0397 – empty cup on a wooden surface, 0399 – empty plate on a wooden surface, 0401 – wooden chair on the floor 0462 – stool, 0463 – hammer

R’s photism in response to a vision of the sky is red (images 0086, 0156, 0158, 0265, 0325, 0393, 1731, 551, 8186). A red aura is elicited by attractive people (images 0193, 0131, 0379, 0438, 2005, 2025, 2375, etc.) but interestingly enough, it is also triggered by images of a firearm pointing at someone’s head (images 0090, 0327 y 0332). Images of dead bodies (images 0033, 0035, 0075, 0076, 0077, 0138, 0139, 0140, 0179, 0202, 0203, 0204) and frightening or disgusting scenes (images 0005, 1205, 9301 y 0234, 0292) are “green” (as you can see in Table 1, one of the aura shades that R sometimes calls “green” is actually corresponding to “grey11”). Yellow photism is associated with penetration (meaning either sexual penetration or the penetration of something pointy like a knife or a syringe), with pain (images 0201, 0266, 0240, 0251, 0315, 0319, 0331, 0362, 0427, 1525, etc.) and with joy as well (images 0266, 0319 y 0340). Finally, R considers some portraits “green” and unpleasant that are usually evaluated as pleasant by others (images 0021, 0029, 0080, 00135, 00145, 00148, 00149, 0190, 0192, and 0194).

Colors of emotion (Experiments 4 and 5)

Given the typical pattern of R’s photisms, we asked him to choose at least ten pictures for each of the following categories: emotionally positive “red” pictures, unpleasant “green” pictures, and neutral “brown” pictures and “yellow” pictures (see Table 2). In order to evaluate R’s emotional perception of the images, R ran the Spanish version of the Self-Assessment Manikin or SAM (Moltó et al., 1999; Vila et al., 2001), that provided us with ratings for each picture along the following dimensions: valence (unpleasant-pleasant), arousal (low-high) and dominance (dominated- in control). Basically, SAM scales allowed us to put a figure on R’s subjective feelings in relation to IAPS images that we were going to use later on.

Since we were dealing with a single-case design, we used the C statistic (Young, 1941; Suen & Ary, 1989) to assess the horizontal stability of our results and to detect if they showed any evident trend. (It must be mentioned that the C statistic does not indicate the direction of a trend; however this can be inferred from the representations of the data.) In order to analyze SAM scores along aura color categories, we devised a series with ten points taking into account the order in which R evaluated the IAPS pictures. Every point corresponded to the score of one picture in one dimension (valence, arousal or control). With respect to arousal, C was not significant for the within-group comparison of red pictures (C=0.22, p=0.217), yellow pictures (C=0.12, p=0.33), green pictures (C=0.23, p=0.20) and brown pictures (C=-0.09, p=0.62). In actuality, C was non-significant for all three emotional dimensions in all color categories. The mean scores in valence, arousal and control for red pictures were 6.5, 6.2 and 6.3 respectively on a 1-9 scale. (Ratings are scored such that 9 represents high rating on each dimension, i.e., high pleasure, high arousal, high dominance, and 1 represents a low rating on each dimension, i.e., low pleasure, low arousal, low dominance.) The average SAM pattern for green pictures was 3.7, 6.5 and 4.8. For yellow pictures it was 5, 5.4 and 6.5, and for brown pictures 4.9, 3.3 and 6.7. The results suggested that the images activating same aura-colors were equal in emotional self-assessment. However, we observed a difference in emotional valence between “red” and “green” images (C=0.77, p=0.003) and also a difference in arousal between “red” and “brown” category images (C=0.66, p =0.009) and between “brown” and “green” images as well (C=0.62, p=0.01). Finally, emotional assessment of the yellow category was not significantly different from the rest. This can probably be attributed to the affective ambiguity of the color yellow.

In conclusion we can affirm that the emotional assessment of the images is robustly correlated with the photisms elicited, rather than with the emotional categories stated in the IAPS manual. Interestingly, pictures 0021, 0026 and 0029, showing a close-up of the same person with a smile, with an angry expression, and with a neutral face, were all “green” (negative) to R. However R pointed out that he perceived the actor’s looks as asymmetric and unpleasant independently of the facial expression.[4] The picture 0032 showing a handgun pointing at someone’s head is considered esthetic and red by R. Blood-spattered scenarios elicit green auras and are associated with negative valence and high arousal, producing the same emotional pattern as in control subjects. Conversely, the images of the sky that trigger red photisms in R are perceived as positive and exciting, meanwhile they are considered as pleasant and tranquil for the “normal” population. In the end, R’s affective responses to images are often hard to predict unless you take into account the relationship between the auras and the emotions in R.

In the Experiment 5, R again answered the SAM questionnaire for some of the IAPS images belonging to green and red categories (five items per category). However, this time the pictures were presented in a frame that was either congruent or incongruent with R’s photism. For example, the image 0021 was displayed either with a congruent Olive Drab 3 color frame or with an incongruent Orange Red 3 frame. We analyzed how the congruent/incongruent condition affected the SAM scores. Our results indicated that the arousal scores were higher for congruent frames with respect to incongruent frames in the red category, $F(1, 4) = 10.28$, $p < 0.03$. The same was observed for the valence scale of the green category, $F(1, 4) = 16$, $p < 0.001$. The C statistic was significant in the time series of 5 “no frame-pictures” followed by the 5 pictures of the same photism category, but with congruent colored frames. It occurred for arousal in red pictures ($C=0.58$, $p=0.02$) and also for valence in green pictures ($C=0.7$, $p=0.04$). The difference between the “no-frame condition” and the “incongruent frame condition” was significant only for the valence scale of green pictures ($C=0.48$, $p=0.04$). The average arousal value for red pictures was 6.9 for the frame-congruent condition and 5.6 for the frame-incongruent condition. The average valence for congruent green pictures was 2.8 versus a mean value of 4.2 for green pictures with an incongruent frame. Simply said, the color frames could influence R’s affective judgments following R’s subjective emotional values of the colors. (See Figure 1.)

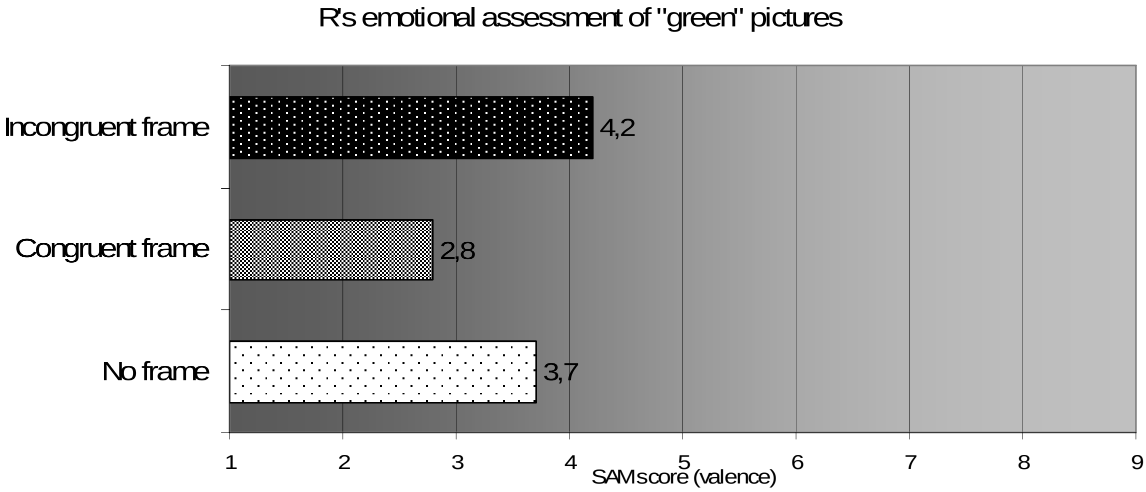


Figure 1: R's subjective perception of emotional valence of IAPS images is influenced by color frames. An incongruently colored frame leads to a slightly more positive evaluation of the otherwise negative green-aura pictures, while a congruent frame makes them even more negatively perceived.

Aura Stroop (Experiment 6)

We wanted to see if R's aura photisms could interfere with a color-naming task (a Stroop-like task that we called Aura Stroop). We used 21 pictures selected at random from the Table 2 (five or more pictures per color category). Every image was presented on a computer screen for 3 seconds and followed immediately by a screen-sized color patch. The subject's task was to indicate the color of the patch (yellow, red, green or brown) by striking a key: V for yellow, B for red, N for green and M for brown. The keys were covered with patches of corresponding colors to facilitate the response. All the IAPS images were combined with all the colors. For each color category (yellow, red, green or brown) we randomly picked one specific shade out of the colors that R had selected as corresponding to his photisms in preceding experiments. R ran two sessions of 84 trials each. The experiment was designed with E-prime (Schneider et al., 2002). The instructions emphasized precision over speed.

We performed two item analyses, one considering the four color categories and another considering the 21 pictures. We found Stroop effect in both cases, $F(1, 3) = 20.92$, $p<.019$ and $F(1, 20) = 23.76$, $p<.0009$ respectively. (See Figure 2.) The mean RT was 620 ms for congruent and 870 ms for incongruent trials. For accuracy, the means difference for congruent (100%) and incongruent trials (92%) was significant, $t=39.68$ ($p=0.00$).

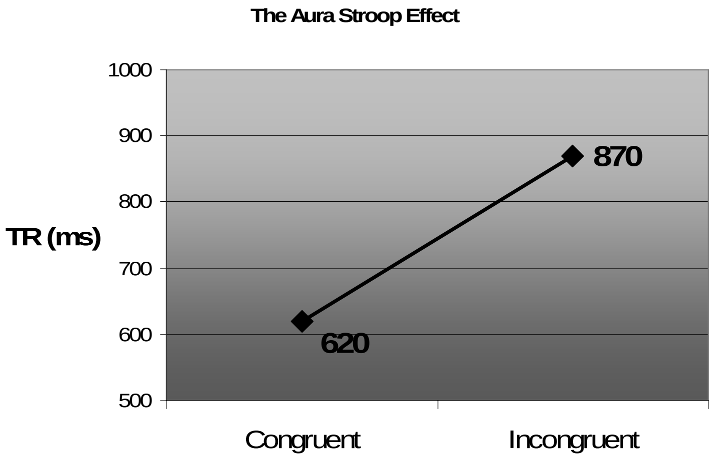


Figure 2: The Aura Stroop Effect. In Experiment 6, each of the 21 IAPS images were presented on a computer screen for 3 seconds and followed immediately by a screen-sized color patch. R's task was to indicate the color of the patch. When the hue was incongruent with the aura associated to the picture stimulus, R took significantly longer to respond.

To further support our analysis, we also ran a randomization resampling test with 100,000 samples, using Resampling Procedures freeware (Howell, 2002). This additional test demonstrated the significance of our data, t = 4.098 (p=0.00008), ruling out the possibility of random effects. In summary, R's aura photisms triggered by visual images seem to produce Stroop interference in color naming. We did not detect any Stroop effects for 10 control subjects (non-synaesthetes with normal color vision) who ran the same task; F (1, 9)=0.26, p<0.61. Mean RTs were 531 ms and 546 ms for congruent and incongruent trials respectively.

In summary, for R we observed no traditional color Stroop but we found Aura Stroop triggered by imaginary colors. On the other hand, the control subject did not show any Aura Stroop but normal color Stroop effects were present.

General discussion

Before analyzing any theoretical implications of our study, we would like to mention a few methodological aspects. Within the field of color perception research, it is of vital importance to discriminate between "real colors" (i.e., the physical qualities of an object), "perceived colors" (i.e., the quale of color) and "color labels" (i.e., the verbal descriptions of the experience of color). The procedure described in Experiment 3 allowed us to correlate R's verbal reports with "real colors" and subsequently to use this information to study R's subjective experience. We consider this methodological approach as fundamental for experimental exploration of synaesthesia and of qualia in general.

Experimental data suggests that R's photisms are strongly related to emotions, modulating his judgments about people and objects. Albeit rare, emotionally mediated synaesthesia has been reported elsewhere, particularly as a reaction to the affective valence of words and to faces of known persons (Ward, 2004). In fact, a recent theory suggests an existence of hyperconnectivity between limbic regions and cortical areas responsible for color processing in synaesthetes (Ramachandran & Hubbard, 2001b). This could explain both the emotional responses that sometimes accompany the photisms (Cytowic, 1993) and the phenomenon of emotionally triggered auras.

Nevertheless, in comparison with the cases reported up to date, R shows a much wider range of “emotional photisms”, not limited to the lexical stimuli or the people’s faces. More interestingly, while some of R’s affective responses follow common patterns, others do not. For example, blood is exciting and of negative emotional valence for R. According to research in color psychology, the relationships between colors and emotions are quiet universal; for most people red is exciting and blue is calming (Heller, 2004). Hence an image of the sky usually has soothing effects on us. However, the latter relationship between an object and an affective response seems to be inverted in R who perceives the sky as stimulating and exciting because of its association with red photism. In this sense, R’s peculiar synaesthesia could make Dennett’s “inverted spectrum experiment” (Dennett, 1988; see Locke, 1690, for the original inverted spectrum argument) a reality.[5] Dennett’s question is: what would happen if we changed someone’s brain wiring in such a way that he would see red skies and blue blood? If this person kept using a “red” label for blood and a “blue” label for the sky, the experimenter might not be able to assess the value of the qualia, given that the inverted-spectrum person would behave in all aspects just like we do. The study could not be accomplished by comparing verbal accounts of red and blue objects because the subject would use the same verbal terms as “normal” control subjects. In other words, it would be unattainable for a scientist to show conclusively that two subjects were experiencing different subjective color spectra (Dennett, 1988). In R’s case the qualia inversion is not complete, i.e. R perceives the difference between real colors and his photisms. However, the latter are qualitatively different from normal people’s experiences and they consistently affect R’s reactive dispositions. Therefore, we can obtain differential behavioral measures with respect to the normal population (unaffected by synaesthesia and/or daltonism) and we can also take up Dennett’s inverted qualia approach to explore what goes on with R. For example, does R experience arousal when watching the sky? Or is it the other way around and R’s reactive dispositions to objects remain unaffected? R’s assessment of IAPS images shows that his reactions can vary with respect to normal population, depending on the photism. In some cases images that are either positive or negative for most of us, acquire an opposite affective valence for R. However, we are not dealing with a chaotic cross-wiring between stimuli and responses. R’s reactions seem to follow a relatively stable pattern of relationships between photisms and real world objects, where emotion is the key factor. Even if we observe certain variability in R, such as when smiling faces can elicit either red or green aura, emotional connotations remain always the same: disgust is green, sexual attraction and beauty are red, and joy and pain are yellow.

Although our data does not allow for causal inferences (i.e., to distinguish whether an aura is green because the perceived image is unpleasant or vice versa), the experiments show that R’s qualia and his reactive attitudes are firmly connected: changes in qualia lead to changes in reactions or the opposite. However, R’s qualia are not rigidly linked to the early sensory perception. Following Dennett’s distinction between early and late pathways, we can say that there is certain variability in early pathways (associations between items of the same category and photisms). This suggests that reactive judgments are not direct outputs of perceptual functions. On the other hand, there is no variability in late pathways (associations between photisms and emotional reactions). Therefore, Dennett’s thought experiment about the coffee masters makes no sense because the quale and the reaction seem to be rigidly connected and cannot change independently.

As we have seen in Experiment 1, R shows no Stroop effect which is probably a consequence of his daltonism. Interestingly the photisms triggered by IAPS images do lead to a Stroop-like interference. Now we can turn to a philosophical question: Do the colors exist in the real world (i.e., are they physical qualities of objects) or are they only a projection of our minds (i.e., do they constitute a subjective quality)? R experiences both real colors (bottom-up processing) and mental, synaesthetic colors (top-down processing). How do these two sources of color experience interact to set up R's color perception? Current research suggests photisms produce cortical activation patterns in a very similar way as real colors do. For example, Hubbard et al. found that when looking at letters and numbers, fMRI responses in color-selective areas (V4) were larger for grapheme-color synaesthetes than for control subjects (Hubbard et al., 2005). The central issue is what kind of processing can lead to discrimination between different color categories. Churchland (1989) describes a possible mechanism by which the human visual system comes to recognize colors: when a newborn first sees a color, a specific neural pattern is set up within V4. Let us say that "blue" corresponds to X-oscillation in V4, "red" is equivalent to Y-oscillations, etc. In R's case, due to his daltonic condition, the patterns for red and green must be very similar in the same way as the patterns for a dark red and just a slightly darker red can be indistinguishable for a normal person. In other words, R's Y-oscillation would be common for red and green, making two neighboring shades impossible to differentiate. What happens when R observes a sky? We can expect that there is an X-oscillation due to the blue color of the sky and a Y-oscillation due to the red photism. The latter is followed by a positive emotional response of pleasant arousal.[6] However, what happens when a blood-spattered scene triggers a green photism? In R's brain the oscillations for red and green should be impossible to distinguish. In theory, it could be that the oscillations for real colors of red and green were alike while the patterns for red and green photisms were different. However, following Churchland's approach, this explanation seems less plausible. We consider that both the red of the blood and the green photism activate a Y-oscillation. So how can we explain that the same oscillation pattern can lead to positive feelings in the case of the "red" sky and negative ones for "green" blood? It is possible that color categories in V4 are not established only by experience but they are intrinsic to some extent. Perhaps color perception is also dependent on interconnections of V4 with other brain areas, such as structures involved in emotional and verbal processing. (See also speculations put forward by Ramachandran & Hubbard, 2005, based on their observations of a color blind synaesthete S.S.)

In conclusion, the approach of the present study to phenomenological experience is an instrumentalistic one. We think that the notion of quale provides an explanatory power to describe and understand R's emotional reactions to the outer world. R as a subject is unique in at least two ways. First, although he suffers from a perceptual impairment of color vision that most likely leads to the absence of color Stroop effect, his synaesthetic condition produces an unusual Stroop elicited by phantom colors. Secondly, the pattern of R's emotional reactions linked to photisms demonstrates that in any case, an inverted spectrum is a real possibility. The case study that has been presented raises further questions about the emotional value of colors both in synaesthetes and normal population. Are colors an intrinsic category hardwired in the brain? Is there a general pattern of emotional significance in relation to these categories? We expect future research to inspect the plausibility of these hypotheses.

Endnotes:

1. It should be noted that this cognitive-conceptual synaesthesia cannot be explained purely by standard graphemic/phonemic processes, i.e. R's concept-color and name-color associations are not predictable on the basis of the graphemes or phonemes making up the word. R's friend Luis is red despite the fact that there are no "red letters" in his name.

2. R reports that very rarely the color elicited is not consistent with his knowledge about a person (e.g., a good friend bringing out "negative", green color photism). Since this kind of "color contradictions" is highly unpleasant, he tries to suppress or at least not to attend to the photism. (The feeling could be compared to a situation where a close person suffers from halitosis. It might be very uncomfortable, but people normally do not change their attitude towards the person in question.)

3. R also presents relatively common grapheme-color photism. However, synaesthetic color of words or numbers consisting of more than two graphemes usually is not associated with the photisms of individual graphemes. R does not report any incongruent specific photisms related to the words "red", "green" and "blue".

4. This suggests that certain low level features like symmetry might play a role in R's synaesthesia in addition to the emotional valence.

5. R's "inversion" is in terms of relations between objects and emotions (e.g., "exciting sky"). We would like to stress, that common associations between colors and emotions are preserved in R: red is exciting for him as well as it is for normal population.

6. According to R, the vision of the sky produces an intense mental activation that he experiences as very pleasant. This kind of arousal is similar to the excited state of mind when R is engaged in his favorite artistic activity - painting.

References

Bailey, M.E.S., & Johnson, K.J. (1997). Synaesthesia: is a genetic analysis feasible? In S. Baron-Cohen & J.E. Harrison (Eds.), *Synaesthesia: Classic and Contemporary Readings* (pp. 182–207). Oxford, England: Blackwell.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., and Bolton, P. (1996). Synaesthesia: prevalence and familiarity. *Perception, 25*, 1073–1079.

Chalmers, D. J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*. New York: Oxford University Press.

Churchland, P. (1989). Knowing Qualia. A Reply to Jackson. In P. Churchland, *A Neurocomputational Perspective: The Nature of Mind and the Structure of Science* (pp. 67-76). Cambridge, MA: MIT Press.

Cytowic, R.E. (1989). *Synaesthesia: A union of the senses.* New York: Springer.

Cytowic, R.E. (1993). *The Man Who Tasted Shapes: A Bizarre Medical Mystery Offers Revolutionary Insights into Reasoning, Emotion, and Consciousness.* New York: Putnam.

Dennett, D.C. (1988). Quining Qualia. In Marcel, A. & Bisiach, E. (Eds.), *Consciousness in Modern Science* (pp. 42-47). New York: Oxford University Press.

Dixon, M.J., Smilek, D. & Merikle, P.M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4* (3), 335-343.

Heller, E. (2004). *Psicología del Color*. Barcelona: Gustavo Pili.

Howell, D. C., *Resampling Statistics: Randomization and the Bootstrap*, http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html (2002)

Hubbard, E.M., Arman, A.C., Ramachandran, V.S. & Boynton, G.M. (2005). Individual differences among grapheme-color synesthetes: brain-behavior correlations. *Neuron, 45*(6), 975-85.

Jackson, F. (1982). Epiphenomenal Qualia. *Philosophical Quarterly, 32*, 127-36.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (1999). *The International Affective Picture System. Technical Manual and Affective Ratings*. Gainesville, Florida: The Center for Research in Psychophysiology, University of Florida.

Locke, J. (1690). *An essay concerning human understanding*. Cleveland: Meridian Books.

Moltó, J., Montañés, S., Poy, R., Segarra, P., Pastor, M.C., Tormo, M.P., Ramírez, I., Hernández, M.A., Sánchez, M., Fernández, M.C., & Vila, J. (1999). Un nuevo método para el estudioexperimental de las emociones: The International Affective Picture System (IAPS). Adaptación española. *Revista de Psicología General y Aplicada, 52*, 55-87.

Nagel, Th. (1974). What is it like to be a bat? *Philosophical Review, 83*, 435-50.

Ramachandran, V. S., & Hubbard, E. M. (2001a). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society Biological Sciences Series B, 268* (1470), 979-983.

Ramachandran, V. S., & Hubbard, E. M. (2001b). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*, 3–34.

Ramachandran, V. S., & Hubbard, E. M. (2005). The emergence of the human mind: Some clues from synesthesia. In L. C. Robertson & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 147-190). New York: Oxford University Press.

Schneider, S. (1988). Micro Experimental Laboratory: An integrated system for IBM PC compatibles. *Behavior Research Methods, Instruments, & Computers, 20*, 206271.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime Reference Guide*. Pittsburgh: Psychology Software Tools Inc.

Searle, J. (1992). *The Rediscovery of Mind.* Cambridge: The MIT Press, Bradford Books.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Suen, H. K. & Ary, D. (1989). *Analyzing Quantitative Behavioral Observation Data.* Hillsdale: Lawrence Erlbaum & Associates.

Vila, J., Sánchez, M., Ramírez, I., Fernández, M.C., Cobos, P., Rodríguez, S., Muñoz, M.A. Tormo, M.P., Herrero, M., Segarra, P., Pastor, M.C., Montañés, S., Poy, R., & Moltó, J. (2001). El Sistema Internacional de Imágenes Afectivas (IAPS): Adaptación española. Segunda parte. *Revista de Psicología General y Aplicada, 54*, 635-657.

Ward, J. (2004). Emotionally mediated synaesthesia. *Cognitive Neuropsychology, 21* (7), 761-772.

Walsh, J.K. (2006). *RGB to Color Name Mapping (Triplet and Hex).* Retrieved April 26, 2006, from http://web.njit.edu/~walsh/rgb.html

Winderickx, J., Battisti, L., Motulsky, A. G., & Deeb, S. S. (1992a). Selective expression of human x chromosome-linked green opsin genes. *Proceedings of the National Academy of Sciences of the United States of America, 89*(20), 9710-9714.

Winderickx, J., Lindsey, D. T., Sanocki, E., Teller, D. Y., Motulsky, A. G., & Deeb, S. S. (1992b). Polymorphism in red photopigment underlies variation in colour matching. *Nature, 356*(6368), 431-433.

Young, L. C. (1941). On randomness in ordered sequences. *Annals of Mathematical Statistics, 12*, 153-162.

Chapter 4

Do Colors Really Matter? Emotional and Physiological Impact of Colors in Chromatic Synaesthesia

Abstract

Anecdotal reports suggest that synaesthetes often show pronounced emotional reactions to colors. Moreover, it is generally believed that colors are linked with emotions, e.g. red is often considered exciting and erotic. Given its subjective significance, it seems surprising that very few experimental studies have examined people's physiological responses to color; the results are, at best, inconclusive. Experimental series described here explores physiological reactivity to colors in R, a subject with a rare, emotionally conditioned synaesthesia. Although we did not find any interpretable pattern of physiological reactions to colors in a control group of non-synaesthetes, the synaesthete's physiological responses were determined by his emotional perception of the colors presented. Colors perceived as pleasant attenuated the subject's startle reaction to sudden noise, while colors perceived as unpleasant enhanced it. The discovery of such emotional modulation is possibly the first strong evidence in favor of the purported neural hyperconnectivity between the limbic system and the cortical color-processing areas in synaesthesia.

Introduction

Synaesthesia is a condition in which one type of sensory stimulation evokes the sensation of another, as when the hearing of a sound produces photisms or mental percepts of colors. The "phantom" sensation which accompanies the stimulation of synaesthetes' senses is usually spoken of as concurrent sensation or, more shortly, a concurrent. There are at least 48 known varieties of synaesthesia (Day, 2006), corresponding to different combinations of sensory modalities. Despite the fact that any of the human senses can act as a concurrent in synaesthesia, in the sheer majority (up to 84%) of cases color is the concurrent sensation (Hochel & Milán, in press; Rich, Bradshaw, & Mattingley, 2006). As various papers report, the experience of photisms is frequently accompanied by positive or negative emotions (e.g.,Cytowic, 1993; Ramachandran & Hubbard, 2001; Ward, 2004).

In an earlier study (Milán et al., 2007) with a synaesthete subject, R, we demonstrated that most of the synaesthete's photisms could be subjectively categorized in line with their emotional valence. When we explored R's synaesthetic sensitivity to human faces and visual scenes, an underlying pattern emerged. Pleasing pictures and faces were typically red to R, while repulsive visuals or unpleasant human faces elicited a pale green color in R's mind's eye. As a general rule, R's most distinctive photisms presented specific emotional logic: positive emotions seemed to be associated with red or purple colors; green usually indicated something repulsive or unpleasant and brown photisms were triggered by emotionally neutral or boring objects. Yellow was the only color that was somewhat ambivalent to R, with both joy and pain associated to it. Even though it was not clear whether it was the photism color or the inducing stimulus or both, which determined the affective response to a given inducer, we wondered whether R's emotional sensitivity to colors was only a phenomenological experience or eventually it would also have an impact on his physiological variables. With the aim of exploring this issue, we took the first step and carried out a bibliographical search for materials that would give us some hints concerning physiological responses to colors. We were frankly surprised to discover that there was almost no serious literature with this respect.

It is generally believed that colors are linked with emotion (Heller, 2004; Kaiser, 1984). Plenty of folk psychology books and articles are devoted to scrutinizing the alleged impact of color on people's state of mind. Indeed, empirical studies confirmed that colors have an important subjective component, mostly by using self-report methods (Abbas, Kumar, & McIachlan, 2005; Adams & Osgood, 1973; Gelineau, 1981; Valdez & Mehrabian, 1994). The use of color is a widely studied phenomenon in the field of consumer behavior and marketing. Given the importance and the subjective significance of color, it seems surprising that only a handful of experimental studies (e.g., Lüscher, 1971; Wilson, 1966) examined physiological components of people's emotional responses to color shades. The few researchers, who did so, employed a variety of measures: cardiac response, galvanic skin response, heart rate, respiration rate, eye blink frequency, blood pressure, etc. Nonetheless, results from these studies were more often than not inconclusive (Kaiser, 1984). Two more recent studies examined people's reactions to short colored video clips (Detenber, Simons, Roedema, & Reiss, 2000) and to colored artificial lighting (Abbas et al., 2005). Again, no regular pattern was observed, suggesting that if there are any physiological responses to color, they vary from one person to another in a way that no generalizable conclusions may be drawn.

Despite this discouraging scenario, we considered that, as far as the physiological reactivity to colors is concerned, the subject of our study, R, could be different from normal, non-synaesthete population. Given that to R color hues were clearly affect-laden, we first explored the subjective emotions associated to colors (Experiment 1). In Experiment 2 we compared the cardiac response to different color shades in the synaesthete and in three non-synaesthetes. In Experiment 3 the startle reflex paradigm was employed in order to study R's physiological changes in relation to colors and photisms.

Experiment 1: Are colors emotionally relevant?

R is a 20 year old male who, in addition to colors for letters and numbers, also has colors from first names, surnames, town and city names, abstract concepts, natural sounds and music. He also responds synaestheticly to viewing of human figures and faces. As we mentioned in the introduction to this paper, R's photisms are closely related to the emotional value of the inducer. Moreover, R claims that every color has a particular subjective, emotional quality: red and purple shades are positive; green means something very unpleasant or disgusting; blue is emotionally neutral, brown is boring and uninteresting, etc. R also claims that as a general rule he prefers vivid, saturated colors to faint and desaturated hues (e.g., a pale green was the "worst shade ever").

In order to explore R's claims concerning colors, he was presented a serious of basic color hues, including partially desaturated versions of some of them[1] (See Table 1.). We asked R to evaluate their emotional quality, using a Spanish version of the Self-Assessment Manikin or SAM (Lang, Bradley, & Cuthbert, 1999; Moltó et al., 1999; Vila et al., 2001), that provided us with ratings for each color shade along the following dimensions: valence (unpleasant – pleasant), arousal (low – high) and dominance (dominated – in control). Basically, SAM scales allowed us to put a figure on R's subjective feelings in relation to colors. R answered the SAM questionnaire for all the hues which were presented, one by one, as square color patches on a computer screen. (In SAM ratings are scored such that 9 represents high rating on each dimension, i.e., high pleasure, high arousal, and 1 represents a low rating on each dimension, i.e., low pleasure and low arousal. Given that the dimension of dominance did not seem to be relevant to R in relation with colors, we will only focus on the assessment of valence and arousal.)

Table 1: Color hues used in Experiment 1.

RGB	Color shade	Saturation	Subjective Color Category
0, 0, 255	blue 1*	Saturated	Blue
89, 89, 167	blue 1 D	Desaturated	Blue
0, 255, 216	blue 2	Saturated	Blue
206, 79, 128	blue 2 D*	Desaturated	Blue
0, 139, 255	blue 3*	Saturated	Blue
89, 134, 167	blue 3 D	Desaturated	Blue
103, 0, 0	brown	Saturated	-
68, 36, 36	brown D	Desaturated	-
97, 255, 0	green 1	Saturated	Green
119, 167, 89	green 1 D*	Desaturated	Green
0, 255, 60	green 2*	Saturated	Green
89, 167, 107	green 2 D*	Desaturated	Green
255, 109, 0	orange*	Saturated	Red
167, 121, 89	orange D	Desaturated	Red
255, 0, 199	purple	Saturated	-
166, 90, 150	purple D	Desaturated	-
255, 0, 37	red*	Saturated	Red
167, 89, 101	red D	Desaturated	Red
255, 152, 233	rose*	Saturated	Red
221, 187, 215	rose D	Desaturated	Red
255, 152, 152	salmon	Saturated	Red
156, 0, 255	violet	Saturated	-
136, 89, 167	violet D	Desaturated	-
255, 255, 0	yellow	Saturated	-
167, 167, 89	yellow D	Desaturated	-

Note: The nine shades marked with an asterisk correspond to colors which were used in Experiment 2.

First, we analyzed the effects of saturation on arousal and valence. This effect was significant; $F(2, 22)=6.2048$, $p=.00730$. Univariate results confirmed R's claims: saturated colors received higher valence score (mean = 6.78) than the desaturated colors (mean = 4.81) and this difference was significant; $F(1, 23)=10.215$, $p=.00402$. In addition, saturated colors also elicited higher arousal (6.60) than the desaturated shades (4.54); $F(1, 23)=9.5535$, $p=.00516$.

Secondly, given R's subjective reports from the preliminary interviews, we grouped and analyzed separately those hues that R categorized as belonging to green, blue and red categories. According to R, these color shades had the most distinctive emotional significance for him. (Red was clearly positive, green negative and blue completely neutral to R.) We followed R's subjective color classification (which incorporated rose and orange hues into a more general red category) in order to see if his verbal reports would match the behavioral output. (The remaining colors, not classified within either red or green or blue category, were excluded from this analysis.) We performed a one-way ANOVA with color category as independent variable. What we found was a differential emotional assessment of color shades through different color categories. (See figure 1.) Specifically, the mean valence value was 7.08 for red color hues, 5.33 for blue hues, and 4 for green hues. The main effect of color category was significant ($F(2, 14)=5.9824$, $p=.013251$). There was no effect of color category on arousal.

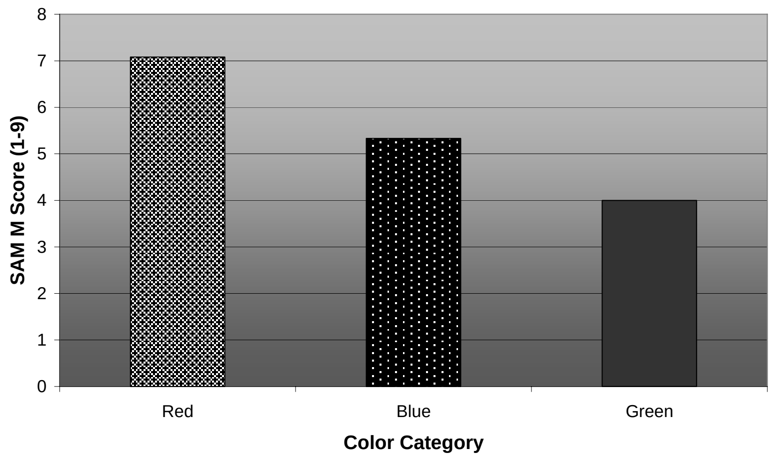


Figure 1: R's emotional assessment of color hues across different color categories.

A group of three control subjects performed the same task. First we analyzed the effect of saturation by means of item-analysis which included the scores of all control subjects. There was a main effect of arousal ($F(2, 72)=14.563$, $p<.00001$). Univariate results revealed that saturated colors received higher arousal scores (mean = 6.07) than desaturated colors (mean = 4.3), $F(1, 73)=28.893$, p<,00001. The same was observed for valence, $F(1, 73)=11.889$, $p=.00094$, with mean valence of 6.13 for saturated colors and 5.05 for desaturated shades. When the responses of each subject were analyzed individually, no effect of color category was observed, while the effect of saturation on arousal and valence was still significant in all three controls. (It must be noted that colors included in the categories corresponded to the classification proposed by the synaesthete subject, R.)

What conclusions can we draw from the data that we just presented? First of all, we have confirmed R's verbal reports by establishing an obvious emotional pattern for red, green and blue color categories. Red hues are perceived more positively than shades of blue, while green shades are clearly the most negative to R. Secondly, we have seen that emotional perception of colors is affected by saturation, i.e. saturated colors are perceived as more positive and more arousing than desaturated hues. This is true for both the synaesthete subject and the controls.

Experiment 2: Physiological responses to colors: myth or reality?

After analyzing the emotional perception of color shades in the synaesthete and the non-synaesthete subjects, the next logical step was to see whether this first person experience had any measurable physiological correlates. Out of the various physiological indexes we opted for the cardiac change (difference of heartbeat frequency with respect to a baseline), since it has been widely studied in relation to the autonomic regulation and the emotion (Ruiz-Padial, Sollers, Vila, & Thayer, 2003; Thayer & Siegle, 2002). However, the more traditional approach of indexing cardiac activity in response to colors was substituted by the measure of cardiac changes that accompany human startle reflex. The startle reflex (SR) is a bodily reaction in response to a sudden unexpected stimulus, such as a flash of light, a loud noise, or a quick movement near the face. In laboratory experiments a white noise of 95 to 105 dB, 50 to 500 ms duration and an instant rise time is usually used to produce the typical pattern of motor and physiological reactions (Martín, 2006; Vrana, Spence, & Lang, 1988). SR is a reflex action implemented within a more general defence system of the organism (Landis & Hunt, 1939). The modulation of the SR (its amplification or reduction) when viewing affect-laden images, is one of the most robust experimental effects within the SR research (Bradley, Cuthbert, & Lang, 1990, 1991; Lang, Bradley, Cuthbert, & Patrick, 1993). The SR is typically enhanced by exposition to photographs of unpleasant visuals, while it is diminished when viewing photographs with emotionally positive content (Bradley et al., 1990, 1991; Lang, Bradley, & Cuthbert, 1990; Vrana et al., 1988). The same effect is obtained with video sequences, reading of emotionally charged texts and also with non-visual stimuli such as sounds and smells (Martín, 2006). Lang (1995; Lang, Bradley, & Cuthbert, 1997) explains the aforementioned SR modulation in terms of motivational priming, as a result of emotional congruence (or incongruence) between two motivational forces. Namely, both the white noise and the unpleasant images used in laboratory SR experiments activate a defense system seeking to avoid aversive stimuli. Unpleasant photographs induce in the viewer a motivational stance which is in line with the defensive response triggered by another aversive stimulus (i.e. the white noise), therefore resulting in an amplified SR. On the other hand, positive stimuli (e.g., pleasant images, smells or music) act in the opposite direction, inducing appetitive motivation which reduces the subject's psychophysical responses to aversive stimulation. In addition to blinking, the most widely used method of measuring SR in laboratory conditions, cardiac change is another significant correlate of the SR and a useful index for observing the emotional modulation effects in SR experiments (Ruiz-Padial et al., 2003).

The main objective in Experiment 2 was to explore the possibility of SR modulation with colors. Given that the synaesthete subject presented a clear emotional pattern associated to specific color categories, we let R choose 9 colors – the only criterion was that he should select 3 most representative hues for the three color categories (red, green, blue) that presented distinctive emotional values in the first experiment. Therefore, the stimuli consisted of three shades of red, three greens and three blues (See Table 1.). The question was whether these color hues would produce any detectable changes in the normal time course of SR cardiac pattern.

Subjects' heartbeat was registered every 300 ms. The startle sound of 105 dB was transmitted to the subject through earphones. (See the Methods section for details.) The sound rise time was instantaneous. We presented the nine color hues on a computer screen. Each shade filled the whole area of the screen during 6 seconds and then it was followed immediately by the next stimulus. The colors were presented in random order; there were 8 trials per hue (i.e. 72 trials) as well as 8 blank screen trials with no color presented and 8 trials with no sound in order to avoid habituation. Dependent variable was the heart rate change, operationally defined as beat-to-beat alterations in R's heart rate with respect to a baseline obtained during a 3 seconds period previous to the stimulus onset. The measure of heart beat alterations was based on R peak detection. The heart rate change was obtained by measuring the heart period and transforming it into average heart rate every 300 ms.

Participants' data were analyzed individually. In every subject, mean cardiac change was computed for each of the 9 color shades, across the 18 measures registered during 6 seconds. The design included the following variables: Time (18 measures of cardiac change; 1 per 300 ms) and Color Category (red, green, blue). We performed an item analysis (repeated measures ANOVA) for each subject separately; independent variables were Time and Color Category.

For the synaesthete subject the main effect of Time was significant ($F(17, 102)=3.2849$, $p=.00010$), as well as the interaction between Time and Color Category ($F(34, 102)=1.9127$, $p=.00683$). While the first effect (Time) comprises normal heartbeat changes as a consequence of the white noise, the interactive effect suggests that there is a differential response depending on the color presented (See figure 2.). During approximately the first 3 seconds, red hues (evaluated as positive by R) seem to decelerate the synaesthete's pulse while the blue and the green shades does not seem to alter the cardiac response significantly. In the second stage, roughly corresponding to the time interval after the sound onset, this scenario changes, green shades make R's heartbeat decelerate below base line, red colors slightly accelerate it with respect to the previous stage and blue hues first decrease the pulse and than speed it up.

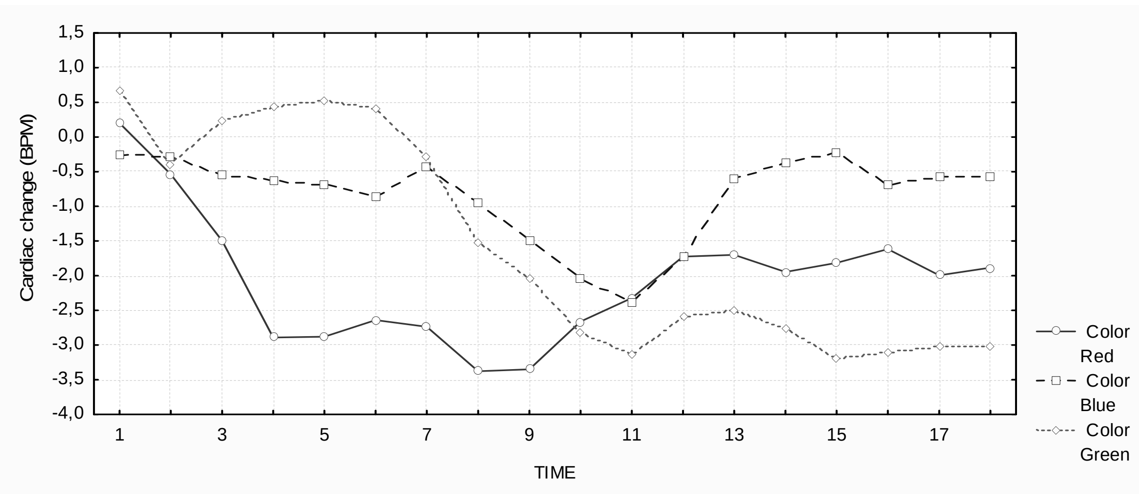


Figure 2: The synaesthete's heartbeat pattern induced by different color hues.

Control subjects presented a somewhat confusing pattern of results. For unknown reasons, one of the subjects presented no significant cardiac change at all, i.e. no detectable SR. In the second control subject, the effect of Time was significant ($F(17, 102)=6.8183$, $p=.00000$) but no interaction with Color was observed, indicating an absence of modulation of the cardiac response by color. Finally, in the third non-synaesthete both effects were significant: the main effect of Time ($F(17, 102)=3.1524$, $p=.00017$) and the interaction Time x Color Category ($F(34, 102)=1.6460$, $p=.02954$). Again, this suggests for a differential cardiac response to red, green and blue hues.

At first sight the significant result obtained with the synaesthete subject might seem promising. However, the observed significant effect of color was hard to decipher. First, the modulation of cardiac response involves both the sympathetic and the parasympathetic nervous systems. In consequence, a downward modulation (i.e., attenuation) of the cardiac response may be attributed to at least two causal mechanisms: a) an appetitive motivational system triggered by a positively perceived stimulus, or b) a mechanism of attentional orientating triggered by the fact that a salient stimulus captures the subject's attention. Secondly, the synaesthete's heartbeat pattern did not seem to be in line with his subjective assessment of colors. In a typical SR experiment you expect positive stimuli to exert a downward modulation of the physiological responses, while negative stimuli usually enhance the SR. However, in R the green color category, evaluated as unpleasant, in fact produces the most clear-cut downward modulation, i.e. an inhibition of the SR. (See Figure 2.) The color blue, evaluated as neutral by R, led to the highest heart rate by the end of the trial when compared to the color green and the color red, which lay in the middle. Moreover, this pattern was different from that observed in the third control subject who presented significant results, too. (See figure 3.) Overall, this outcome is to some extent similar to that obtained by Abbas et al. (2005) who studied the effects of colored light on people's heartbeat during longer periods of time (10 minutes). They observed a significant effect of different colors, nonetheless both the effect of different colors and the direction of the change (up or down) was entirely subject dependent.

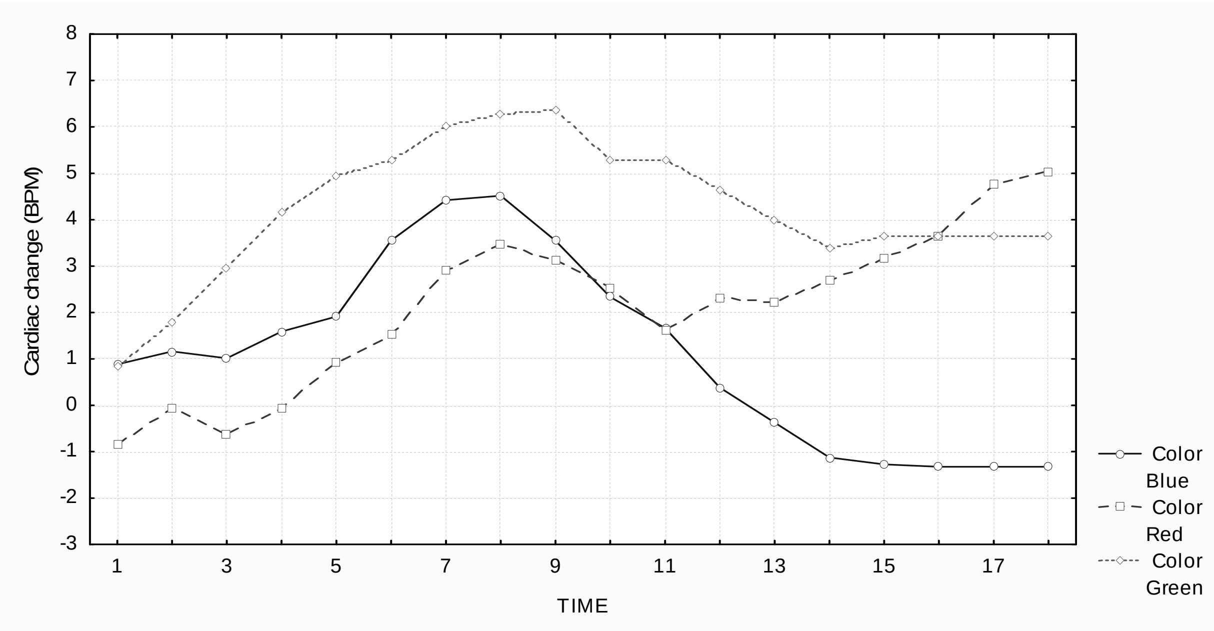


Figure 3: Figure represents differential cardiac change depending on the color shade presented on a computer screen, registered in one of the control subjects.

Experiment 3: Photisms, real colors and the startle response

Even thought the aforementioned results were not easy to interpret, they inspired us to go further in the exploration of physiological influence of colors in synaesthesia. We wondered whether photisms of different colors could lead to differential heart rate pattern. We decided to use number stimuli which were, in principal, emotionally neutral for the synaesthete. In order to do so, R was asked to categorize all the color hues corresponding to his number photisms as emotionally positive, negative or neutral. (See Table 2.) During the experimental session R was presented with the numbers 1, 2, 4, 5, 6, 8 and 9[2] with a white frame or a frame of the same color as the associated photism. Each stimulus appeared on a computer screen for 6 seconds. Again, the SR inducing sound (white noise) was randomly presented within the time interval from 2.5 to 4.5 seconds. The apparatus and other technical aspects of the design were the same as in Experiment 2. The analysis included the following independent variables: Frame (white frame or colored frame), Color/Photism Valence (positive, negative and neutral), Stage (1 and 2) and Time. The Time variable included fewer measurements (16) than in Experiment 2, since part of the data had to be eliminated from the analysis for technical reasons. In order to study particular interaction effects, the heartbeat timeline was split into two segments: Stage 1 (the first 8 measurements) and Stage 2 (the remaining 8 measurements). These stages roughly corresponded to time intervals before (Stage 1) and after (Stage 2) the white noise onset.

Table 2: Number stimuli employed in Experiment 3. The table depicts color shades of the photisms corresponding to each number, as well as the associated emotional valence of these colors.

Number	RGB code	Color sample	R's subjective color name	Emotional quality of the color
1	220,220,220		white	neutral
2	178,34,34		red	neutral
4	79,148,205		blue	positive
5	205,0,0		red	positive
6	181,181,181		pinkish grey	neutral
8	54,36,1		brown black	negative
9	255,255,0		ocher	negative

The interaction of all four variables was significant, F (7,14)= 5.59, p<0.003. No cardiac SR modulation was observed in the white frame condition, suggesting that photisms by themselves did not have significant influence upon R's heartbeat. However, when the colored frame condition was considered, the interaction between the Photism/Color Valence (positive or negative), the Stage and the Register Time was significant, F(15,30)=2.45, p<0.01. In other words, the photisms (triggered by number stimuli) by themselves did not alter R's cardiac startle response but the condition were a congruent colored frame was presented did lead to SR modulation. (See figure 4.) Besides, the observed pattern was in line with the emotional valence of the stimuli, i.e. colors evaluated as positive visibly led to a downward modulation of the SR.

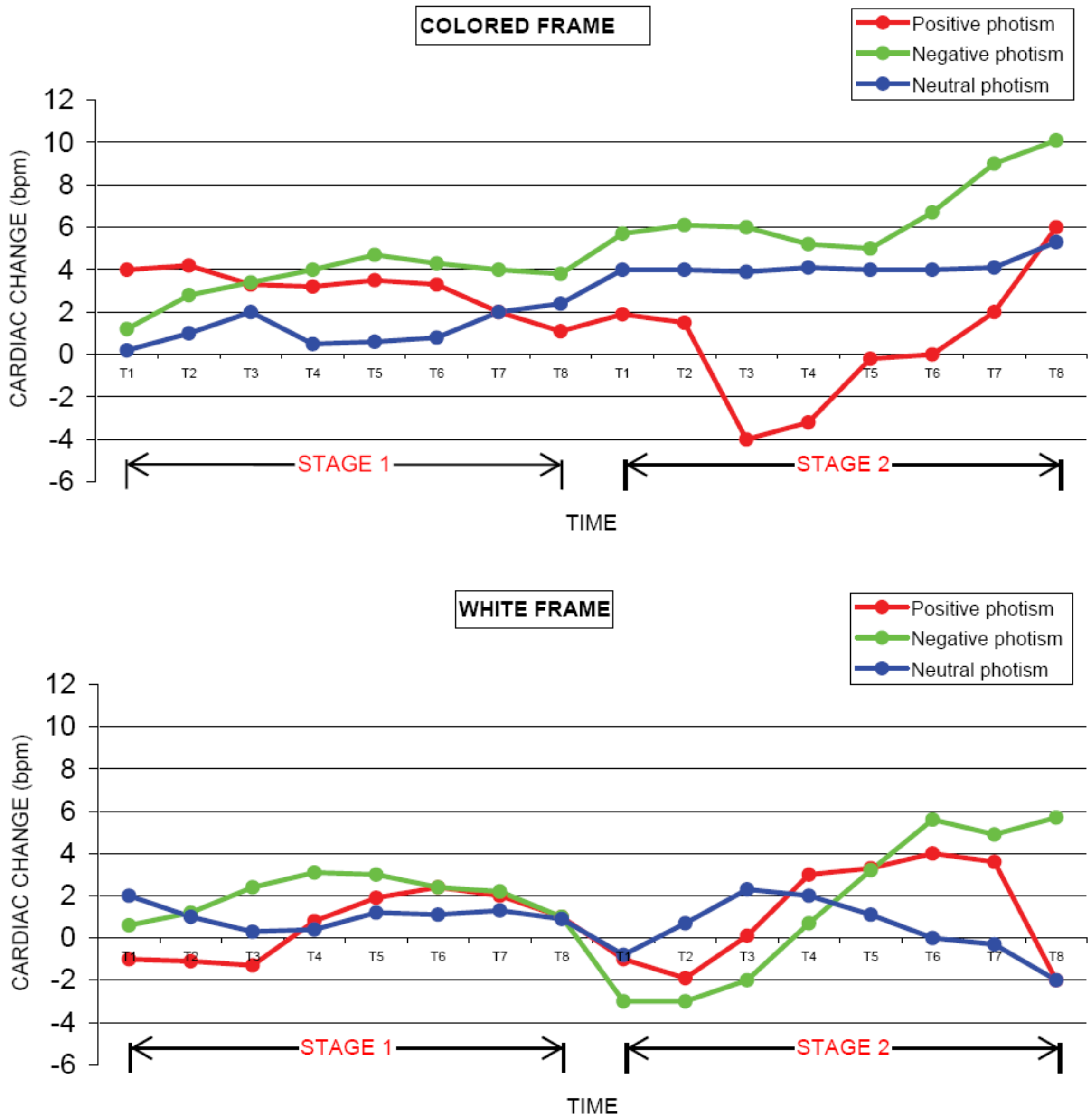


Figure 4: Cardiac change patterns as observed in the synaesthete subject in Experiment 3. Positively colored frames led to an attenuation of R's startle reflex, while negative colors enhanced it. This modulation was not observed when number stimuli were presented in a white frame.

When considering the aforementioned pattern, one might object that such physiological modulation could be explained by the subject's expectation to produce a specific result related to his feelings about the colored frames. Even though it is highly unlikely that a non-trained person would be able to consciously modulate his/her cardiac response in such way, we wanted to back up the heartbeat data by using an additional physiological measure: the electromyography (EMG) of the left orbicular eye muscle. The EMG is frequently used as a general index of SR due to its overall high consistency and relatively uncomplicated detection. To register the activity of the left eye orbicular muscle, we placed miniature electrodes with double-sided adhesive discs on the corresponding region of R's face. The EMG sampling frequency was 1000 samples per second; the signals were registered from 500 ms before the stimulus onset until 1000 ms after it. The SR measure was operationally defined as the maximum amplitude of the integrated electromyographic response of the orbicular muscle, initiated within the first 100 ms following the sound stimulus onset. During the rest of the trial time the EMG response was measured 10 times per second. The EMG record was obtained in the same experiment and at the same time as the cardiac response data.

The experimental design included the following independent variables: Frame (colored frame or white frame) and Photism (positive, negative, neutral). The maximum amplitude of the integrated electromyographic response of the orbicular muscle was the dependent variable. The interaction Frame x Photism was significant, $F(2,5)=6.40, p<0.04$. Again, R's startle reflex seemed to be influenced by the frame color while the photisms by themselves did not influence R's EMG in the white frame condition. In the congruent condition, the EMG amplitude comparison between the positive photisms and the negative photisms was significant, $F(1,5)=8.69$, $p<0.03$. (See Figure 5.) In other words, in the colored frames condition R's SR was affected by the emotional valence of the frame color and/or by the photism valence. As expected, negative colors enhanced the EMG response while positive colors attenuated the SR.

When we consider both measures, i.e. the cardiac change response and the EMG, there is no doubt that positive colors lead to a downward modulation of the SR while the negative colors act in the opposite direction. This indicates that even though colors by themselves do not alter the synaesthete's cardiac activity in a predictable way, when colors are linked to objects (numbers in this case), the color valence might exert an important influence on R's physiological responses.[3]

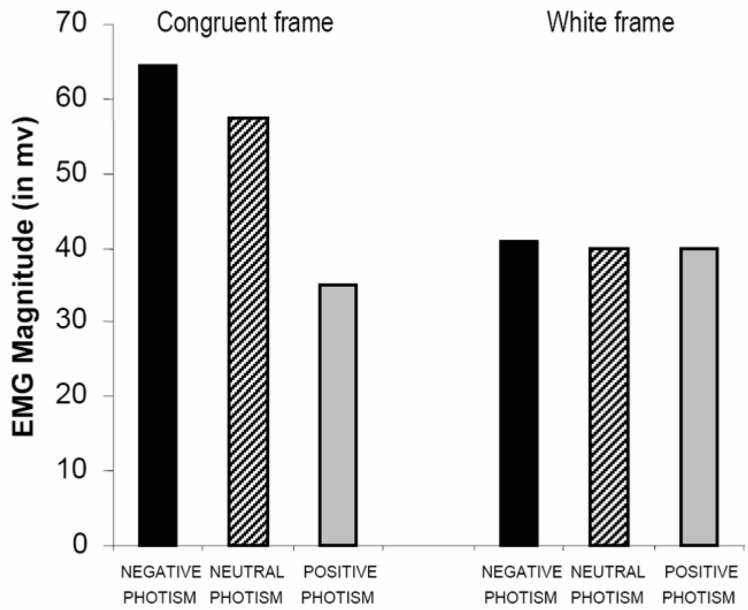


Figure 5: R's blinking response to sudden noise is modulated by differently colored frames. When viewing numbers in frames with pleasant color, the electromyography revealed diminished startle reaction (blinking) with respect to the condition with unpleasantly colored frames.

Discussion

Majority of people have specific preferences for colors they use for dressing up or for decorating their household. Children begin to form color-emotion associations very early and by the age of 5 years they have already acquired evident tendency to express positive emotions for bright colors (Boyatzis & Varghese, 1994). Even though these inclinations can change over time and usually get more sophisticated in adults, yet there is a strong propensity to associate specific color hues with particular moods ("I am feeling blue.") and emotions ("I saw red when I learned they had not invited me.") (Osgood, 1960). Upon viewing the importance that colors certainly have for the most of us, it seems surprising that they do not have a more clear-cut physiological influence, as observed with other affect-laden stimuli such as photographs or music. First of all, it should be noted that the universe of color connotations is in fact more intricate than usually thought. The color-emotion "alliance" is complex; the same color can be associated to negative as well as positive emotions (Heller, 2004). For instance, red can be the color of blood and aggression, as well as the color of positive excitement, love and interpersonal attraction. Green may be associated to nature, to the concept of hope but also to sickness and putrefaction. Some of these associations have more or less identifiable cultural origins, while others arise from a more direct experience with colors (e.g., "to catch someone red-handed"). Despite the fact that for most people colors may not be associated to strictly defined emotional values, certain tendencies seem to be quite universal, such as the preference for saturated hues (Valdez & Mehrabian, 1994) which has also been confirmed in the present study. In contrast to normal population, our synaesthete subject seemed to perceive color-emotion associations as strictly unipolar: red hues were positive while green color shades were unequivocally negative. Colors presented on a computer screen also exerted specific influence on R's physiological responses (heart rate) and this was also observed in one of the control subjects. Nonetheless, in accordance with earlier studies (Abbas et al., 2005), no interpretable general pattern could have been established. The synaesthete's physiological responses did not correspond with his emotional "perception" of colors and the physiological indexes were different in the two subjects (the synaesthete and the control). On the other hand, when colors were linked to a synaesthetic trigger (a number) in Experiment 3, the synaesthete R showed the typical pattern of SR cardiac modulation, where emotionally positive color shades (red hues) led to the SR inhibition. The same pattern emerged when R's blinking response was measured. Even though we are dealing with a single synaesthete subject and therefore caution is necessary when interpreting the results, it may have a series of implications for our understanding of colors. First of all, in the light of earlier studies as well as of the data obtained with control subjects in this study, we believe that physiological reactivity to colors (when present), most probably shows considerable inter-individual variability. The absence of a general pattern may be due to the fact that colors tend to be emotionally bipolar in normal population: there are neither "universally bad" colors nor "universally good" colors. In consequence, it could be impossible to predict what effect (if any) a specific color will have on a given individual. In the real world, color is not an "independent variable"; it is always inseparably connected to an object (that *is colored*). Therefore, the emotional interpretation of any particular color depends on its object: a pink evening dress does not give the same impression on a very young woman than when it is worn by an elderly lady. Secondly, the positive results obtained with the synaesthete subject in

Experiment 3 are most probably due to the fact, that we presented colors in connection with number stimuli which at the same time are linked to specific color photisms. Even though photisms by themselves did not induce a physiological modulation of the SR, colors coupled with numbers did so. It is not clear why the connection of a real color (colored frame) and a synaesthetic trigger (number) was necessary to produce the observed physiological modulation of the SR in R (i.e., neither colors nor photisms by themselves were sufficient to alter the SR). One possible hypothesis is that colors must be linked to objects (numbers) in order to exert an observable influence on R's physiological variables.

It needs to be emphasized that R's particular sensitivity to colors and photisms is unique in multiple ways. First, R's photisms seem to be closely related to the affective valence of the triggering stimulus and they typically bring out a consistent pattern of emotional responses (Milán et al., 2007). Moreover, be it a consequence of the synaesthesia or not, R strictly categorizes colors according to their respective emotional value. Therefore, the results obtained with R are hardly generalizable to non-synaesthetes or even to the population of synaesthetes. However, it is to be expected that similar physiological effects could be observed in those subjects whose synaesthesia is "emotionally mediated" (Ward, 2004). In any case, we believe that the data obtained with R may have important implications for current neurocognitive models of synaesthesia. The fact that R's physiological responses are influenced by colors and/or photisms is in line with theories which advocate the existence of hyperconnectivity between limbic regions and cortical areas responsible for color processing (Ramachandran & Hubbard, 2003). Even though this might not be the case of all synaesthetes, the discovery of SR modulation by colors and photisms is possibly the first strong evidence in favor of the purported limbic hyperconnectivity. Further research in this direction will be necessary in order to reveal the degree of implication of the limbic system in the neurocognitive mechanisms of synaesthesia.

Methods

The following equipment was used in Experiments 2 and 3: (a) Grass polygraph with a 7P4 preamplifier to record the electrocardiogram at lead II; (b) Coulbourn audio system (modules S81-02, S84-04, S82-24 and S22-18) to generate the white noise and present it binaurally through earphones (Telephonic TDH Model-49). (The sound intensity had been calibrated with a sonometer Bruel and Kjaer, model 2235, and an artificial ear Bruel and Kjaer, model 4153.) (c) Pentium 4 PC was used to present visual stimuli. (The PC was interconnected via serial port RS 232 with a second, Pentium 2, PC which registered the polygraph signal.); (d) an Advantech card (model PCL812PG), with digital input–output functions and a 12 bit analog-to-digital converter, operated by the Pentium 2 PC, to control the experimental session through the VPM software (Cook, 1997); (e) Beckman miniature electrodes with double-sided adhesive discs to register the activity of the left eye orbicular muscle; (f) The orbicular muscle activity was measured using a pre-amplifier (V75-04) and an integrator (V76-23A).

Endnotes:

1. Interestingly, R also suffers from a mild form of color blindness (dichromatic daltonism), thus having difficulty in discriminating between certain shades of red, brown and green (Milán et al., 2007). For that reason R had to be tested for correct identification (i.e., naming the color) of all color hues which were employed in this experimental series. Color hues which he was not able to identify were excluded from the design.

2. We decided to eliminate the number 3 because R mentioned that he perceived the associated photism (yellow) as being incongruent with the number shape, which was slightly disturbing for him. The number 7 was not included because it did not induce any synaesthetic response in R.

3. A non-synaesthete control subject, who participated in Experiment 3, showed no modulation of the SR as a function the emotional valence of the colors presented.

References

Abbas, N., Kumar, D., & McIachlan, N. (2005, September 1-4). *The Psychological and Physiological Effects of Light and Color on Space User.* Paper presented at the Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China.

Adams, F. M., & Osgood, C. E. (1973). A cross-cultural study of the affective meanings of color. *Journal of Cross-Cultural Psychology, 4*, 135-156.

Boyatzis, C. J., & Varghese, R. (1994). Children's emotional associations with colors. *Journal of Genetic Psychology, 155*(1), 77.

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1990). Startle reflex modification: emotion or attention? *Psychophysiology, 27*(5), 513-522.

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1991). Startle and emotion: lateral acoustic probes and the bilateral blink. *Psychophysiology, 28*(3), 285-295.

Cook, E. W., III. (1997). *VPM Reference Manual*. Birmingham, AL: Author.

Cytowic, R. E. (1993). *The man who tasted shapes*. New York: Putnam.

Day, S. A. (2006). Types of synaesthesia. Retrieved 12 December, 2006, from http://home.comcast.net/%7Esean.day/Types.htm

Detenber, B. H., Simons, R. F., Roedema, T. M., & Reiss, J. E. (2000). The effects of color in film-clips on emotional responses. *Media Psychology, 2*(4), 331-355.

Gelineau, E. P. (1981). A psychometric approach to the measurement of color preference. *Perceptual and Motor Skills, 53*, 163-174.

Heller, E. (2004). *Psicología del Color*. Barcelona: Gustavo Pili.

Hochel, M., & Milán, E. G. (in press). Synaesthesia: the existing state of affairs. *Cognitive Neuropsychology*.

Kaiser, P. (1984). Physiological response to color: a critical review. *Color Research and Application, 9*, 29-36.

Landis, C., & Hunt, W. A. (1939). *The Startle Pattern*. New York: Farrar and Rinehart.

Lang, P. J. (1995). The emotion probe. Studies of motivation and attention. *The American Psychologist, 50*(5), 372-385.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review, 97*(3), 377-395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Attention and Orienting: Sensory and Motivational Processes. In P. J. Lang, R. F. Simons & M. Balaban (Eds.), *Attention and Orienting: Sensory and Motivational Processes*. Hillsdale: Erlbaum Associates.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *The International Affective Picture System. Technical Manual and Affective Ratings*. Gainesville, Florida: The Center for Research in Psychophysiology, University of Florida.

Lang, P. J., Bradley, M. M., Cuthbert, B. N., & Patrick, C. J. (1993). Emotion and psychopathology: a startle probe analysis. *Progress in experimental personality & psychopathology research, 16*, 163-199.

Lüscher, M. (1971). *Der Lüscher Test: Persönlichkeitsbeurteilung durch Farbwahl*. Rowohlt: Reinbek.

Martín, J. L. M. (2006). *Mecanismos atencionales y preatencionales de los reflejos defensivos.* Unpublished doctorate thesis, University of Granada, Spain, Granada.

Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., et al. (2007). Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75-95.

Moltó, J., Montañés, S., Poy, R., Segarra, P., Pastor, M. C., Tormo, M. P., et al. (1999). Un nuevo método para el estudioexperimental de las emociones: The International Affective Picture System (IAPS). Adaptación española. *Revista de Psicología General y Aplicada, 52*, 55-87.

Osgood, C. E. (1960). The cross-cultural generality of visual-verbal synesthetic tendencies. *Behavioral Science, 5*, 146-169.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.

Ramachandran, V. S., & Hubbard, E. M. (2003). The Phenomenology of Synaesthesia. *Journal of Consciousness Studies, 10*(8), 49-57.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2006). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-color associations. *Cognition, 1*(98), 53-84.
Ruiz-Padial, E., Sollers, J. J., Vila, J., & Thayer, J. F. (2003). The rhythm of the heart in the blink of an eye: Emotion-modulated startle magnitude covaries with heart rate variability. *Psychophysiology, 40*, 306-313.
Thayer, J. F., & Siegle, G. J. (2002). Neurovisceral integration in cardiac and emotional regulation. *Engineering in Medicine and Biology Magazine, 21*(4), 24-29.
Valdez, P., & Mehrabian, A. (1994). Effects of Color on Emotions. *Journal of Experimental Psychology: General, 123*(4), 394–409.
Vila, J., Sánchez, M., Ramírez, I., Fernández, M. C., Cobos, P., Rodríguez, S., et al. (2001). El Sistema Internacional de Imágenes Afectivas (IAPS): Adaptación española. Segunda parte. *Revista de Psicología General y Aplicada, 54*, 635-657.
Vrana, S. R., Spence, E. L., & Lang, P. J. (1988). The startle probe response: A new measure of emotion? *Journal of Abnormal Psychology, 97*(4), 487-491.
Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.
Wilson, G. D. (1966). Arousal properties of red versus green. *Perceptual and Motor Skills, 23*, 947-949.

Chapter 3

Congruence or Coherence? Emotional and Physiological Responses to Colors in Synaesthesia

***** *Accepted paper (European Journal of Cognitive Psychology)*

Abstract

Lexical-chromatic synaesthesia is a condition in which letters and/or words elicit percepts of synaesthetic colors, termed photisms. Anecdotal data suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world, e.g. it can be annoying and unpleasant for them to see a letter printed in a color different than the respective photism color. For R, a synaesthete subject who participated in the present study, the photisms possess specific emotional values (a red photism is pleasing and attractive, green is repulsive and unpleasant, etc.). In contrast to the anecdotal data, R does not always find the color-photism incongruence to be disturbing. More importantly, he states that it is the emotional coherence between the stimulus and the corresponding photism that matters. In a series of experiments, we studied this new concept of emotional coherence on three levels - subjective (self-report), behavioral and physiological, corroborating R's introspective statements. Besides the implications of the concept of coherence itself, the results presented here suggest that even highly subjective cognitive constructs can be approached and measured experimentally, uncovering the workings of the underlying psychophysiological mechanisms.

Introduction

Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound leads to the perception of colors. The first legitimate report on synaesthesia is attributed to Sachs in 1812 (also in Dann, 1998; cited in Krohn, 1892), who described the condition in himself and his sister as a part of a PhD dissertation on his albinism. In the nineteenth century there might have been a dozen of reported cases of possible synaesthetes but these early studies seem to have aroused very little interest. (For a review, see Wheeler, 1920.) Within the scientific community synaesthesia was “brought into existence” by Francis Galton (1880/1997), who observed that a small number of people had the peculiar capacity of experiencing the stimulation of one sense in a multimodal way, i.e. in two or even more sensory modalities (Ramachandran & Hubbard, 2001b). Unfortunately, many decades after Galton’s discovery, “seeing sounds” was still considered a mere curiosity or even a fake. The comeback of synaesthesia to the domain of empiric science occurred a few decades ago, when a number of contemporary researchers have transformed synaesthesia into a scientific reality whose existence can be demonstrated and studied empirically (Hochel & Milán, in press). Hubbard and Ramachandran (Hubbard & Ramachandran, 2005; Ramachandran & Hubbard, 2001a, 2001b) emphasized the importance of the investigations into the neural substrates of synaesthesia for our understanding of the organization of the brain, as well as for the study of more enigmatic properties of the human mind such as the qualia, the language and the metaphor. The present case study is in line with this previous psychophysiological research, seeking to explore the interplay between photisms and real colors in chromatic synaesthesia. In a series of experiments we sought both behavioral and physiological indexes in order to reveal the influence of synaesthetic perception on a synaesthete’s performace and bodily reactions.

The subject of our study, R, is a 20 year old male who, in addition to the relatively common grapheme-color synaesthesia, presents a broad variety of synaesthetic associations. Not only numbers and letters but also first names, surnames, town and city names, abstract concepts, faces, natural sounds and music elicit percepts of color in his mind’s eye (Following Dixon, Smilek & Merikle (2004), R could be categorized as an “associator” synaesthete.). For example, the town of Granada is “red”, hope is “white”, intelligence is “yellow”, classical music is “dark brown”, both pain and joy are “yellow”, love is “red”, etc.[1] R is a unique case of synaesthesia for at least two reasons. First, he suffers from a mild form of red-green colorblindness (See Milán *et al.*, 2007) and, second, he shows an unusual variety of emotional synaesthesia where most of his photisms can be subjectively categorized in line with their emotional valence. When we explored the subject’s synaesthetic sensitivity to human faces and visual scenes, an underlying pattern emerged. Pleasing pictures and faces were typically red to R, while repulsive visuals or unpleasant human faces elicited a pale green color in R’s mind’s eye. As a general rule, R’s most distinctive photisms presented definite emotional logic: positive emotions seemed to be associated with red or purple colors; green usually indicated something repulsive or unpleasant and brown photisms were triggered by uninteresting or boring objects. Blue was emotionally neutral and yellow was the only color that was somewhat ambivalent to R, with both joy and pain associated to it. Finally, the association of photisms to emotions was also present in R’s reactions to real colors (Milán *et al.*, submitted).[2]

The fact that R's emotional responses to colors appeared to be much more pronounced in comparison to non-synaesthetes was not a surprise. Numerous papers (e.g., R. E. Cytowic, 1989; R.E. Cytowic, 1993; Ramachandran & Hubbard, 2001b; Ward, 2004) reported strong emotional responses to colors and photisms in synaesthetes. Anecdotal data suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world (R. E. Cytowic, 1989; Ramachandran & Hubbard, 2001b). For instance, for a lexical-chromatic synaesthete it can be particularly "annoying" when a letter or a word is presented in a color incongruent with respect to the photism color. Such incongruence can lead to a modulation of emotional judgments, as has been reported recently by Callejas, Acosta & Lupiáñez (2007). In this single-case study, a synaesthete subject, M.A., who experienced colors for words, was asked to assess the emotional valence of a set of words, according to their respective semantic meanings. The authors found that for M.A. incongruently colored words affected the judgment of emotional valence, leading to a more negative rating with respect to black words or congruently colored words. Furthermore, the negative affect elicited by the color-photism incongruence also interfered with a speeded valence categorization task.

Interestingly, the synaesthete studied by our group mentioned that it was not the color-photism incongruence that bothered him the most. When discussing visual art, he claimed a strong dislike for specific artistic styles where "the use of colors was completely groundless and incoherent." Nonetheless, he pointed out that he did not expect specific hues (corresponding to his photisms) to be applied in art, following a would-be congruency rule in a straightforward manner. For instance, even though the physical beauty or the strength is red to R, it is "completely acceptable" when such artistic motifs are depicted in purple, orange or even yellow hues. This is because the emotional values of these colors are not in conflict with the inherently positive feelings associated to the red hue. On the other hand, for R it is "absolutely intolerable" when these themes (physical beauty and strength) are represented in shades of green, because green has the opposite (negative) emotional charge with respect to the color red. The same "logic" applies to situations when words are depicted in a color that differs from the synaesthetic concurrent, or even to emotionally neutral stimuli, such as numbers, printed in incongruent colors. (E.g., the number 5 is red to R, but it does not bother him if it is printed in different colors as long as the shade is emotionally consistent with the photism.)

In summary, if we were to trust R's introspective reports, more than mere congruency mattered. R seemed to be sensitive to the emotional coherence between the stimulus and the corresponding photism. The primary goal of the present experimental series was to determine whether the subjective impact of emotional color coherence, as reported by R, had any behavioral and physiological correlates. Since we wanted to examine R's emotional dispositions towards colors (real colors and photisms) per se, we used number stimuli as synaesthetic inducers. (It should be noted that numbers do not have any emotional charge for R.) First, we wanted to analyze R's feelings concerning both photisms and colors in a quantifiable manner (Experiments 1). This was achieved using Self-Assessment Manikin or SAM (Moltó *et al.*, 1999; Vila *et al.*, 2001). Secondly, we wondered whether or not R's emotional dispositions towards colors had any behavioral consequences (Experiment 2). This goal was accomplished by means of an odd-even decision task, where numbers were presented in colored frames which could be or not emotionally coherent with respect to the photism color. Finally, we subjected R to a psychophysiological testing that would further corroborate subjective and behavioral measures (Experiment 3a, 3b).

Experiment 1: Emotional value of colors and photisms

The main ambition of Experiment 1 was to evaluate R's emotional responses to both real colors and photisms, exploring the interplay between the two. However, before proceeding with the exploration of R's emotional responses to real colors and photisms, it was necessary to obtain a thorough classification of R's synaesthetic colors. This was achieved by means of a customized computer program developed in the C# language, that would display a synaesthetic inducer (a number in this case) on the left side of the screen and a palette of color shades on the other side. Samples of colors were vertically arranged in rectangles; both the grapheme (in white) and the color samples were presented on a black background. There was a scroll button next to the color samples that allowed the subject to scroll up and down to see all the shades of a given color. (See Milán et al., 2007, for a complete description of this procedure.) Information previously gathered from R allowed us to reduce the number of color shades presented for each stimulus, using only shades of the color that R reported as his synaesthetic response to a given number (e.g., shades of red for the number five). R's task was to observe a stimulus on the left side of the screen and then to choose a color sample that was closest to his synaesthetic experience. His responses were recorded in a data file, including color name and its hexadecimal encoding. Following this procedure, R went through the numbers from one to nine. After selecting the color hues matching his photisms, R was asked to categorize all the shades as emotionally positive, negative or neutral. In Table 1 you can see the correspondence between the numbers and specific color shades as well as the associated emotional value. It should be noted that in spite of being Daltonic, R was fairly confident about the colors corresponding to his photisms. The number-color correspondence was reliable and consistent over time. In a retest 2 weeks later, R selected the same color hues in 92% of the trials. (Errors typically consisted in choosing the neighboring shade of the same color.)

Table 1: Results of the assessment of R's photisms with the corresponding representation in real colors. For numbers 8 and 9, R did not find an appropriate color equivalent to his photism within the samples offered. He preferred to use Microsoft ® Paint color mixer to get hues exactly matching his photisms. Number 7 is not included because, according to R, it does not induce any synaesthetic response.

Number	Color name	RGB code	Color sample	R's subjective color name	Emotional quality of the color
1	gainsboro	220,220,220		white	neutral
2	firebrick	178,34,34		red	neutral
3	yellow2	238,238,0		yellow	positive
4	steel blue3	79,148,205		blue	positive
5	red3	205,0,0		red	positive
6	grey71	181,181,181		pinkish grey	neutral
8	-	54,36,1		brown black	negative
9	-	255,255,0		ocher	negative

Method

The hues matching R's synaesthetic experience were employed to create colored frames which would be displayed along with numbers 1 through 6, 8 and 9. (Number 7 was eliminated because it did not trigger any photism in R.) For the frames, we used three positive colors (yellow2 /number 3 photism; steel blue3 /number 4 photism; red3 /number 5 photism), three neutral colors (gainsboro /number 1 photism; firebrick /number 2 photism; grey71 /number 6 photism) and three negative colors (brown-black /number 8 photism; ocher /number 9 photism; desaturated green /RGB: 119,167, 89)[3]. Each stimulus consisted in a number presented in a colored frame which was either congruent or incongruent with the photism associated to the number. In addition to the congruent/incongruent condition, we also took into account the emotional values of both the photisms and the color frames. As a result, the experimental design would include the following independent variables: frame (congruent, incongruent negative, incongruent positive); photism valence (positive, negative or neutral). Note that when the frame color was different (incongruent) with respect to the photism, it could be or not be emotionally coherent with the valence of the photism associated to the inducer. This set-up led to 3 frame–photism combinations, as depicted in Figure 1.

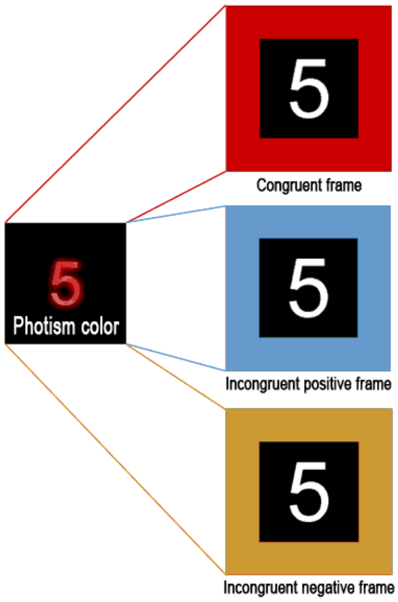


Figure 1. We combined color frames with number stimuli that were either congruent or incongruent with the photism associated to the number. In addition to the congruent / incongruent condition, we also manipulated the emotional value of the color frames in such a way, that the valence of the frame could be the same as or opposite to the valence of the photism. In this example, the red photism elicited by the number 5 is perceived as pleasant by R, being emotionally consistent with the blue, positive frame and inconsistent with the ocher frame which is emotionally negative.

R's task was to evaluate the emotional quality of these stimuli, using a computerized Spanish version of the Self-Assessment Manikin or SAM (Moltó *et al.*, 1999; Vila *et al.*, 2001), which allows to assess a given stimulus on three emotional dimensions: Valence (pleasant-unpleasant), Arousal (high-low) and Dominance (in control-dominated). Ratings are scored such that 9 represents high rating on each dimension, i.e., high pleasure, high arousal, high dominance, and 1 represents a low rating on each dimension, i.e., low pleasure, low arousal, low dominance. Given the objectives of the experiment, only Valence and Arousal dimensions were included. This allowed for an evaluation of the stimuli as pleasant, neutral or unpleasant (Valence) and as producing either low or high Arousal. The resulting scores permitted us to put a figure on R's subjective feelings with respect to the framed number stimuli. The experiment was run on a PC using e-prime (Schneider, Eschman, & Zuccolotto, 2002). Each number stimulus was presented on the screen for 6 seconds and immediately followed by the SAM questionnaire screen. After responding to the SAM scale by clicking on the corresponding value, the next stimulus was shown on the screen.

Results

Firstly, we analyzed how the congruent/incongruent condition affected the SAM scores. The results revealed that the arousal scores were higher for congruent frames (mean score 6) with respect to incongruent frames (mean score 4.2), $F(2,10) = 6.67$, $p<0.01$. For the valence scores, we found a significant interaction ($F(4,10)=8.98$, $p<0.002$) between the frame variable (congruent, incongruent negative or incongruent positive) and the perceived valence of the photisms associated to the numbers. (See Figure 2.)

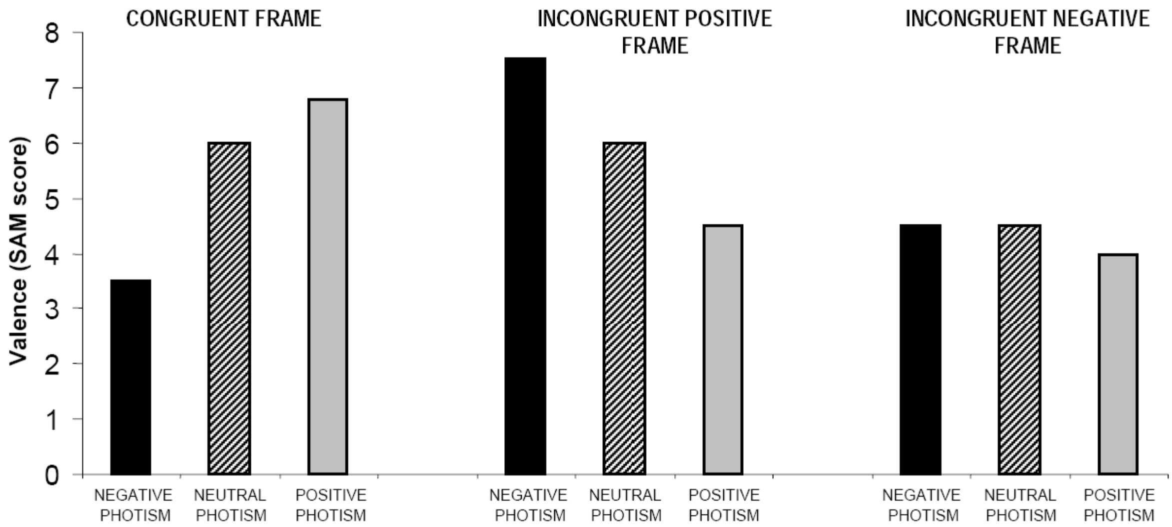


Figure 2. Emotional assessment of framed number stimuli. The incongruence between the color of the photism and the color of the frame does not lead to a more negative emotional disposition automatically. When the two valences are not consistent (e.g., a positive photism and a negative frame or a neutral photism and a positive frame), the valence of the frame seems to prevail, shifting the emotional perception in the corresponding direction. When the two valences agree (negative photism and negative frame), the valence score tends towards more central values, i.e. it gets higher for the negative photisms / frames and lower for the positive ones.

More specifically, for the photisms previously categorized as neutral, we found significant differences in valence between the congruent frame condition and the incongruent negative frame condition, $F(1,5)=7.5$, $p<0.04$; as well as between the incongruent negative frame and the incongruent positive frame condition, $F(1,5)=81.2$, $p<0.00$. For negative photisms, the following differences in valence were significant: the difference between the congruent frame condition and the incongruent negative frame condition, $F(1,5)=22$, $p<0.00$; between the congruent frame condition and the incongruent positive condition, $F(1,5)=23.33$, $p<0.00$; between the incongruent negative and the incongruent positive frame, $F(1,5)=5.95$, $p<0.05$. Concerning positive photisms, there was a significant difference between the congruent condition and the incongruent positive frame condition and also between the congruent and the incongruent negative conditions, $F(1,5)=8.62$, $p<0.03$ and $F(1,5)=10.41$, $p<0.02$, respectively.

Discussion

These data imply that for R the incongruence between the color of the photism and the color of the external stimulus does not straightforwardly lead to negative emotions, as has been suggested elsewhere (Callejas *et al.*, 2007). There is an interplay between the valences of frames and photisms. In our opinion, the pattern observed in our data reflects the workings of an underlying mechanism that we termed emotional coherence. Here (and in the subsequent experiments), the coherence is defined as an interaction between the photism valence and the frame color valence. Considering the SAM scores, when the two valences are not consistent (e.g., a positive photism and a negative frame or a neutral photism and a positive frame), the valence of the real color (i.e., the frame) seems to prevail, shifting the emotional perception in the corresponding direction. More specifically, for the combination of a negative photism combined with a positive frame it was 7.5 (more positive with respect to the both the congruent frame and the incongruent negative frame conditions). In case of a positive photism and a negative frame the mean valence score was 4 (more negative than in the congruent frame condition). However, it should be noted that for positive photisms the difference between the incongruent negative and the incongruent positive frame was not significant. This might be due to the fact that in those cases where the two valences agree (negative photism and negative frame or a positive photism and a positive frame), the valence score seem to lean towards more central values, i.e. it gets higher for the negative photisms / frames and lower for the positive ones. (The mean valence was 4.5 in both cases.)

Experiment 2: Emotional incoherence between real colors and photisms affects performance

The Experiment 2 assessed the impact of emotional coherency onto R's behavioral performance.

Method

The same stimuli as in Experiment 1 were used to design an odd-even decision task. On a given trial a framed number was presented on a computer screen for 3 seconds. R's task was to decide, as fast as possible, whether the number was odd or even. The responses were emitted by striking a key (N for odd, B for even in session one; inversed mapping was used in session two.) R ran two sessions of 72 trials each (8 numbers x 3 frames x 3 trials per condition). The instructions emphasized precision over speed.

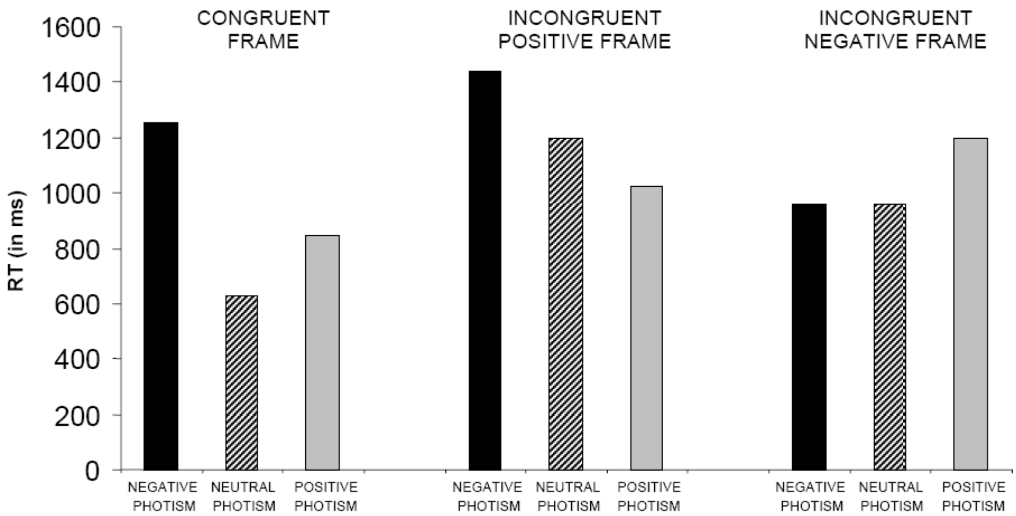


Figure 3. R's reaction times in an odd/even task with framed number stimuli. We observed that the RT performance was negatively affected when the valence of the photism and the valence of the color frame were not consistent. Interestingly, when the stimuli were emotionally coherent, i.e. of the same valence, the frame-photism color incongruence did not have any effect upon R's performance.

Results

We performed an item analysis considering the numbers. The design had the following structure: Photism Valence (positive, neutral, negative) x Frame (congruent, incongruent positive, incongruent negative), i.e. a 3x3 design. A main effect of the frame was observed, $F(2,26)=4.54$, $p<0.02$, as well as a significant interaction between the photism valence and the frame $F(4,26)=2.71$, $p<0.04$. (See Figure 3.) Concerning the neutral photisms condition, there was a significant difference between the congruent frame condition and the incongruent negative frame condition, $F(1,8)=5.43$, $p<0.04$, as well as between the congruent condition and the incongruent positive condition, $F(1,8)=27.29$, $p<0.01$. In other words, for neutral photisms we observed an increase in RT for the two incongruent conditions with respect to the congruent condition. (The two incongruent conditions did not differ significantly.) For positive photisms, the effect of the frame was significant, $F(2,6)=5.43$, $p=0.04$. However, we only detected significant interference in the case of the negative incongruent frame, i.e. when there was incoherence between the photisms valence and the frame valence. The difference between the negative incongruent condition and the congruent condition was close to significant (F (1,3)07.72, $p=0.06$). For negative photisms, the effect of the frame was not significant. On the other hand, when the incongruent negative frame condition was analyzed across the three photism conditions, we found that the RT was longer for the positive photisms than for the neutral photisms ($F(1,13)=9.27$, $p=0.009$) and the negative photisms ($F(1,13)=4.85$, P=0.04.2). Therefore, we can assume that the combination of the negative photism and the incongruent positive frame interfered with R's performance. (Note that the latter is again a case of incoherence between the frame valence and the photism valence.)

Discussion

As a general rule we observed that the RT performance was negatively affected by the incoherence between the valence of the photism and the valence of the color frame or, as we might also say, facilitated by the emotional coherence. This can be understood best by examining the pattern in Figure 3. For the incongruent conditions the photism which is of opposite valence with respect to the frame (e.g., a positive photism and a negative frame) always leads to the longest RT. On the other hand, when the colors are congruent with the photism, R's performance seems to be negatively affected by colors perceived as emotionally negative.

Experiment 3: Colors, photisms and the startle response

The startle reflex (SR) is a bodily reaction in response to a sudden unexpected stimulus, such as a flash of light, a loud noise, or a quick movement near the face. In laboratory experiments a white noise of 95 to 105 dB, 50 to 500 ms duration and an instant rise time is usually used to produce the typical pattern of motor and physiological reactions (Martín, 2006; Vrana, Spence, & Lang, 1988). SR is a reflex action implemented within a more general defense system of the organism (Landis & Hunt, 1939). One of its main and most widely studied components in humans is blinking. Due to its overall high consistency and uncomplicated detection it is frequently used as a general index of SR, being measured through an electromyography (EMG) of the left orbicular eye muscle.

The modulation of the SR (its amplification or reduction) when viewing affect-laden images, is one of the most robust experimental effects within the SR research. The SR is typically enhanced by exposition to photographs of unpleasant visuals, while it is diminished when viewing photographs with emotionally positive content (Bradley, Cuthbert, & Lang, 1990, 1991; Lang, Bradley, & Cuthbert, 1990; Lang, Bradley, Cuthbert, & Patrick, 1993). The same effect is obtained with video sequences, reading of emotionally charged texts and also with non-visual stimuli such as sounds and smells (Martín, 2006). The main objective of Experiment 3 was to explore the possibility of SR modulation with photisms and real colors.

Lang (1995; Lang, Bradley, & Cuthbert, 1997) explains the aforementioned SR modulation in terms of motivational priming, as a result of emotional congruence (or incongruence) between two motivational forces. Namely, both the white noise and the unpleasant images used in laboratory SR experiments activate a defense system seeking to avoid aversive stimuli. Unpleasant photographs induce in the viewer a motivational stance which is in line with the defensive response triggered by another aversive stimulus (i.e. the white noise), therefore resulting in an amplified SR. On the other hand, positive stimuli (e.g., pleasant images, smells or music) act in the opposite direction, inducing appetitive motivation which reduces the subject's psychophysical responses to aversive stimulation. Davis (1989; 1992; Davis, Hitchcock, & Rosen, 1992) provided evidence supporting the idea that the same brain structures are involved in the defensive motivational system and in the SR. Several studies pointed out that the amygdala (part of the defensive system) is the principal responsible for the SR being modulated by fear (Everitt, Dickinson, & Robbins, 2001; LeDoux, 1990, 1995, 1996). A number of neural pathways allow the amygdala to control different types of responses within the autonomic nervous system. More specifically, the SR seems to be modulated thanks to a pathway terminating in the caudal pontine reticular nucleus (Davis, 1997; Fendt & Fanselow, 1999).

Ruiz-Padial, Sollers, Vila & Thayer (2003) demonstrated that, in addition to the blinking reflex, cardiac response was another significant correlate of the SR and a useful index for observing the emotional modulation effects in SR experiments. However, even though heart beat frequency is sensitive to the emotional valence of stimuli, it is usually more complicated to obtain cardiac response measures of the SR modulation, because these effects require simultaneous activation of both the sympathetic and the parasympathetic nervous systems. In the experiment that follows, we used the heart rate phasic response as an index of the cardiac component of the startle reflex in order to study the influence of colors and photisms on R's SR.

Method

The same stimuli as in Experiments 2a and 2b were used, but there was an additional white frame condition, which served to study the influence of photisms per se. R was presented with the numbers 1, 2, 4, 5, 6, 7 and 9 with a congruently colored frame, an incongruently colored frame or a white frame. (At this stage of our experimental series, we decided to eliminate the number 3 because R mentioned that he perceived the associated photism (yellow) as being "somewhat incongruent" with the number shape itself, which was slightly disturbing for him and could therefore contaminate the results.) Each stimulus appeared on a computer screen for 6 seconds. The SR inducing sound (white noise) was randomly presented within the time interval from 2.5 to 4.5 seconds. The total of experimental trials was 96 (24 per condition); in addition there were 9 trials where no sound was presented and 9 trials with no image, in order to eliminate habituation. Dependent variable was the heart rate change, operationally defined as beat-to-beat alterations in R's heart rate with respect to a baseline obtained during a 3 seconds period previous to the stimulus onset. The measure of heart beat alterations was based on R peak detection. The heart rate change was obtained by measuring the heart period and transforming it into average heart rate every 300 ms.

The following equipment was used: (a) Grass polygraph with a 7P4 preamplifier to record the electrocardiogram at lead II; (b) Coulbourn audio system (modules S81-02, S84-04, S82-24 and S22-18) to generate the white noise and present it binaurally through earphones (Telephonic TDH Model-49). (The sound intensity had been calibrated with a sonometer Bruel and Kjaer, model 2235, and an artificial ear Bruel and Kjaer, model 4153.) (c) Pentium 4 PC was used to present visual stimuli. (The PC was interconnected via serial port RS 232 with a second, Pentium 2, PC which registered the polygraph signal.); (d) an Advantech card (model PCL812PG), with digital input–output functions and a 12 bit analog-to-digital converter, operated by the Pentium 2 PC, to control the experimental session through the VPM software (Cook, 1997).

Analysis design and results

The experimental design included the following variables: Frame (incongruent positive, incongruent negative, congruent and white frame), Photism Valence (positive, negative and neutral) and Register Time (16 time points, 1 every 300 ms). General ANOVA revealed a significant interaction of the three variables, $F (90, 180) = 1.37$, $p<0.03$. In order to study particular interaction effects, the heartbeat timeline was split into two segments: Stage 1 (the first 8 measurements) and Stage 2 (the remaining 8 measurements). Because the white noise was presented randomly within the time from 2.5 to 4.5 seconds, Stage 1 mostly contained measures recorded before the white noise onset, while the Stage 2 mostly includes measures recorded during and after the white noise presentation. (See Figure 4.)

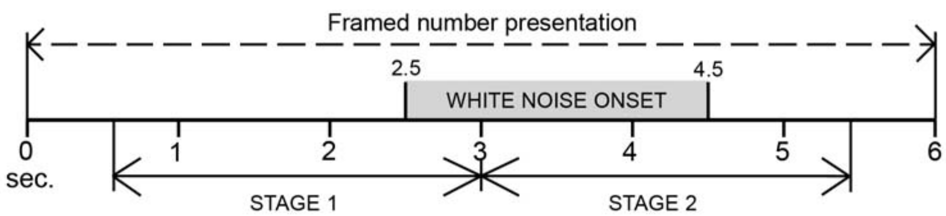


Figure 4. Schematic timeline of a trial in Experiment 3. The framed number stimulus was presented during 6 second; the onset of the SR inducing sound (white noise) occurred randomly within the time interval from 2.5 to 4.5 seconds. R's heart rate was registered every 300 ms during the Stage 1 (8 records) and the Stage 2 (8 records).

The resulting design had an additional variable called Stage (1 or 2) with a nested Register Time variable consisting of 8 measurements (8 per stage, 1 per 300 ms). In order to determine the presence of the cardiac startle response (CSR) in R, we studied the interaction between the Stage and the Register Time variables. The variables Frame and Photisms Valence allowed us to explore the modulation of the CSR.

Given the complexity of the design, we divided the analysis in two parts. First, we considered the data from the white frame and the congruent frame conditions in order to analyze the influence exerted by the photisms and the real colors in terms of heart beat variability. Secondly, we wanted to study the effect of emotional coherence between the photism valence and the color frame valence. With this aim in mind, we contrasted the incongruent positive frame condition with the incongruent negative frame condition.

The effect of colors and photisms on the Cardiac Startle Response

The analysis included the following variables: Frame (congruent or white frame), Photism Valence (positive, negative and neutral), Stage (1 and 2) and Register Time. The interaction of all four variables was significant, $F(7,14) = 5.59$, $p<0.003$. The CSR modulation, considered here as a function of photism valence, only appears in the congruent frame condition. In this condition, the interaction between the Photism Valence (positive or negative), the Stage and the Register Time was significant, $F(15,30)=2.45$, $p<0.01$. There is no such modulation effect in the white frame condition. In other words, the photisms do not alter R's cardiac startle response while the real colors do. (See figure 5.)

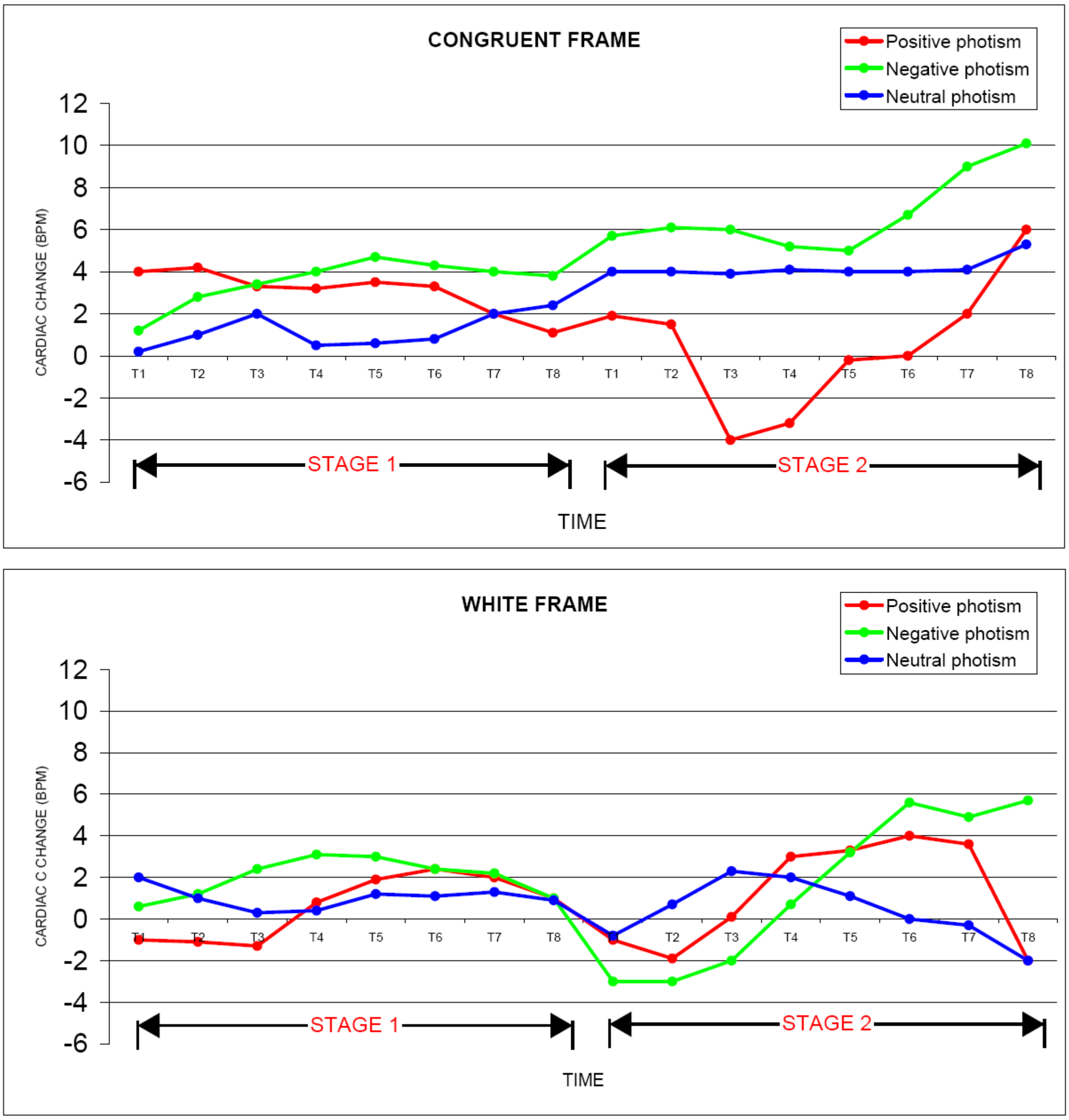


Figure 5. Modulation of the cardiac startle response by color frames congruent with the photisms. The congruent color frames shape the synaesthete's cardiac response in line with their emotional valence. Positively perceived colors attenuate the SR while the negative ones enhance it. The photisms by themselves (white frame condition) do not seem to exert any modulation of the heartbeat.

The effect of photism-color valence coherence

The analysis included the following variables: Frame (incongruent positive or incongruent negative), Photism Valence, Stage and Register Time. The interaction between the Frame, the Photism Valence and the Stage was significant, $F(2,4)=10.04$, $p<0.02$. (See Figure 6.) The analysis of the CSR (the interaction between the Stage and the Register Time variables), computed separately for the incongruent positive and the incongruent negative color frame, was significant for the negative frame condition only. In this condition the SR was affected by the photism valence, $F(14,28)=2.22$, $p<0.05$.

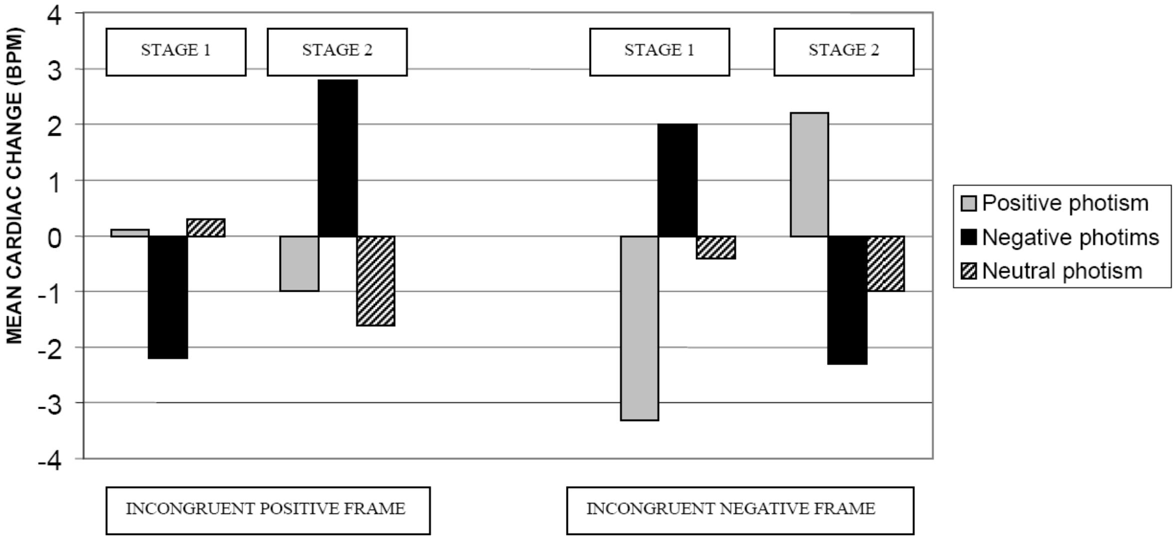
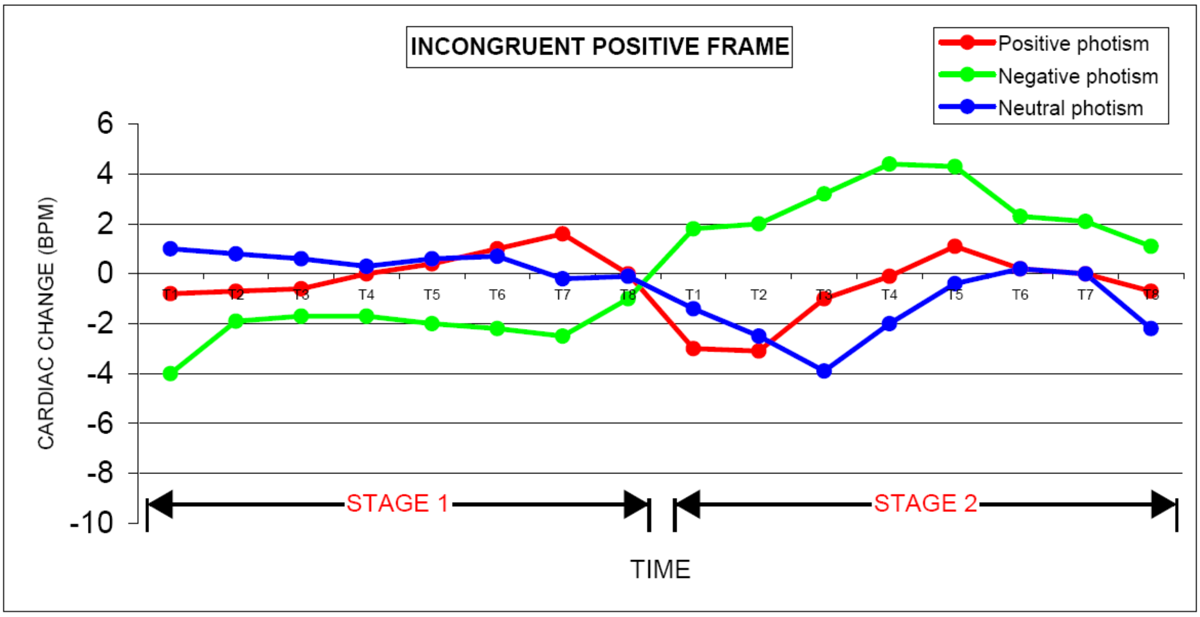


Figure 6. Mean cardiac change (with respect to baseline) observed in response to a startle producing sound, as a function of emotional valence of photisms (induced by number stimuli) and incongruent color frames. Note that cardiac startle response is inhibited for both the positive and the neutral photisms in the incongruent positive frame condition. Similar pattern is observed for the negative and the neutral photisms in the incongruent positive condition.

As shown on Figure 7, when the numbers are presented in incongruent positive color frames, negative photisms lead to heartbeat deceleration during Stage 1. In Stage 2, R's heartbeat is strongly accelerated showing normal SR pattern. The positive and neutral photism conditions do not show any significant cardiac changes when the aversive noise is presented, i.e. there is no sign of CSR in these experimental conditions.

For the negative color frames, positive photisms lead to distinct heartbeat deceleration during Stage 1, followed by a fast acceleration, i.e. the cardiac startle response is present. Negative photisms seem to lead to an opposite pattern, i.e. first they accelerate R's heartbeat but in Stage 2 R's heart slows down. This could be interpreted in terms of an CSR inhibition.



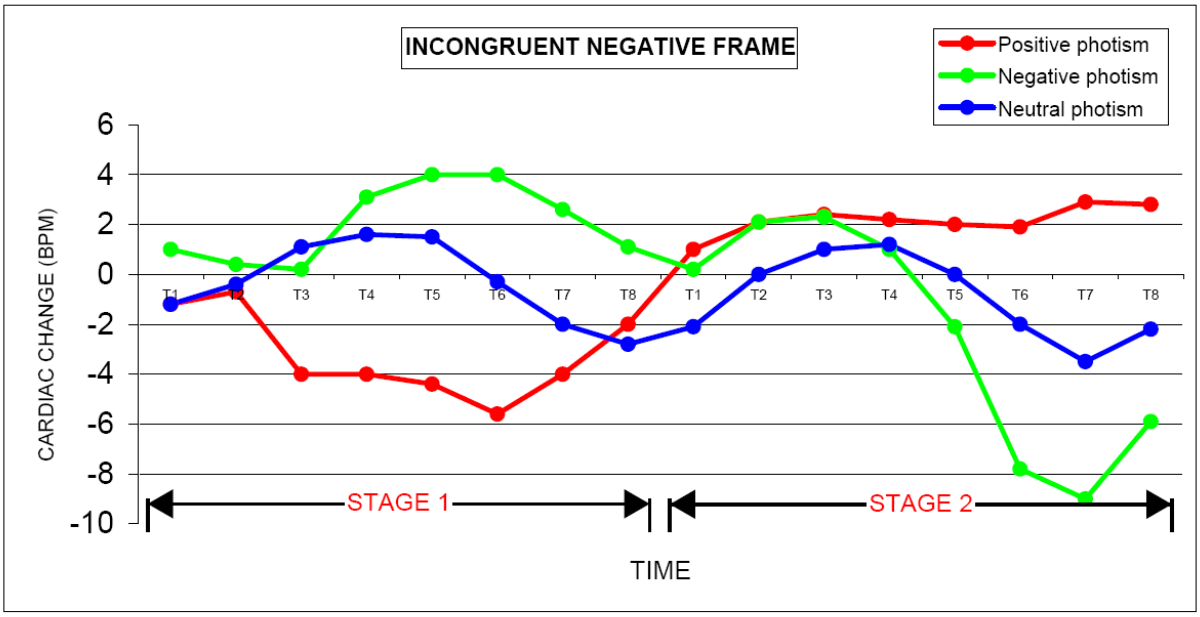


Figure 7. Modulation of the cardiac startle response by color frames incongruent with the photisms. Distinct cardiac response patterns are observed as a function of emotional valence of the photisms that interacts with the valence of the color frames.

Discussion

Upon contrasting the results of the two incongruent conditions it appears that when the photism and the color frame are emotionally coherent (i.e., of the same valence), R's CSR becomes weaker, independently of the emotional valence. Apparently the emotional coherence has an assuasive effect on R. On the other hand, when the photism and the color frame are of opposite valences, the CSR is clearly present.

Despite the fact that we have observed significant differences between the different conditions, the interpretation of the results is quite complex. This is because the modulation of heart rate involves both the sympathetic and the parasympathetic nervous systems. In consequence, a downward modulation (i.e., attenuation) of the cardiac response may be attributed to at least two causal mechanisms: a) an appetitive motivational system triggered by a positively perceived stimulus, or b) a mechanism of attentional orientation triggered by the fact that a salient stimulus captures the subject’s attention. In any case, differential physiological measures were obtained across different experimental conditions, i.e. the trials with emotionally incoherent stimuli had a differential effect on R’s cardiac response when compared to conditions perceived as emotionally coherent by R.

General discussion

For R, both the real colors and the synaesthetically triggered percepts of color have an implicit emotional message which can influence R’s affective dispositions towards people and visual scenes (Milán *et al.*, 2007). Albeit rare, emotionally mediated synaesthesia has been reported elsewhere, particularly as a reaction to the affective valence of words and to faces of known persons (Ward, 2004). Moreover, even in those cases where synaesthesia is not directly mediated by emotions, it is quite common for synaesthetes to experience the congruency between the synaesthetically and the normally perceived features of the outer world as “correct” or even pleasant. The opposite may apply to situations of incongruity, particularly in those situations when a photism and a real color of the inducing stimulus do not agree; this is usually experienced as unpleasant and annoying (R. E. Cytowic, 1989; Ramachandran & Hubbard, 2001b). A study by Callejas et al. (2007) confirmed earlier informal reports by showing that the perception of an “incorrectly” colored word affected the judgments of emotional valence.

The present case study explored the influence of (real) color - photism incongruity on three levels: subjective, behavioral and physiological. However, in contrast to the study by Callejas et al. (2007), our experimental design was also aimed at examining the influence of R’s emotionally tinted synaesthesia. More specifically, it was inspired by R’s subjective claims concerning his perception of certain stimuli as “emotionally incoherent”. The resulting data suggest that the synaesthete’s emotional perception of colors modulates the effect of incongruity (between real colors and photisms). In R’s case both real colors and photisms can influence behavioral and physiological indexes in a way determined by the affective valences of colors and/or photisms. Different color hues (colored frames) shape R’s subjective assessment of the synaesthetic inducers, they affect his reaction times in behavioral tasks and modulated his cardiac startle response to an aversive sound. The impact of incongruity between colors and photisms is not straightforward because it seems to interact with R’s emotional perception of colors. More specifically, the pattern of his behavioral as well as physiological reactions is determined by the presence (or absence) of emotional coherence between the respective emotional valences of photisms and real colors.

Despite the fact that the results presented here may be found compelling, there is at least one empirical effect which may raise doubts concerning our interpretation of the data. R's subjective assessment of the stimuli in Experiment 1 indicated that the emotional valence of the real color prevails in the presence of emotional incoherence between photisms and colored frames. On the other hand, behavioral data (Experiment 2) as well as the cardiac response measure (Experiment 3) suggest that emotional incoherence always has a negative impact, interfering with R's performance and enhancing his SR. Such apparent inconsistence in the data might be explained by the different nature of these experiments. Experiment 1, which involves direct, subjective assessment of the stimuli, consists of a more cognitive and conscious interpretation of synaesthetic inducers by the subject. On the other hand, both the behavioral task and the physiological measure bring out the influence of coherence on R's actions and bodily reactions. Consequently, certain differences in the outcome of these qualitatively different measures are to be expected.

Finally, there is a series of empirical and theoretical issues that will require further investigation. First, it would be interesting to explore whether the behavioral and physiological effects related to emotional coherence are also present in other synaesthetes or whether it is an idiosyncratic feature of R or, eventually, it is only present in emotionally conditioned synaesthesias. In addition, it is also possible that similar mechanism occur in non-synaesthetes when shown real word in contexts which produce "emotional conflict". For instance, the word "joy" printed in dark blue color could be perceived as "emotionally incoherent" (due to the association of dark colors with depressive states) and eventually lead to similar effects as observed in R. Secondly, as we mentioned in the introduction to this paper, for R the concept of coherence extends to the field of aesthetic judgments. Simply put, he generally likes artworks that he perceives as coherent and he hates those where the use of color, from R's point of view, is arbitrary and incoherent. Further research in this respect could allow for a completely new cognitive, behavioral and maybe even neuropsychological approach to the domain of aesthetic judgment which is generally very hard to grasp in a scientific manner.

As a final point we would like to emphasize the connection of the results with the notion of qualia, i.e. subjective, non-transferable, first-person experiences (e.g., Chalmers, 1996; Jackson, 1982; Searle, 1992). The present study suggests that even such an idiosyncratic subjective concept, the emotional coherence of colors, can lead to empirically measurable outcome: it affects both R's performance and his bodily reactions. The pattern of R's reactions would hardly make sense unless we made reference to his unique, first-person point of view concerning colors. Hence, it seems reasonable to affirm that the concept of qualia, so frequently overlooked by the mainstream science, is a necessary ingredient for understanding of the outcome of behavioral, psychophysiological and neurological studies on synaesthesia.

Endnotes:

1. For the sake of clarity it should be noted that R's lexical-chromatic synaesthesia (colors for words) is independent from his grapheme-color synaesthesia, i.e. photisms for words are neither a compound of colors for individual graphemes, nor they are tinted with the color-photisms of the first letter or letters.

2. Even though colors also have emotional connotations for normal, non-synaesthete population (e.g., Heller, 2004), they are not as specific as observed in R. While normal people's perception of emotional values of colors tend to be ambiguous (e.g., red can be perceived as erotic and energizing, but it can also evoke blood and aggression.), as a general rule R seems to associate certain colors (red, purple, violet) with positive emotions whereas other hues (shades of green) are laden with negative affect.

3. In order to put together a smooth experimental design, we added another "negative" color hue that had been obtained in our pilot experiments, namely a desaturated green shade (RGB: 119,167, 89).

4. Remember that the SR inducing stimulus (white noise) was presented at random within the interval from 2.5 to 4.5 during the 6 seconds when the framed number stimulus appeared on the screen. That is why it could have appeared within Stage 1 as well as Stage 2. Nonetheless, most of the measures included in Stage 1 correspond to the time before the white noise, while the majority of the measures within Stage 2 match the time after the white noise.

References

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1990). Startle reflex modification: emotion or attention? *Psychophysiology, 27*(5), 513-522.

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1991). Startle and emotion: lateral acoustic probes and the bilateral blink. *Psychophysiology, 28*(3), 285-295.

Callejas, A., Acosta, A., & Lupiáñez, J. (2007). Green love is ugly: emotions elicited by synesthetic grapheme-color perceptions. *Brain Research, 1127*(1), 99-107.

Cook, E. W., III. (1997). *VPM Reference Manual*. Birmingham, AL: Author.

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses*. New York: Springer.

Cytowic, R. E. (1993). *The man who tasted shapes*. New York: Putnam.

Chalmers, D. J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*. New York: Oxford University Press.

Dann, K. T. (1998). *Bright Colors Falsely Seen: Synaesthesia and the Search for Transcendental Knowledge*. New Haven: Yale University Press.

Davis, M. (1989). Sensitization of the acoustic startle by footshock. *Behavioral Neuroscience, 103*, 495-503.

Davis, M. (1992). The Role of the Amygdala in Fear and Anxiety. *Annual Review of Neuroscience, 15*, 353-375.

Davis, M. (1997). The neurophysiological basis of acoustic startle modulation: Research on fear motivation and sensory gating. In P. L. Lang, R. F. Simons & M. T. Bakabab (Eds.), *Attention and Orienting: Sensory and Motivational Processes* (pp. 69-96). London: Lawrence Erlbaum Associates.

Davis, M., Hitchcock, J. M., & Rosen, J. R. (1992). Anxiety and the amygdala: Pharmacological and anatomical analysis of fear-potentiated startle paradigm. In C. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory.* San Diego: Academic Press.

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4*(3), 335-343.

Everitt, B. J., Dickinson, A., & Robbins, T. W. (2001). The neuropsychological basis of addictive behavior. *Brain Research Review, 36*, 129-138.

Fendt, M., & Fanselow, M. S. (1999). The neuroanatomical and neurochemical basis of conditioned fear. *Neuroscience and Behavioral Reviews, 23*, 123-133.

Galton, F. (1880/1997). Colour associations. In S.Baron-Cohen & J.E.Harrison (Eds.), *Synaesthesia: Classic and Contemporary Readings* (pp. 43-48). Oxford: Blackwell.

Heller, E. (2004). *Psicología del Color*. Barcelona: Gustavo Pili.

Hochel, M., & Milán, E. G. (in press). Synaesthesia: the existing state of affairs. *Cognitive Neuropsychology*.

Hubbard, E. M., & Ramachandran, V. S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron, 48*, 509–520.

Jackson, F. (1982). Epiphenomenal Qualia. *Philosophical Quarterly, 32*, 127-136.

Krohn, W. O. (1892). Pseudo-chromaesthesia, or The Association of Color with Words, Letters, and Sounds. *American Journal of Psychology, 5*, 20-41.

Landis, C., & Hunt, W. A. (1939). *The Startle Pattern*. New York: Farrar and Rinehart.

Lang, P. J. (1995). The emotion probe. Studies of motivation and attention. *The American Psychologist, 50*(5), 372-385.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review, 97*(3), 377-395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Attention and Orienting: Sensory and Motivational Processes. In P. J. Lang, R. F. Simons & M. Balaban (Eds.), *Attention and Orienting: Sensory and Motivational Processes*. Hillsdale: Erlbaum Associates.

Lang, P. J., Bradley, M. M., Cuthbert, B. N., & Patrick, C. J. (1993). Emotion and psychopathology: a startle probe analysis. *Progress in experimental personality & psychopathology research, 16*, 163-199.

LeDoux, J. E. (1990). Information flow from sensation to emotion: Plasticity in the neural computation of stimulus value. In M. Gabriel & J. Moore (Eds.), *Learning and Computational Neuroscience* (pp. 3-51). Cambridge, MA: Bradford Books (MIT Press).

LeDoux, J. E. (1995). Emotion: clues from the brain. *Annual Review of Psychology, 46*, 209-235.
LeDoux, J. E. (1996). *The Emotional Brain*. New York: Simon and Schuster.
Martín, J. L. M. (2006). *Mecanismos atencionales y preatencionales de los reflejos defensivos.* Unpublished doctorate thesis, University of Granada, Spain, Granada.
Milán, E. G., Hochel, M., Domínguez García, E., Mata, J. L., De Córdoba, M. J., & Vila, J. (submitted). Do colours really matter? Emotional and physiological impact of colours in chromatic synaesthesia. *Brain and Cognition*.
Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., et al. (2007). Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75-95.
Moltó, J., Montañés, S., Poy, R., Segarra, P., Pastor, M. C., Tormo, M. P., et al. (1999). Un nuevo método para el estudioexperimental de las emociones: The International Affective Picture System (IAPS). Adaptación española. *Revista de Psicología General y Aplicada, 52*, 55-87.
Ramachandran, V. S., & Hubbard, E. M. (2001a). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London, 268*, 979–983.
Ramachandran, V. S., & Hubbard, E. M. (2001b). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.
Ruiz-Padial, E., Sollers, J. J., Vila, J., & Thayer, J. F. (2003). The rhythm of the heart in the blink of an eye: Emotion-modulated startle magnitude covaries with heart rate variability. *Psychophysiology, 40*, 306-313.
Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime Reference Guide*. Pittsburgh: Psychology Software Tools Inc.
Searle, J. (1992). *The Rediscovery of Mind*. Cambridge: MIT Press.
Vila, J., Sánchez, M., Ramírez, I., Fernández, M. C., Cobos, P., Rodríguez, S., et al. (2001). El Sistema Internacional de Imágenes Afectivas (IAPS): Adaptación española. Segunda parte. *Revista de Psicología General y Aplicada, 54*, 635-657.
Vrana, S. R., Spence, E. L., & Lang, P. J. (1988). The startle probe response: A new measure of emotion? *Journal of Abnormal Psychology, 97*(4), 487-491.
Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.
Wheeler, R. H. (1920). The synaesthesia of a blind subject. *University of Oregon Publications, 5*, 1-61.

Chapter 6

Emotional Interplay Between Colors and Photisms in Chromatic Synaesthesia: a Single Case Study

Abstract

Synaesthesia is a condition in which one type of stimulation involuntarily evokes the sensation of another, as when the hearing of a sound induces perception of colors. Present study explores the emotional impact of color and photisms, i.e. percepts of "mental" colors, in R, a subject with emotionally conditioned synaesthesia. Anecdotal reports and one recent study suggest that synaesthetes are sensitive to inconsistencies between synaesthetic perceptions and outer stimuli, e.g. when a grapheme is depicted in a color different from the photism it induces. Interestingly, R seemed to be more sensitive to the emotional connotations of colors and to the *emotional coherence* of the colors present in outer stimuli. Our data are in line with a recent theory on synaesthesia, suggesting existence of hyperconnectivity between the limbic system and the brain areas responsible for color processing. By means of Startle Reflex paradigm we demonstrate that the absence or presence of emotional coherence modulates R's physiological responses to sudden white noise.

Introduction

R belongs to the unusual group of people with synaesthesia, a rare perceptual alteration where stimulation of one sense leads to sensations through another sensory channel. For instance, the hearing of a specific musical note can trigger the perception of color red in a given synaesthete. Not so long ago synaesthesia was considered mere psychological curiosity or even a fake. Fortunately in the past decades scientific research demonstrated that this “condition” was genuine, i.e. not a product of excessive imagination, delusion or hallucination, and had to do with peculiar neural activity observed in synaesthetes. Several studies on synaesthesia (e.g., Cytowic, 1996, 2002; Grossenbacher & Lovelace, 2001; Ramachandran & Hubbard, 2001; Smilek & Dixon, 2002) emphasized the importance of investigations into neural basis of synaesthesia that would allow us to understand the organization of synaesthetes’ brains and to uncover neurocognitive differences with respect to normal, non-synaesthete population.

R, the subject of our study, presents a variety of synaesthetic associations. In addition to the relatively common grapheme-color synaesthesia where numbers and letters trigger photisms (i.e., percepts of mental colors), also first names, surnames, town and city names, abstract concepts, faces, natural sounds and music elicit colors in R’s mind’s eye. (For example, the town of Granada is red, hope is white, intelligence is yellow, classical music is dark brown, both pain and joy are yellow, love is red, etc.) The present study is a continuation of our previous research (Hochel et al., submitted; Milán et al., 2007) where we explored R’s emotional sensitivity to colors as well as the relationship between photisms and real-world colors.

R is a unique case of synaesthesia for at least two reasons. First, besides being a synaesthete, he also suffers from a mild form of colorblindness; second, many of his synaesthetic associations (particularly those induced by visual scenes and people’s faces) are emotionally conditioned (See Milán *et al.*, 2007). More specifically, most of R’s photisms can be subjectively categorized in line with their emotional valence; e.g. attractive people elicit red photisms and disagreeable persons tend to be green. Overall, R shows an unusual emotional sensitivity to both photisms and real colors. He subjectively classifies colors according to their emotional valence: positive emotions seemed to be associated with red or purple colors; green evokes something repulsive or unpleasant, brown is uninteresting and boring and blue is emotionally neutral. The color yellow is the only shade that is somewhat ambivalent to R, with both joy and pain associated to it. (Even though colors also have emotional connotations for normal, non-synaesthete population (Heller, 2004), they tend to be ambiguous, e.g. red can be perceived as the color of love or the color of blood and aggression.) Our approach to the study of this singular subject is in line with a relatively recent neurocognitive model of chromatic synaesthesia (Ramachandran & Hubbard, 2003) that suggests an existence of hyperconnectivity between limbic regions and cortical areas responsible for color processing. Such anomalous pathways could explain the general tendency of synaesthetes to experience specific feelings accompanying their “phantom” perceptions as well as those rarer cases of synaesthesia (e.g., Milán et al., 2007; Ward, 2004) where emotions seem to act as synaesthetic triggers.

A number of anecdotal reports (Cytowic, 1989; Ramachandran & Hubbard, 2001) as well as one recent study (Callejas, Acosta, & Lupiáñez, 2007) suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world. For example, some lexical synaesthetes "cannot stand it" when a word is printed in a color different from the associated photism. Interestingly, R, the synaesthete subject studied by our research team, claimed that it was not the color-photism incongruence that bothered him the most. For instance, even though "beauty" and "strength" are red to R, it is "completely acceptable" when these words are depicted in purple or orange hues. According to R's claims, this is because emotions subjectively associated to these colors are not in conflict with the inherently positive feelings associated to the color red. Previous research with R suggested that his feelings about colors/photisms were not limited to subjective claims; they showed behavioral and even physiological correlates. When numbers were presented in frames which color was perceived as being emotionally incompatible with the photism triggered by the number, such incoherence affected R's performance in an odd-even decision task and it also modulated R's cardiac startle response to a sudden white noise (Hochel et al., submitted). On the other hand, mere photism-color incongruence did not have a negative impact on R's reactions, as long as the color shades (of the photism and the frame) were associated to the same emotional valence. For instance, the number five (the corresponding photism is RED and positive to R), presented in a purple frame (a color also associated to positive emotions), is perceived as emotionally coherent and therefore does not lead to negative emotions. On the other hand, if the same number is presented in a green frame (emotionally negative), R perceives it as unpleasant, he shows a slower reaction time in the odd-even task and his heartbeat is more strongly accelerated in response to a sudden noise. In summary, more than the color-photism incongruence, it is the emotional incoherence (of the valences of real colors and photisms) that is perceived as unpleasant and has an impact on R's reactions.

In our previous study (Hochel et al., submitted) we employed the startle reflex paradigm in order to demonstrate the impact of emotional incoherence on both R's performance and his physiological reactions. The startle reflex (SR) is a bodily reaction in response to a sudden unexpected stimulus, such as a flash of light, a loud noise, or a quick movement near the face. In laboratory experiments a white noise of 95 to 105 dB, 50 to 500 ms duration and an instant rise time is usually used to produce the typical pattern of motor and physiological reactions (Martín, 2006; Vrana, Spence, & Lang, 1988). The modulation of the SR (its amplification or reduction) when viewing affect-laden images, is one of the most robust experimental effects within the SR paradigm. The SR is typically enhanced by exposition to photographs of unpleasant visuals, while it is diminished when viewing photographs with emotionally positive content (Bradley, Cuthbert, & Lang, 1990, 1991; Lang, Bradley, & Cuthbert, 1990; Lang, Bradley, Cuthbert, & Patrick, 1993). The same effect is obtained with video sequences, reading of emotionally charged texts and also with non-visual stimuli such as sounds and smells (Martín, 2006). Lang (1995; Lang, Bradley, & Cuthbert, 1997) explains the aforementioned SR modulation in terms of motivational priming, as a result of emotional congruity (or incongruity) between two motivational forces. Namely, both the white noise and the unpleasant images used in laboratory SR experiments activate a defense system seeking to avoid aversive stimuli. Unpleasant photographs induce in the viewer a motivational stance which is in line with the defensive response triggered by another aversive stimulus (i.e. the white noise), therefore resulting in an amplified SR. On the other hand, positive stimuli (e.g., pleasant images, smells or music) act in the opposite direction, inducing appetitive motivation which reduces the subject's psychophysical responses to aversive stimulation. In Hochel et al. (submitted) we used cardiac variability measure in order to study possible emotional modulations of the SR by colors and photisms. We observed that the presence or absence of emotional coherence, i.e. the relationship between emotional valences of colors and photisms, determined the direction of the SR modulation. Perceived coherence diminished R's cardiac SR while emotionally incoherent stimuli usually enhanced it. In other words, R seemed to be particularly sensitive to the presence of conflict between his synaesthetic percepts and real colors but the physiological pattern observed was not determined by simple congruity of colors and photisms but rather by the emotional valences associated to colors and photisms. Nonetheless, despite the fact that the (in)coherence had a distinct impact on R's cardiac response, the interpretation of such physiological pattern might be intricate. The modulation of cardiac variability involves both the sympathetic and the parasympathetic nervous systems. In consequence, a downward modulation (i.e., attenuation) of the cardiac response may be attributed to at least two causal mechanisms: a) an appetitive motivational system triggered by a positively perceived stimulus, or b) a mechanism of attentional orientation triggered by the fact that a salient stimulus captures the subject's attention.

If the cardiac downward modulation observed in R a consequence of presenting an emotionally coherent stimulus was due to the fact that R perceived such coherence as pleasant, the same physiological pattern should be found when using a different measure, namely the blinking reflex. This is probably the most widely used index of SR, due to its high consistency and uncomplicated detection. It is measured through an electromyography (EMG) of the left orbicular eye muscle. Our hypothesis was that the EMG measure would go in the same direction as the results obtained with cardiac variability, i.e. blinking response to sudden white noise would be enhanced by emotionally incoherent stimuli (where photisms and real colors have conflicting emotional valences) and it would be diminished, or at least not influenced, by stimuli perceived as emotionally coherent.

Method

Since we wanted to examine R's emotional reactions towards colors per se (both real colors and photisms), we used number stimuli as synaesthetic inducers. (Different synaesthetic inducers, such as words or musical sounds, might not be as emotionally neutral to R as numbers and could therefore contaminate the data.) However, before proceeding with our exploration of R's emotional responses to real colors and photisms, it was necessary to obtain a thorough classification of his "phantom" colors. This was achieved by means of a customized computer program developed in the C# language, that would display a synaesthetic inducer (a number in this case) on the left side of the screen and a palette of color shades on the other side. R's task was to observe the inducer presented and then to choose the color sample that was closest to his synaesthetic experience. (See Milán et al., 2007, for detailed description of this procedure.) R went through numbers from one to ten; his responses were recorded in a data file. In Table 1 you can see the correspondence between the numbers and specific color shades as chosen by R. The number-color correspondence was reliable and consistent over time. In a retest 2 weeks later, R selected the same color hues in 92% of the trials. (It should be noted that in spite of being Daltonic, R was fairly confident about the colors corresponding to his photisms. Errors typically consisted in choosing the neighboring shade of the same color.)

Table 1: Results of the assessment of R's number photisms with the corresponding representation in real colors. For numbers 8 and 9, R did not find an appropriate color equivalent to his photism within the samples offered. He preferred to use Microsoft ® Paint color mixer to get hues exactly matching his photisms. Note that number 7 does not induce any synaesthetic response in R.

Number	Color name	RGB code	R's subjective color name	Emotional quality of the color
1	gainsboro	220,220,220	white	neutral
2	firebrick	178,34,34	red	neutral
3	yellow2	238,238,0	yellow	positive
4	steel blue3	79,148,205	blue	positive
5	red3	205,0,0	red	positive
6	grey71	181,181,181	pinkish grey	neutral
8	-	54,36,1	brown black	negative
9	-	255,255,0	ocher	negative

Color shades corresponding to R's number photisms, identified by means of the aforementioned procedure, were employed to create experimental stimuli. The main ambition of this study was to evaluate R's psychophysiological responses to both real colors and photisms and to explore the interplay between the two. In order to do so, we first asked R to categorize all the color hues corresponding to his number photisms as emotionally positive, negative or neutral. (See Table 1.) Afterward we used these hues to create colored frames that would be displayed along with the number stimuli. In order to put together a smooth experimental design, we added one more color shade that had been obtained in a pilot experiment, namely a desaturated green shade (RGB: 119,167, 89), evaluated as unpleasant by R. For the color frames, three positive colors (yellow2 /number 3 photism; steel blue3 /number 4 photism; red3 /number 5 photism), three neutral colors (gainsboro /number 1 photism; firebrick /number 2 photism; grey71 /number 6 photism) and three negative colors (brown-black /number 8 photism; ocher /number 9 photism; desaturated green /119,167, 89) were used. Next, number stimuli (digits 1-2, 4-6, 8-9) were combined with colored frames that were either congruent or incongruent with the photism associated to the number. In addition, a white-frame condition was employed in order to study the possible effects of photisms by themselves.

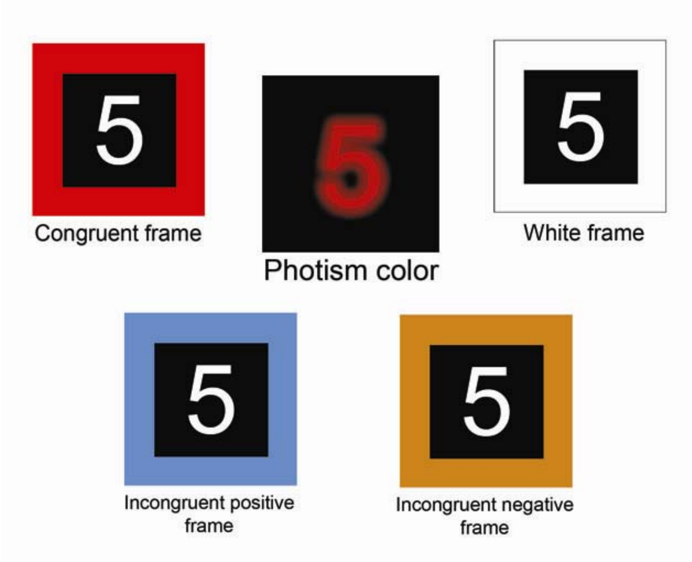


Figure 1: We combined color frames with number stimuli that were either congruent or incongruent with the photism associated to the number. In addition to the congruent / incongruent condition, we also manipulated the emotional value of the color frames in such a way, that the valence of the frame could be the same as or opposite to the valence of the photism. In this example, the red photism elicited by the number 5 is perceived as pleasant by R, being emotionally consistent with the blue, positive frame and inconsistent with the ocher frame which is emotionally negative. White frame condition was employed to study the influence of photisms themselves.

Besides the congruent/incongruent condition, the emotional values of both the photisms and the color frames were considered in the experiment. The resulting experimental design would include the following independent variables: frame (congruent, incongruent negative, incongruent positive and white frame); color/photism valence (positive, negative or neutral). Note that when the frame color was different (incongruent) with respect to the photism, it could be or not be emotionally coherent with the valence of the photism associated to the inducer. This set-up led to 4 frame–photism combinations, as depicted in Figure 1. (The white frame was perceived as a "no-color" condition and therefore it was neither considered congruent nor incongruent with respect to photisms; its valence was not included in the design.)

In the experiment that follows, we used these stimuli along with randomly presented white noise in order to study the influence of colors and photisms on R's startle response. Previous experiments (Hochel et al., submitted) had shown that R's cardiac startle reaction was enhanced by the presentation of emotionally incoherent stimuli. If the same pattern was found with an additional physiological measure, this would further corroborate the hypothesis that the concept of emotional coherence of colors does not only have subjective significance, but it also affects the synaesthete on a physiological level.

Apparatus

To register the activity of the left eye orbicular muscle, we placed Beckman miniature electrodes with double-sided adhesive discs on the corresponding region of R's face. Electrolytic gel was applied. The muscle activity was measured using a pre-amplifier (V75-04) and an integrator (V76-23A). In order to induce the SR, a white noise was generated by an auditory stimulator (Coulbourn V85-05) and an amplifier (IMQ Stage Line). The sound intensity was calibrated using a sonometer (Brüel & Kjaer, model no. 2235) and an artificial ear (Brüel & Kjaer, model no. 4153). The resulting sound of 105 dB was transmitted to the subject through earphones (Telephonics, model no. TDH49P). The sound rise time was instantaneous. The SR measure was operationally defined as the maximum amplitude of the integrated electromyograpic response of the orbicular muscle, initiated within the first 100 ms following the sound stimulus onset. The EMG sampling frequency was 1000 samples per second; the signals were registered from 500 ms before the stimulus onset until 1000 ms after it. During the rest of the trial time the EMG response was measured 10 times per second.

Procedure

The experiment took place in a dimly lit, sound-insulated room. R's task was to observe the numbers 1, 2, 4, 5, 6, 7 and 9[1], presented with a congruently colored frame, an incongruently colored frame or a white frame, on an LCD monitor (Acer AL1714, 17"). Each stimulus appeared on a computer screen for 6 seconds. The SR inducing sound (white noise) was randomly presented within the time interval from 2.5 to 4.5 seconds. The total of experimental trials was 96 (24 per condition); we also included 9 trials where no sound was presented, and 9 trials with no image, in order to eliminate habituation.

Results

The experimental design was 4x3 with the following variables: Frame (congruent, incongruent positive, incongruent negative and white frame) and Valence of the photism triggered by the number stimulus (positive, negative and neutral).

Statistical analysis revealed a significant main effect of the Frame, $F(3,15) = 3.91$, $p<0.03$, as well as an interaction between the Frame and the Photism valence, $F(6,15)=3.27$, $p<0.02$. (See Figure 4.) Considering the main effect of the frame, the EMG amplitude (in microvolts) was of 50.87 in the congruent condition, 40.25 in the white frame condition, 35.68 in the incongruent positive condition and 48.50 in the incongruent negative condition. There was a significant difference between the incongruent positive and the congruent conditions, $F(1,5)=7.28$, $p<0.04$. There was also a significant difference between the white frame condition and the incongruent negative condition ($F(1,59) = 12.40$, $p<0.01$) and between the white frame condition and the congruent condition ($F(1,5) = 7.80$, $p<0.03$). In brief, R's startle reflex was influenced by the frame color.

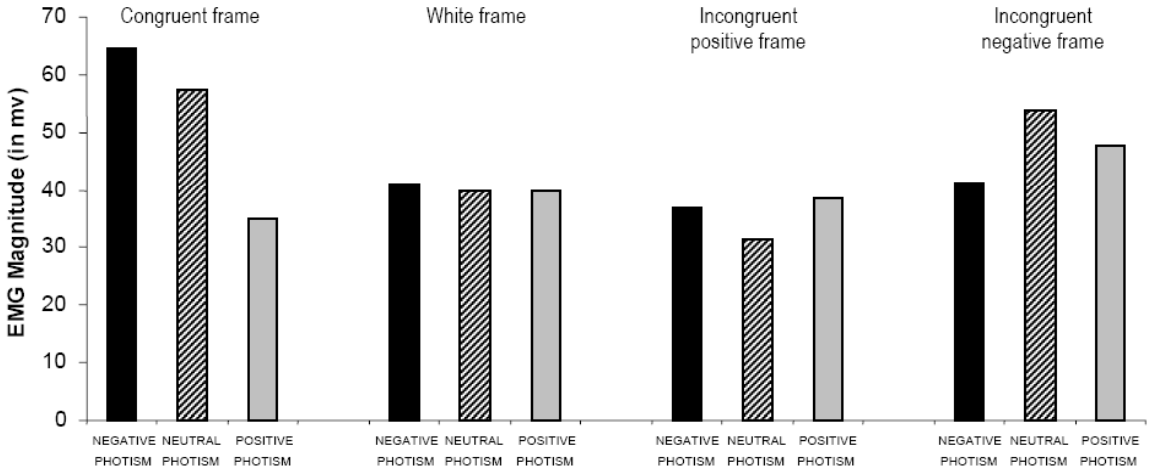


Figure 2. Modulation of the EMG startle response by framed number stimuli. When the frame color and the photism are congruent, the SR modulation behaves according to the expected pattern: it is enhanced by the stimuli of negative valence and attenuated by the positive ones. However, when the colors do not match, the emotional coherence seems to be important. With opposite emotional valences between the frame and the photism, the real color valence is dominant, modulating the SR in the corresponding direction. When the valences are consistent, such coherence seems to exert a positive role, i.e. it attenuates the SR. The photisms by themselves do not seem to modulate the SR.

First, we will consider the interactive effects that appeared in the results. The photism valence did not influence R's EMG in the white frame condition and the incongruent positive frame condition. In the incongruent negative condition, there was a marginally significant difference between the negative photisms and the neutral photisms, $F\ (1,5)=5.48$, $p<0.06$. In the congruent condition, the EMG amplitude difference between the positive photisms and the negative photisms was significant, $F\ (1,5)=8.69$, $p<0.03$. In other words, when the color of the frame was the same as the color of the photism, R's SR was affected by the emotional valence of the photism or the valence of the frame color or both. As expected, negative colors enhanced the EMG response while positive colors attenuated the SR. When the color frame was emotionally positive and incongruent with respect to the photism, the SR was smaller, independent of the photism valence. For incongruent negative frames, the SR was smaller for the negative photisms only. In the white frame condition, the SR did not seem to be affected by the photisms at all.

Now let's focus on the role of the photism valence. For emotionally neutral photisms, there was a marginally significant difference between the incongruent positive frame condition and the incongruent negative frame condition, $F\ (1,5)=4.76$ $p<0.08$. For negative photisms, the following comparisons were significant: congruent frames with respect to both the incongruent positive and the incongruent negative frames, $F\ (1,5)=7.82$, $p<0.03$ and $F\ (1,5)=7.10$, $p<0.04$ respectively. There was also a significant difference between the white frame condition and the congruent frame condition, $F(1,5)=19.10$, $p<0.00$. For positive photisms, the congruent frame condition and the incongruent negative frame condition were statistically different, F (1,5)=5.69, $p<0.05$. In summary, for neutral photisms the SR is weakened when the frame color is positive to R. For positive photisms, the SR is enhanced by the incongruent negative frames when compared to the incongruent positive frame condition, the congruent frame condition and the white frame condition. For negative photisms, the SR is intensified in the congruent condition and it is smaller in the two incongruent conditions.

Overall we could summarize the interaction between the valences of frames and photisms in a series of rules. First of all, the photisms by themselves do not seem to modulate the SR. Secondly, in the case of color congruency between the frames and the photisms, the SR modulation behaves according to the expected pattern: it is enhanced by the stimuli of negative valence and attenuated by the positive ones. Finally, when the colors of the frame and the photism do not agree, the emotional coherence appears to be important. When the colors (of the photism and the frame) have opposite emotional valences, the real color valence is dominant, modulating the SR in the corresponding direction. (See Table 2.) More interestingly, when the valences are consistent (even though the colors are not), such coherence seems to exert a positive role, i.e. it attenuates the SR. This effect is obvious at least in the case of negative photisms/frames. (The reason why an EMG attenuation may be harder to observe in the case of positive frames is because these, by themselves diminish the SR in both the negative photism condition and the congruent condition, hence disguising the effect of emotional coherence in the incongruent condition.)

Table 2: the role of emotional coherence in the startle reflex of the synaesthete subject R. The table represents the hypothesized influence of emotional coherence between the photisms (induced by numbers) and the real colors (colored frames), in presence of color incongruence between the two. The arrows indicate the direction of the EMG modulation: an up-arrow means an increased response; the down-arrow a decreased response.

FRAME VALENCE	PHOTISM VALENCE	STARTLE RESPONSE (EMG)
+	-	↓
-	+	↑
-	-	↓
+	+	↓*

** Note that in the case of positive valences the purported EMG reduction might be harder to detect, as we explain in the text.*

Discussion

According to previous experimental results obtained with R (Hochel et al., submitted; Milán et al., 2007), both real colors and photisms can influence the synaesthete’s behavioral and physiological indexes in a way determined by the affective valences of colors and/or photisms. The colored frames influenced R’s subjective judgments, they affected his reaction time in a behavioral task and they shaped cardiac startle response to aversive sound. The continuation of this experimental series by using an additional physiological measure, the EMG of the left orbicular eye muscle, yields new data which go in the same direction.

Nevertheless, before discussing the main findings, it is convenient to comment on a series of effects which are more intricate and one an only speculate on their origins. First, R's EMG patterns show that the photisms in the white frame condition do not have a direct impact on R's responses. (Note that this result is equivalent to that obtained with the cardiac variability measure.) Why do not the photisms by themselves modulate the SR? A possible explanation might arise form the fact that R perceives photisms in his mind's eye; he can be classified as an associator synaesthete (Dixon, Smilek, & Merikle, 2004). In consequence, it could be that in the given experimental context the photisms (perceived in his mind's eye) were not sufficiently "attention-grabbing" so as to lead to the modulation of the SR. On the other hand, when a color frame is present, it may turn R's attention towards the photisms because of being of the same color (congruent) or, conversely, of an incongruent color with respect to the photism.

Another question is why the effect of emotional coherence is not observed in the congruent condition, which is, by definition, emotionally coherent. For instance, why does not the emotional coherence attenuate the SR in the congruent, negative photism condition? A possible conjecture is that the mechanism of emotional coherence may only be important to R when the real world colors do not match his photisms. Such situations could seize R's attention, while contexts where "everything matches" simply shape R's emotional responses (and the SR) in a straightforward manner, by activating the corresponding motivational system.

In any case, by applying the EMG measure we have obtained additional evidence in favor of the hypothesis that the concept of emotional coherence is not limited to R's subjective point of view. Its effects can be shown on multiple levels, now including the modulation of R's blinking response to a startle producing sound. As a whole the data from the previous experiments (Hochel et al., submitted) and the present study converge nicely, suggesting that R's perception of the stimuli as emotionally coherent and therefore positive, leads to the expected downward modulation of the SR. (The opposite occurs with emotionally incoherent stimuli, producing an upward modulation.) These results may have important implications for current neurocognitive models of synaesthesia. Most importantly, the fact that both real colors and photisms can influence the synaesthete's behavioral and physiological indexes is in line with the theory suggesting an existence of hyperconnectivity between limbic regions and cortical areas responsible for color processing (Ramachandran & Hubbard, 2003). Research focused on emotional modulation of the SR suggests that the amygdala (a part of the limbic system) is the principal responsible for the SR being modulated by fear (Everitt, Dickinson, & Robbins, 2001; LeDoux, 1990, 1995, 1996). A number of neural pathways allow the amygdala to control different types of responses within the autonomic nervous system. On that account, it is probable that specific neural pathways connecting the limbic system to cortical areas responsible for color processing are working in R's brain, giving raise to the observed modulatory effects. However, it should be noted that these conjectures might only apply to the single case presented here. Further research will be necessary to corroborate whether the behavioral and physiological effects related to emotional impact of colors are also present in other synaesthetes or whether it is an idiosyncratic feature of R or, possibly, of emotionally conditioned synaesthesias.

Endnotes:

1. The number 8 was not included because it did not induce any synaesthetic response in R. We decided to eliminate the number 3 because R mentioned that he perceived the associated photism (yellow) as being incongruent with the number shape itself, which was slightly disturbing for him.

References

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1990). Startle reflex modification: emotion or attention? *Psychophysiology, 27*(5), 513-522.

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1991). Startle and emotion: lateral acoustic probes and the bilateral blink. *Psychophysiology, 28*(3), 285-295.

Callejas, A., Acosta, A., & Lupiáñez, J. (2007). Green love is ugly: emotions elicited by synesthetic grapheme-color perceptions. *Brain Research, 1127*(1), 99-107.

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses*. New York: Springer.

Cytowic, R. E. (1996). Synesthesia: Phenomenology and neuropsychology [Electronic Version]. *Psyche*, *2*. Retrieved 10 january 2007 from http://psyche.cs.monash.edu.au/v2/psyche-2-10-cytowic.html.

Cytowic, R. E. (2002). Touching tastes, seeing smells—and shaking up brain science. *Cerebrum, 4*(3), 7–26.

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4*(3), 335-343.

Everitt, B. J., Dickinson, A., & Robbins, T. W. (2001). The neuropsychological basis of addictive behavior. *Brain Research Review, 36*, 129-138.

Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synesthesia: cognitive and physiological constraints. *Trends in Cognitive Science, 5*, 36–41.

Heller, E. (2004). *Psicología del Color*. Barcelona: Gustavo Pili.

Hochel, M., Milán, E. G., Mata, J. L., González, A., Domínguez García, E., Tornay, F., et al. (submitted). Congruence or coherence? Emotional and physiological responses to colors in synaesthesia.

Lang, P. J. (1995). The emotion probe. Studies of motivation and attention. *The American Psychologist, 50*(5), 372-385.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review, 97*(3), 377-395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Attention and Orienting: Sensory and Motivational Processes. In P. J. Lang, R. F. Simons & M. Balaban (Eds.), *Attention and Orienting: Sensory and Motivational Processes*. Hillsdale: Erlbaum Associates.

Lang, P. J., Bradley, M. M., Cuthbert, B. N., & Patrick, C. J. (1993). Emotion and psychopathology: a startle probe analysis. *Progress in experimental personality & psychopathology research, 16*, 163-199.

LeDoux, J. E. (1990). Information flow from sensation to emotion: Plasticity in the neural computation of stimulus value. In M. Gabriel & J. Moore (Eds.), *Learning and Computational Neuroscience* (pp. 3-51). Cambridge, MA: Bradford Books (MIT Press).

LeDoux, J. E. (1995). Emotion: clues from the brain. *Annual Review of Psychology, 46*, 209-235.

LeDoux, J. E. (1996). *The Emotional Brain*. New York: Simon and Schuster.

Martín, J. L. M. (2006). *Mecanismos atencionales y preatencionales de los reflejos defensivos.* Unpublished doctorate thesis, University of Granada, Spain, Granada.

Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., et al. (2007). Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75-95.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.

Ramachandran, V. S., & Hubbard, E. M. (2003). The Phenomenology of Synaesthesia. *Journal of Consciousness Studies, 10*(8), 49-57.

Smilek, D., & Dixon, M. J. (2002). Towards a Synergetic Understanding of Synaesthesia: Combining Current Experimental Findings Withs Synaesthetes' Subjective Description [Electronic Version]. *Psyche*, *8*. Retrieved December 12, 2006 from http://psyche.cs.monash.edu.au/v8/psyche-8-01-smilek.html.

Vrana, S. R., Spence, E. L., & Lang, P. J. (1988). The startle probe response: A new measure of emotion? *Journal of Abnormal Psychology, 97*(4), 487-491.

Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.

Part III

Creativity in Synaesthesia

Chapter 5

Are Synaesthetes More creative Than Non-synaesthetes?

***** *Submitted paper (Creativity Research Journal)*

Abstract

Synaesthesia involves a mixing between (or among) different sensory modalities. Typically one type of sensory stimulation evokes the sensation of another, as when the hearing of a sound leads to photisms, i.e. mental percepts of color. Synaesthesia has often been associated with artistic creativity. A series of authors speculated that synaesthesia may lead to an above-average creative potential. The present paper explores this hypothesis by examining three components of creativity (cognitive fluency, flexibility and originality) in synaesthetes and non-synaesthete subjects. The subjects' creative potential was assessed by means of standardized psychometric measures as well as a non-standard creative imagery task.

Introduction

Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound produces photisms, i.e. mental percepts of colors. In the past, the idiosyncrasy of this phenomenon, as well as the natural mistrust of scientists towards the subjective, consigned synaesthesia to the periphery of scientific interest. Nonetheless, long before synaesthesia was recognized as a genuine sensory phenomenon, worthy of serious study, there had been anecdotal data about peculiar people who could “see music”, “smell personalities” or “appreciate the color of phonemes”. Many of these anecdotes were related to personages belonging to artistic circles (e.g., see Cytowic, 1989; Day, 2005; Mulvenna, 2007). The list of synaesthete artists is considerably long: writer Vladimir Nabokov, composers Jean Sibelius, Amy Beach, Franz Liszt and Nikolai Rimsky-Korsakov, the jazz legend Miles Davis, painters David Hockney, Wassily Kandinsky, etc. The term synaesthesia has also been used (sometimes quiet deliberately) to denote a more general use of cross-modal associations in literature, visual arts as well as theater and musical performances which seek to stimulate spectator’s senses in novel ways. Altogether, the context surrounding the role of synaesthesia in the arts suggests for a seemingly strong relationship between synaesthesia and artistic creativity. The question is: do we have any data (beyond anecdotal reports) supporting the claim that synaesthetes are actually more creative than non-synaesthetes? Obviously anecdotal reports cannot be sufficient by any means to draw casual conclusions. As an illustration, consider the following names: Jack Kerouac (writer), Syd Barrett (musician; member of Pink Floyd band), John Nash (mathematician; Nobel Prize), James Watson (co-discoverer of DNA; Nobel Prize). What all these personages have in common, in addition to their extraordinary artistic or scientific skills, is having suffered from schizophrenia. On these grounds, would anybody suggest that schizophrenic condition enhances creativity? Most probably not.

Going back to synaesthesia, a small number of studies provided statistical evidence on the purported higher prevalence of synaesthesia among artists (Dailey, Martindale, & Borkum, 1997; Domino, 1989). A recent study by Rich, Bradshaw, & Mattingley (2006) confirms earlier accounts on this issue. According to their data, recollected from 158 questionnaires, up to 24% of synaesthetes are involved in artistic professions. (This proportion is much higher than the one observed in general population.) Yet, even though one may be inclined to interpret this piece of information in terms of higher creativity of people with synaesthesia, there is at least one alternative explanation. Certainly, one would not expect all “non-synaesthetes”, who could score high on some kind of creativity test, to be involved in artistic professions. Thus, it is possible that synaesthetes are simply more prone to work in artistic field than non-synaesthetes and the proportion of people with above-average creative potential is the same in both populations. (What's more, being a professional artist does not necessarily imply that one is original and creative.)

In summary, the evidence concerning higher proportion of artists among synaesthetes is indirect in nature. Are there any other clues pointing to above-average creativity in synaesthetic population? Yes, there are. Domino (1989) tested 61 self-reported synaesthetes and 61 controls on four measures of creativity. The results demonstrated that on average the synaesthetes scored higher than the controls on the four measures. Unfortunately, the study suffered from a major methodological flaw – the author did not test the subjects' synaesthetic condition, relying on self-report only. More recently, Sitton & Pierce (2004) used a verbal creativity test, responded online by 210 subjects. Again, the analysis yielded a significant correlation between scores on Synaesthesia and Verbal Creativity. However, the study had the same inconvenience as the one by Domino – absent experimental measure of synaesthetic experience. Another recent study (Ward, Thompson-Lake, Ely, & Kaminski, in press) suggests that synaesthetes may perform better on some measures of creativity than non synaesthetes, but this does not necessarily imply that they are overall more creative.

In addition to demographic and psychometric data, there are also theoretical grounds in favor of the synaesthetes' higher creativity. Virtually all current neurocognitive models of synaesthesia suggest an existence of some kind of neural hyperconnectivity between specific regions of synaesthete's brains (See the review by Hochel & Milán, in press; also see Hubbard & Ramachandran, 2005). Ramachandran and Hubbard (2001) proposed that if the hypothesized "cross-wiring" was more diffusely expressed, it could lead to "a greater propensity and opportunity for creatively mapping from one concept to another." Indeed, in its essence, creative skills typically involve combining elements (words, concepts, materials, etc.) in novel ways. In a more general sense, creative ability (or creative potential) could be understood as a result of specific, "creative" neural patterns of the human brain.

In summary, besides the well-known cases of synaesthete artists, there are a number of empirical and theoretical reasons suggesting that people with synaesthesia might be, on average, more creative than "normal" population. However, the evidence available up to date suffers from a series of problems which make it less compelling. First, the close relationship between art and synaesthesia in all its aspects exerts a very suggestive influence, creating a more or less generalized social perception of synaesthetes as "creative people." Secondly, even though there is some evidence in favor of synaesthetes' higher creativity, a major part of the data available is indirect in nature and does not allow for causal inferences (e.g., higher percentage of synaesthetes among art students). Finally, there have been very few psychometric studies of creativity in synaesthesia and their results are far from conclusive. Some of them (Domino, 1989; Sitton & Pierce, 2004) relied on self-reported synaesthetes, without testing the synaesthetic condition in neither the synaesthetes nor the control subjects. The most recent study by Ward et al. (in press) did not provide conclusive evidence. In summary, the case for higher creativity in synaesthetes could not be as strong as it may possibly seem. In order to shed some light on this issue, the present study describes a series of experimental explorations which could provide new data on the account of the purported relationship between synaesthesia and creativity.

In very general terms, the creativity of any given individual can be approached in at least two ways. Usually a person is considered creative when she/he produces an above-average number of innovative and original solutions to a given problem, whatever this problem is (construction of a building, a mathematical enigma, an artistic performance, etc.). In contrast to this socially motivated view, psychology tends to see creativity as an aptitude or a cognitive potential which may but need not to be put into practice. The present study is in line with the latter approach, which is reflected in psychometric models of creativity. The concept of creativity, along with constructs such as intelligence or consciousness, constitutes a very foggy domain with no clear-cut definition. However, it is outside the scope of this study to account for the numerous theoretical models that have appeared up to date. The methodology employed here was inspired by the view originally proposed by Guilford (1950; 1957; 1968), who considered creative ability as a compound of a series of cognitive components or factors. Even though the number of "primary mental abilities", as proposed by the author, is relatively large, there are only three main factors considered critical for creativity, particularly in the field of artistic expression: fluency, flexibility and originality (Guilford, 1957). In general terms cognitive *fluency* implies the ability to produce a high number of meaningful ideas/responses when confronted with a problem. The *flexibility* component has two slightly different facets: spontaneous flexibility is a "disposition to avoid repeating oneself or an urge to vary one's behavior" and adaptive flexibility is the ability to vary ones behavior in response to a situation which requires doing so. Finally, *originality* makes reference to unusual, uncommon and "clever" solutions to a problem.

In order to evaluate the creative potential of synaesthetes and non-synaesthetes, we employed a series of tools aimed at each of the three cognitive components. Verbal fluency was assessed by means of a phonological fluency test and a semantic fluency test (Spreen & Strauss, 1991). Cognitive flexibility tests included were Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993), Stroop Color and Word Test (Golden, 1994) based on the Stroop paradigm (Stroop, 1935) and Trail Making Test (Reitan, 1992). Finally, originality was evaluated by means of an adapted version of Finke's creative imagery task (Finke, 1990; Finke & Slayton, 1988). Performance of a group of three synaesthetes was compared to a group of three non-synaesthetes.

Experiment 1: Cognitive Fluency in Synaesthesia

Participants

Participants were three self-reported synaesthetes and three non-synaesthetes. The synaesthetes were L, a music-color synaesthete, R, a lexical-chromatic synaesthete, and M, a texture-color synaesthete. During preliminary interviews, the synaesthetes were asked about their specific synaesthetic associations. One week later, they were re-interviewed in order to asses the stability of their synaesthesia. All the synaesthetes showed 100% consistence in their claims. To further explore their synaesthetic condition, the subjects were also asked to fill in an online version of the Synaesthesia Battery (Eagleman, Kagan, Sagaram, & Sarma, 2007). The test results were positive for the three synaesthetes.

The control subjects were psychology students who participated in exchange for course credits. They were approximately the same age as the synaesthetes (20 to 25) and were matched for gender. In order to rule out possible presence of synaesthesia, the controls also passed the Synaesthesia Battery which gave a negative result for all of them.

Method

In the phonological fluency task the subjects were instructed to say aloud as many words starting with the letter “P” as possible. The time limit was 60 seconds. The task was executed by each subject individually, in a quiet room. For the semantic fluency task the subjects were asked to generate words belonging to a given lexical category which was “animals”. The time limit was 60 seconds, too.

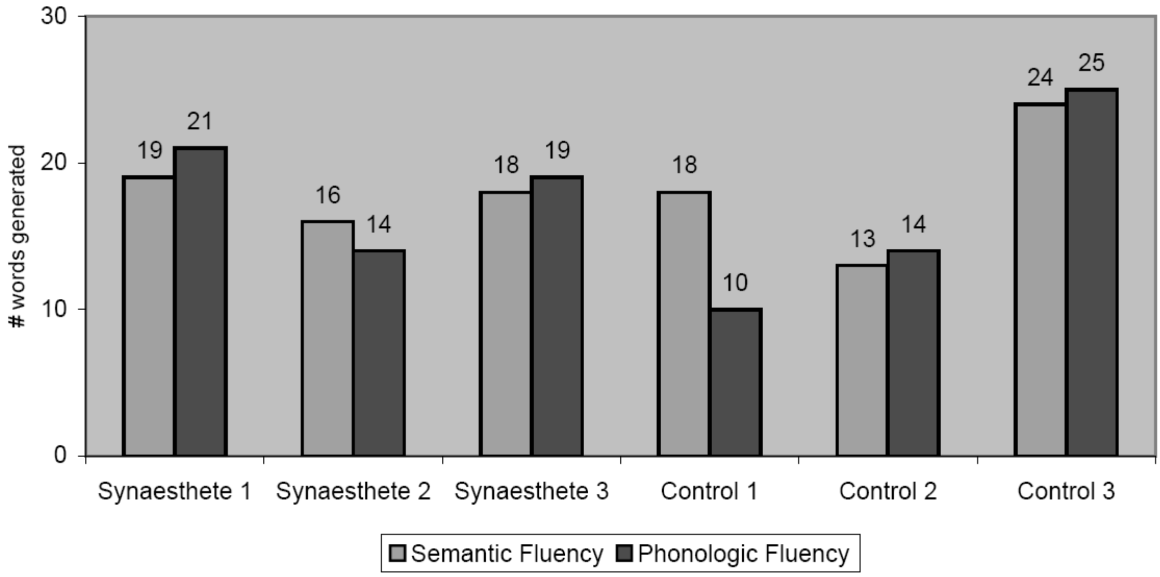


Figure 1: The number of words generated by synaesthetes and non-synaesthetes in the semantic and the phonological fluency tasks.

Results

The mean number of words generated by the synaesthetes and the controls in the semantic fluency task was 17.7 and 18.3 respectively (t= -0,2, p=0.85). In the phonological fluency task the synaesthetes generated on average 18 words and the controls 16.3 words. The latter difference was not significant (t=0.34, p=0.75). The results suggest that there are no significant differences in performance between the synaesthetes and the control subjects, in neither of the two cognitive fluency tasks. (See Figure 1 for individual raw scores of all subjects.)

Experiment 2: Cognitive Flexibility in Synaesthesia

The ability to switch attention from one aspect of an object to another is commonly referred to as cognitive flexibility. There are a number of tests which are supposed to measure the functioning of this cognitive mechanism. Some of them, such as the Wisconsin Card Sorting Test (Heaton et al., 1993) or the Trail Making Test (Reitan, 1992) are commonly employed in clinical assessment of neurological patients. In principle it is impossible to decide which test is best for measuring cognitive flexibility. The present study includes three measures which are widely used for clinical and/or experimental purposes. In addition to the two tools mentioned above, the participants were subjected to the Spanish version of Stroop Color and Word Test (Golden, 1994).

Participants

The same as in Experiment 1.

Method

Each participant individually passed the three tests mentioned above, i.e. Wisconsin Card Sorting Test (WCST), Trail Making Test (TMT) and Stroop Color and Word Test.

WCST consists of a set of cards (similar to regular playing cards) that can vary on three dimensions: color (blue, red, yellow or green), form (crosses, circles, triangles or stars), and number of objects (1, 2, 3 or 4). The participant is given a stack of 128 cards and is asked to sort each response card under one of four stimulus cards (situated in front of her/her) along one of three dimensions. After each sort, the subject is told whether the sort was right or wrong, but she/he is never informed of the correct sorting principle. The sorting principle is arbitrarily changed (without forewarning) once that the participant has sorted correctly 10 cards in a row. The test is completed after six correct categories achieved or when all cards 128 cards have been used.

The following indexes defined in the WCST manual (Heaton et al., 1993) were used for the analysis: (1) Number of trials to successfully complete the first category, reflecting initial conceptual ability; (2) Number of perseverative errors, i.e., errors reflecting tendency towards perseveration; (3) Number of non-perseverative errors; (4) Number of perseverative responses (regardless of whether they were correct or not); (5) Categories achieved: number of times 10 correct responses in a row were made; (6) Conceptual Level Response: proportion of consecutive correct responses occurring in runs of 3 or more, reflecting insight into the correct sorting principles; (7) Total number of trials ; (8) Total number of errors.

The Trail Making Test (TMT) (Reitan, 1992) is a paper-and-pencil task assessing the ability to shift attention between different verbal sets. It consists of two parts, TMT A and TMT B. The TMTA is always administered first and requires subjects to rapidly connect (in ascending order) numbers ranging from 1 to 25 which are randomly distributed on a sheet of paper. In the TMT B part, both numbers (1 – 13) and letters (A – L) are randomly positioned across the sheet and subjects have to alternately connect the numbers and the letters in ascending order (i.e.: 1–A–2–B–3–C–4–D….) as quickly as possible. The subjects were instructed to perform each subtask of the test. The RTs needed for the completion of each of the two subtasks were the dependent variables. The corresponding shifting costs were computed as a difference between the RTs of the two subtests (TMT B – TMT A).

Stroop Color and Word Test (Golden, 1994) assesses the ability to inhibit a reading response tendency in the face of interfering information in the verbal domain. On separate subtests, subjects are instructed to read out color names printed in black ink (“Read” task), name the colors of “XXXX” letters printed in color (“Name” task) and name the ink color of printed color names (“Interference” task) where the ink color is different from the color name (e.g., the word “red” printed in green ink). The three subtasks “Read”, “Name” and “Interference”, each containing 100 stimuli (color names, colored “XXXX” or colored color words), were administered in the order specified above. The time limit for each subtask was 45 seconds. Dependent variables were the number of word read (“Read” task) and the number of colors named (“Color” and “Interference” tasks). “Interference score” was computed following the formula specified in the manual (Golden, 1994).

Results

In the WCST all subject successfully completed 6 categories (i.e., achieved 6 times 10 correct responses in a row). Raw WCST scores were analyzed using a t-test for the significance of the differences between the mean raw scores of the synaesthetes and the controls. There were no significant differences between the synaesthete participants and the controls in none of the WCST indexes included in the analysis (p>0.1). (See Table 1.) In theory, if the synaesthetes were to show higher cognitive flexibility than the control subjects, they should have scored better then the controls, at least in some of the WCST indexes (e.g., should have presented a significantly lower number of perseverative errors or a lower number of perseverative responses). However, this was not the case.

Table 1: Results of t-tests for the significance of the differences between the mean WCST scores of the synaesthetes and the controls

WCST Index	*Synaesthetes (mean score)*	*Controls (mean score)*	*t value (two tailed, independent samples)*	*p value*
Trials to complete first category	10,33	17,67	-1,56	0,19
Perseverative errors	11,00	9,00	0,52	0,63
Non-perseverative errors	2,33	4,67	-0,94	0,40
Perseverative responses	13,67	9,67	0,82	0,46
Categories achieved	6,00	6,00	-	-
Conceptual Level Response	61,00	62,00	-0,45	0,68

The mean shifting cost on the Trail Making Test (TMT B – TMT A) of the synaesthetes was 30.7 seconds; the controls achieved 24.3 seconds. Again, if the synaesthetes’ cognitive flexibility was higher, they should have shown a smaller cost than the controls. However, the null hypothesis turned out to be true and there was no difference in terms of shifting costs between the synaesthetes and the control participants (t=0.33, p=0.75).

For Stroop Color and Word Test (Golden, 1994), the mean interference score was 3.86 and 6.20 for the synaesthetes and the controls respectively.[1] The difference between means was not significant (t = - 0.36, p = 0.73). This result suggests that, as far as the resistance to interference (from the reading automatism) is concerned, the synaesthetes are not significantly different from the controls. However, it should also be noted that in R’s case the results of the test might have been distorted by the fact that graphemes triggered synaesthetic concurrents.

In summary, the synaesthetes did not significantly outperform the controls in none of the tests employed to assess cognitive flexibility.

Experiment 3: Originality of Visual Creations and Synaesthesia

An adapted version of Finke's creative imagery task (Finke, 1990) was employed to assess the *originality* component. The task consists in combining bi- and/or three-dimensional objects in one's mind's eye in order to come up with a meaningful object. Subjects are given a paper with three shapes (randomly selected out of a battery of objects), e.g. a sphere, a cube and a funnel, and they are instructed to use their imagination to create a meaningful item they can put a name on. Drawing is not allowed during mental imagery; normally the time to perform the task is limited. In a second stage of the test, independent "judges" are asked to evaluate participants' creations.

Participants

The same as in Experiments 1 and 2. Three university students (aged 22 to 24, two females and two males), who participate voluntarily, played the role of "judges".

Method

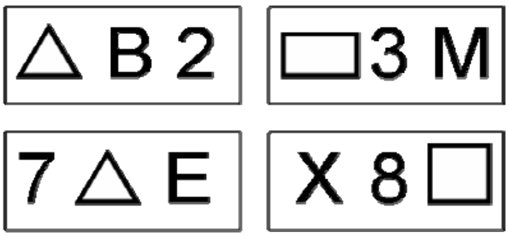


Figure 2: Examples of stimulus triplets employed in Experiment 3.

The main difference of our version of the creative imagery task with respect to the original was in the stimuli employed. Only letters, numbers (1 through 9) and simple geometric shapes (square, equilateral triangle, circle and rectangle) were employed for the task. Each stimulus consisted of a combination of one letter, one geometric shape and a number. Altogether we used 10 different triplets. (See Figure 2, for an example.) During a trial, the subjects were given a paper with the representation of the three figures and they were instructed to "mentally combine" the shapes with the aim of producing a meaningful object. They were allowed to change the relative sizes of the original objects, but not their proportions (e.g., they could not transform a square into a rectangle). The shapes could not be deformed or bent. When a participant came up with a result, she/he was asked to first write down the name of her/his creation and then to draw the corresponding figure. The time limit was 60 seconds.

The creative imagery task was administered to each subject individually. There was a short break after each trial. Resulting creations were given to four independent "judges" who evaluated participants' creations on two scales.

A) <u>Correspondence scale</u> (1-5) referred to the degree of correspondence between the name and the figure. When the object (as named by its author) could be recognized very easily by a judge, it received the maximum score (5). When it was absolutely unrecognizable, it was scored 1. Intermediate scores (2-3-4) could be used when appropriate.

B) <u>Creativity scale</u> (1-5) indicated the perceived degree of originality of the object. When the creation was considered exceptionally original, it was scored 5. If it was absolutely uncreative, it was scored 1. Again, intermediate scores allowed for a more fine-grained evaluation.

All the judges were university students (aged 22 to 24, two females and two males) who participated voluntarily. The judges were not told about the subjects' synaesthetic condition, neither were they informed about the aim of the research. They received a scoring table and detailed instructions about the scoring system. Each judge received participants' drawings in random order. After the scores were recollected, a mean correspondence score and a mean creativity score were calculated for each individual drawing, based on the individual scores from the four judges.

Results

Average scores were 3.05 for Correspondence and 3.42 for Creativity. The synaesthete group reached 2.95 (Correspondence) and 3.37 (Creativity); the non-synaesthetes' scores were 3.14 and 3.37 respectively. Overall there were 9 "blank" trials (no object created), 4 for the synaesthete subjects and 5 for the controls.

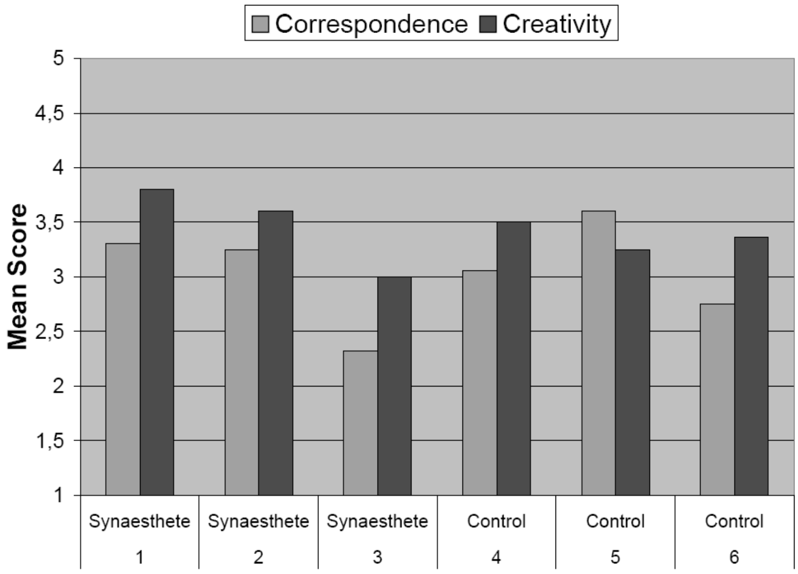
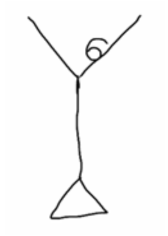


Figure 3: Mean individual scores on Creativity and Correspondence, achieved by the synaesthetes and the control subject.

In order to analyze between-groups differences, we performed item-analysis using the non-parametric Mann-Whitney test. The mean Correspondence score of items made up by the synaesthetes did not differ significantly from the mean score of items created by the controls ($z=-0.14$, $p=0.89$). There was no significant difference between mean scores on creativity neither ($z=0.59$; $p=0.56$). In principle the synaesthetes and the control seemed to be equal in their ability to invent objects ranked as creative by the judges. (See Figure 3, representing the mean scores on Correspondence and Creativity of all the participants.) On the other hand, it must be noted that items with high creativity scores (≥ 4) were mostly created by the synaesthetes (9 out of 13). Nonetheless, in part this is due to the fact that one of the synaesthetes was particularly creative (mean score = 3.8) and invented 5 of the 13 highest ranked objects. There were two objects that received the maximum possible mean score, i.e. 5; one was created by a synaesthete and the other by a non-synaesthete. (See figure 4.)

Right: "Buttocks wearing a tanga" created by a control subject from a rectangle, the letter M and the number 3.



Left: "Cocktail with an olive", created by a synaesthete from a triangle, the letter Y and the number 6.

Figure 4: The 2 "winning objects" which received the maximum score (5) on Originality.

Overall, the mean level of visual creativity observed in the three synaesthete subjects, as measured by the Creative imagery task, was about the same as for the control subjects.[2]

Concerning the judges, the degree of between-judges agreement was considerable. We submitted the raw scores data to repeated measures ANOVAs, dependent variables being creativity and correspondence scores as "measured" by each judge. The result for Creativity was significant (F(3, 150)=15,382, p<,01), indicating that differences between judges corresponded to systematical individual tendencies in rating (See Figure 5.), not to random variability. The same happened for Correspondence scores (F(3, 150)=4,1057, p=,00782), suggesting that some judges are either more "benevolent" than others or they find it easier to recognize the items.

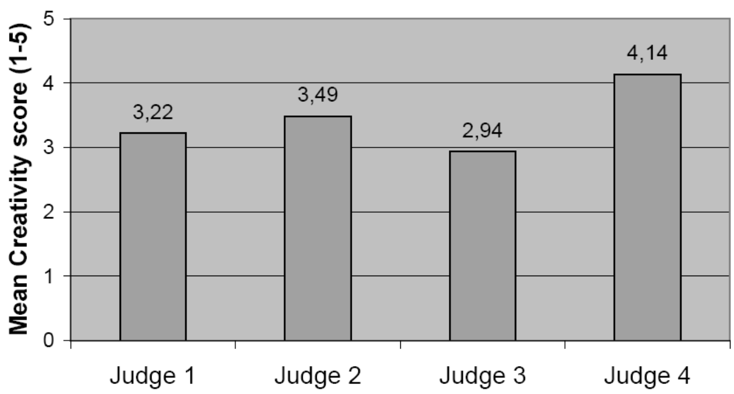


Figure 5: Mean Creativity Scores across different judges.

Discussion

Anecdotal reports as well as demographic data on synaesthete population may give the impression that the presence of synaesthesia correlates with higher creativity. A series of studies (Dailey et al., 1997; Domino, 1989; Rich et al., 2006) showed that synaesthetes tend to be involved in artistic professions much more frequently than the general population. Even though it seems compelling to consider this an evidence in favor of the purported higher creativity of synaesthetes, demographic records should be interpreted with caution. The fact that synaesthetes are more likely to be involved in artistic pursuits does not necessarily mean that they are more original and creative. It has also been hypothesized that a "more generally cross-wired brain" could show particular ease for connecting seemingly unrelated concepts (Ramachandran & Hubbard, 2001). However, it is yet to be confirmed whether (some kind of) generalized neuronal hyperconnectivity is actually present in synaesthetes. More importantly, if such neuronal pattern was discovered in synaesthetes, it would still be an open question whether or not it actually leads to above-average creative skills.

Interestingly, during a series of preliminary interviews with synaesthetes in our lab we found that most of them did not perceive themselves as more creative than the "normal", non-synaesthete population. The results of the present study are in line with these subjective reports, showing that the three synaesthete subjects were not significantly superior to the controls in none of the tasks employed. It should be noted though, that such negative result has a series of limitations. One possible drawback concerns the selection of experimental tools, i.e. the ecological validity of the measures employed. For instance, it may be objected that different type of psychometric tools could have been used to measure the cognitive flexibility component. Another objection could concern the appropriateness of the theoretical background itself, i.e. Guilford's three component model of creativity (1950; 1957; 1968). Indeed, a different theoretical background would most likely lead to a different battery of experimental tools. At the same time, different experimental measures could have been chosen to assess the three cognitive components of creativity. Nonetheless, the ambition of this study is limited to offer a series of indications concerning the possible connection (or an absence of it) between synaesthesia and creativity. While taking into account the aforementioned limitations, the main conclusion put forward by the authors of this paper is that, by using the given experimental tools, which were chosen on the grounds of Guilford's model, the results suggest that there are no significant differences in creativity between synaesthetes and non-synaesthetes. Certainly, the number of subjects was relatively small and therefore the strength of the statistical comparisons might have been limited by this fact. However, if the synaesthetes were likely to obtain higher scores (than normal population) such propensity should have left some kind of trace in the data. It is hardly a coincidence that in none of the tasks the synaesthetes performed significantly better than the controls. Moreover, if individual percentile scores are considered (See Table 2.), it may be observed that there is a relatively great variability both within the groups (synaesthetes and controls) as well as in the individual performance across different measures. On the whole, none of the synaesthete seems to be particularly superior with respect to the population of reference in more than one or two indicators. (E.g., R achieved a relatively high score in the phonological fluency test, but, on the other hand, he seems to have a relatively poor cognitive flexibility as suggested by his results in TMT B and WCST.) In the same line, by simply focusing on the individual scores obtained in the creative imagery task (See figure 2.), we observe that none of the synaesthete subjects obtained an extraordinarily higher score than the control subjects.

Table 2: Percentile ranks corresponding to the scores achieved by synaesthetes and control subjects

		Synaesthete Subjects			**Control Subjects**		
Psychometric Tool	*Measure / Index*	*R*	*L*	*M*	*Control 1*	*Control 2*	*Control 3*
Semantic Fluency	No. Words Generated	32	15	25	25	6	67
Phonological Fluency	No. Words Generated	90	24	69	7	24	99
Stroop Test	Stroop Interference	50	46	66	57	47	58
WCST	Errors Total	25	63	63	42	90	61
	Perseverative errors	10	34	55	30	90	37
	Perseverative responses	6	32	45	34	86	34
	Non-perseverative errors	70	84	75	45	91	81
TMT	Test A	67	<5	12	61	<5	28
	Test B	<1	16	70	20	44	50

Note: Normative data employed for raw score-to-percentile conversion: Semantic Fluency: Ostrosky-Solís, Ardila, & Rosselli (1999); Phonological Fluency: Fortuny, Romo, Heaton & Pardee III (1999); Stroop Color and Word Test: Golden (1994); WCST: Heaton, Chelune, Talley, Kay & Curtiss (1993); Trail Making Test: Tombaugh (2004).

Even though the latter approach, i.e. examination of individual performance, does not rule out the need for between-group comparisons, it is, in our opinion, a very necessary ingredient for synaesthesia research. This is so due to a series of reasons. First, the population of synaesthetes is extremely heterogeneous. There are numerous subtypes of synaesthesia, depending on the sensory modalities involved (e.g, see Hochel & Milán, in press; Rich et al., 2006). Many synaesthetes present more than one combination of inducer-concurrent pairings, e.g. a synaesthete may show a grapheme-color as well as smell-color synaesthesia. Moreover, even within the same subtype of synaesthesia there are substantial interpersonal differences not only in the specific synaesthetic associations (e.g., the color of a grapheme varies from one synaesthete to another), but also in the way synaesthesia is experienced (Dixon & Smilek, 2005). For instance, photisms induced by viewing a letter can be perceived as external projections or they can be "seen" in one's minds eye (e.g., Dixon, Smilek, & Merikle, 2004). The existence of these inter-individual differences raises the question whether all these diverse experiences may or not be put "into the same basket". By averaging individual performance of different types of synaesthetes, we may be loosing important information or even drawing premature conclusions. For instance, the synaesthete subjects who participated in the present study were all *associators* (Dixon et al., 2004), i.e. they perceived synaesthetic colors (photisms) in their mind's eye and not in the external space as observed in *projector* synaesthetes. In theory it is possible that only the latter subtype of synaesthesia correlates with higher creative potential. Taking into account the existence of numerous subtypes of synaesthesia allows for a better and more clear-cut interpretation of experimental results. Hence, despite the fact that the data presented here suggest for an absence of significant differences in creativity between synaesthetes and non-synaesthetes, further research will be necessary to support this claim. Ideally, future studies will include larger samples stratified according to specific subtypes of synaesthesia.

Endnotes:

1. Please, note that higher score indicates “less interference” or, more specifically, a higher resistance to interference from the reading automatism.

2. It should be noted that the task employed is limited to visual aspects of creativity and therefore cannot be generalized to different creative areas such as verbal or musical creativity. In fact, a recent study by Sitton and Pierce (2004) suggests that synaesthetes are better than non-synaesthetes in making-up puns. However, the study was administered online and did not test subjects’ synaesthetic condition experimentally.

References

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses*. New York: Springer.

Dailey, A., Martindale, C., & Borkum, J. (1997). Creativity, Synesthesia, and Physiognomic Perception. *Creativity Research Journal, 10*(1), 1-8.

Day, S. (2005). Some Demographic and Socio-cultural Aspects of Synesthesia. In L. C. Robertson & N. Sagiv (Eds.), *SYNESTHESIA: Perspectives from Cognitive Neuroscience* (pp. 11-33). New York: Oxford University Press.

Dixon, M. J., & Smilek, D. (2005). The importance of individual differences in grapheme-color synesthesia. *Neuron, 45*, 821-823.

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4*(3), 335-343.

Domino, G. (1989). Synesthesia and Creativity in Fine Arts Students: An Empirical Look. *Creativity Research Journal, 2*(1-2), 17-29.

Eagleman, D. M., Kagan, A. D., Sagaram, D., & Sarma, A. K. (2007). A standardized test battery for the study of Synesthesia. *Journal of Neuroscience Methods, 159*(1), 139-145.

Finke, R. A. (1990). *Creative imagery: Discoveries and inventions in visualization*. Hillsdale, NJ: Erlbaum.

Finke, R. A., & Slayton, K. (1988). Explorations of creative visual synthesis in mental imagery. *Memory & Cognition, 16*, 252-257.

Fortuny, L. A. i., Romo, D. H., Heaton, R. K., & Pardee, R. E. (1999). *Manual de normas y procedimientos para la batería neuropsicológica en español*. Tucson, AZ: M Press.

Golden, C. J. (1994). *Stroop Test de Colores y de Palabras*. Madrid: TEA Ediciones.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*(9), 444-454.

Guilford, J. P. (1957). Creative abilities in the arts. *Psychological Review, 64*(2), 110-118.

Guilford, J. P. (1968). *Intelligence, creativity and their educational implications*. San Diego, CA: Robert Knapp.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual: Revised and expanded*. Odessa (FL): Psychological Assessment Resources.

Hochel, M., & Milán, E. G. (in press). Synaesthesia: the existing state of affairs. *Cognitive Neuropsychology*.

Hubbard, E. M., & Ramachandran, V. S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron, 48*, 509–520.

Mulvenna, C. M. (2007). Synaesthesia, the arts and creativity: a neurological connection. *Frontiers of neurology and neuroscience, 22*, 206-222.

Ostrosky-Solís, F., Ardila, A., & Rosselli, M. (1999). NEUROPSI: A brief neuropsychological test battery in Spanish with norms by age and educational level. *Journal of the International Neuropsychological Society, 5*, 413-433.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.

Reitan, R. M. (1992). *Trail making test. Manual for administration and scoring*. Tucson: Reitan Neuropsychology Laboratory.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2006). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition, 1*(98), 53-84.

Sitton, S. C., & Pierce, E. R. (2004). Synesthesia, creativity and puns. *Psychological reports, 95*(2), 577-580.

Spreen, O., & Strauss, E. (1991). *A compendium of neuropsychological tests: Administration, norms and commentary*. New York: Oxford University Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Studies of interference in serial verbal reactions, 18*, 643-662.

Tombaugh, T. N. (2004). Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology, 19*(2), 203-214.

Ward, J., Thompson-Lake, D., Ely, R., & Kaminski, F. (in press). Synaesthesia, creativity and art: What is the link? *British Journal of Psychology*.

Part IV

Beyond Synaesthesia

Chapter 8

Auric Phenomena in Mysticism and Synaesthesia. Related or Different?

Abstract

One of the relatively infrequent varieties of synaesthesia is the one where photisms are triggered by affect laden stimuli such as emotional words, photographs, human figures and known people's faces. For instance, for F, a synaesthete who participated in this study, seeing a familiar person automatically triggers a mental image of "a human silhouette filled with color." Subjective descriptions of synaesthetic experiences, induced by the visual perception of people's figures and faces, show certain similarities with the reports of persons who claim to possess the ability to see the human *aura*. It has been proposed that the purported auric perception may in fact be easily explained by the presence of a specific subtype of cross-modal perception. In the present study we systematically analyzed subjective phenomenological reports of three synaesthetes who experience colors in response to human faces and figures. These reports are contrasted with descriptions of alleged auric phenomena found in folk psychology literature and with claims made by an expert in esoteric disciplines. Contrary to the abovementioned hypothesis, we believe that there are a number of important discrepancies suggesting that the two phenomena are not alike; they are phenomenologically dissimilar and most probably have different neurocognitive backgrounds.

Introduction

Synaesthesia is a condition in which one type of stimulation evokes the sensation of another, as when the hearing of a sound leads to the perception of mental colors or photisms. Normally the stimulus which triggers the synaesthetic experience in a given individual is termed an *inducer* and the accompanying "phantom" sensation is called a *concurrent*. A large number of inducer-concurrent combinations have been reported in literature (See Hochel & Milán, in press; or Rich, Bradshaw, & Mattingley, 2006), some of them being more common than others. For example, the letter-color synaesthesia is most probably present in more than 50% of synaesthetes (Day, 2006; Rich et al., 2006).

One of the relatively infrequent varieties is the one where photisms are triggered by affect laden stimuli such as emotional words, photographs, human figures and known people's faces (Cytowic, 1989; Milán et al., 2007; Ward, 2004). For instance, for F, a synaesthete who participated in this study, seeing a familiar person automatically triggers a mental image of "a human silhouette filled with color." Different people are typically associated with diverse color hues, depending on the F's affective relationship with the person in question. (E.g., he claims that he has always associated his mother with color blue.)

Subjective descriptions of synaesthetic experiences induced by the visual perception of people's figures and faces, show certain similarities with the reports of persons who claim to possess the ability to see the human *aura*. In parapsychology and related esoteric disciplines it is believed that human beings as well as animals and objects are surrounded by a subtle field of energy (Ashby, 1972; Farrar & Farrar, 1981) or aura, which can be observed by subjects with the corresponding psychic ability. It is not surprising that aura skeptics as well as some researchers interested in synaesthesia have proposed that the cases of auric perception may in fact be easily explained by the presence of a specific subtype of cross-modal perception. According to Ward (2004) "rather than assuming that people give off auras or energy fields that can only be detected by rigged cameras or trained seers" we may consider "a scientific account of the phenomenon in terms of synaesthesia." Even though such explanation of the supposed psychic powers seems more than plausible, certain aspects of synaesthetes' subjective reports point to a series of differences between esoteric descriptions of the aura and synaesthesia as a neuropsychological phenomenon. In the present study we systematically analyzed subjective phenomenological reports of three synaesthetes who experience colors in response to human faces and figures. These reports are compared to descriptions of alleged aura phenomena found in folk psychology literature and to claims made by an expert in esoteric disciplines. It should be noted that the study is in not aimed at testing or judging the veracity of claims found in mysticism and folk psychology literature. The main objective is to see whether the purported special ability of certain individuals to perceive human auras may or not be attributed to and explained in terms of synaesthesia.

Aura in mysticism and New Age belief.

In New Age, mysticism and related disciplines the aura is understood as a subtle field of energy surrounding a person or an object as a cocoon or halo.

Traditionally the human aura is believed to have seven layers that match the seven *chakras* or energy centers located at major branchings of the human nervous system (Anodea, 1996; Arraiza, 2005). According to H.A., an aura expert whom we interviewed, a trained individual (or an especially gifted one) sees the aura as a halo surrounding the body of a person or an object. The different layers of the human aura are "tinted" with colors which are determined by the character of a person, the momentary state of mind and her/his physical condition (Arraiza, 2005). The hues may show sudden changes reflecting alterations in the mood and the emotional stance of the person. The aura cannot be perceived by observing a person's photograph, even though some aura advocates believe that by using special technology such as Kirlian photography it is possible to photograph the aura (Moss, 1979; see Duerden (2004a) and Snellgrove (1996) for scientific explanations of aura imaging techniques.)

It is assumed that seeing the aura does not necessarily require a special talent or a "spiritual gift"; it is a "technique" that may be learnt by anybody who receives appropriate training and guidance. The best conditions for seeing the aura with a naked eye involve dim illumination, the use of peripheral vision and a relaxed, attentive stated of mind. Only people who received extensive training are able too discern clearly all the layers of the aura. The colors present in these layers are attributed specific meanings, defined in esoteric literature. (E.g., the color turquoise as a prevailing color of an aura may be interpreted as indicating a highly energized personality, capability of projection and influencing other people.) Aura interpretations may be considerably complex, depending on subtle variations of color, thickness and shape of aura layers. Different aura experts observing the same subject normally agree on the color of the aura of a particular person. This is to be expected, given that the aura is believed to emanate from the subject and should therefore be seen in the same way by different trained observers. In esoteric and New Age traditions a number of auric techniques are employed for diagnosis and healing of physical and mental problems.

Synaesthetic "aura"

In order to compare the characteristics of the alleged perception of auras to the phenomenon of synaesthesia, we interviewed three self-reported synaesthetes who showed colors in response to seeing human faces and figures. The subjects passed the Synaesthesia Battery (Eagleman, Kagan, Sagaram, & Sarma, 2007) online questionnaire. The result was positive for all of them, revealing the presence of multiple types of synaesthesia, specified below. In order to explore the synaesthetes' subjective experience of "auras", they were shown a series of photographs selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1999) and asked to report about the color of photisms induced by the images. (See Figure 1.) An in-depth interview allowed revealing additional features of their first person experience.

Participants

F, 22 years old student of telecommunications engineering, male. F shows multiple modalities of cross-modal perception, namely the music-color, smell-color and letter color synaesthesias. In addition, he also experiences photisms in response to familiar persons' faces.

R, 20 years, student of audio-visual communication, male. R presents a variety of chromatic synaesthesias: numbers, letters, first names, surnames, persons, town and city names, abstract concepts, natural sounds and music trigger synaesthetic perception of photisms. In R, photisms seem to be closely related to the affective valence of stimuli and typically bring out a consistent pattern of emotional responses.

M, 23 years old student of psychology, female. She also shows four varieties of inducer-concurrent pairings: smell-color, taste-color, people-color and people-smell synaesthesia.

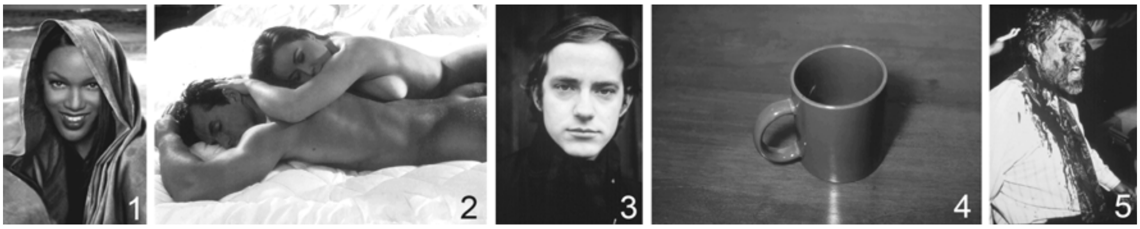


Figure 1: Images selected from the IAPS, shown to M and R.
Note: F was interviewed in a different occasion with a different set of images.

People-color synaesthesia. What is it like?

The interviews revealed that the photism colors experienced in response to a particular IAPS photograph varied between subjects. This was confirmed for M and R who were shown the same set of five pictures selected from IAPS. (See Table 1.) According to the synaesthetes' claims, the synaesthetic color associated to a person mostly depends on aspects such as personality, type of relationship (intimate, close, stranger, etc.) and overall impression and affective reaction associated with the person in question (See also Collins, 1929; Cytowic, 1989; Ward, 2004.). Synaesthesia is experienced both when the person is physically present and when viewing his/her photography. All three subjects experienced photisms in their mind's eye. (Following Dixon et al. (2004), they could be categorized as "associators" in contrast to "projector" synaesthetes who perceive their photisms in the external space.) "Aura" synaesthesia was typically triggered when the synaesthete attended and watched directly at the inducer rather than when he/she was in the periphery of the synaesthete's interest and gaze.

Table 1: Comparison of auras induced by IAPS images in R and M Image numbers corresponds to pictures represented in Figure 1.

Image shown	*Subject*	*Aura color*	*Emotional valence*	*Associated impression/emotion*
1	M	green	very positive	calmness, serenity
	R	red	positive	attraction
2	M	orange	positive	intimacy
	R	red	positive	attraction
3	M	bright orange	negative	pride
	R	green	slightly negative	disagreeable
4	M	blue	very negative	loneliness
	R	brown	neutral	boring
5	M	grey	very negative	despair
	R	yellow	negative	pain

In addition to these general features, there were also a series of idiosyncrasies. In R the synaesthetic sensibility to visual stimuli is extraordinarily wide. Not only people but also images and scenes that are either emotionally or esthetically exciting lead to synaesthetic responses (See Milán et al., 2007, for a single case study of R.). This was not observed in the other two synaesthetes who typically experienced photisms with humans only. R also claims that a photism linked with a particular person never changes. On the other hand, F informed that a color of the “aura” associated to a familiar person may sometimes be transformed when the nature of F’s relationship with the person is altered. Unlike R and M, F did not typically experience photisms for people he did not know. According to his claims, he had to “intentionally focus” his attention in order to experience synaesthesia with strangers. Finally, M was the only subject who informed about an additional concurrent sensation in response to persons; upon viewing people she also experienced smells.

Finally, it should be noted that aura-like synaesthesia can influence the subject’s performance in a color-decision task, as we demonstrated in an earlier single case study with R (Milán et al., 2007).

Aura versus synaesthesia

The study of the three accounts of people-color synaesthesia reported here in addition to the cases mentioned in earlier studies (Collins, 1929; Cytowic, 1989; Riggs & Karwoski, 1934; Ward, 2004) allow us to contrast the phenomenon of synaesthetic “auras” with the claims made in parapsychology and esoteric literature. Contrary to the hypothesis put forward by Ward (2004), we believe that there is a number of important discrepancies suggesting that the two phenomena are not alike. Table 2 offers a summary of differential characteristics of the people-color synaesthesia and the auric experience.

First, the photisms experienced by synaesthetes are idiosyncratic, i.e. the same inducer triggers dissimilar concurrents in different subjects. On the other hand, aura sensitives typically agree (or claim to agree) on the color of the aura observed in a given person. For synaesthetes, “auras” possess subjective significance, normally linked to the impression or emotion experienced while observing the individual who induces the “aura” (Cytowic, 1989; Milán et al., 2007; Ward, 2004). In New Age wisdom and related disciplines the observation of an aura has a diagnostic value, reflecting psychological and physical condition of the individual being examined. Consequently, the aura of a person cannot be appreciated on a photograph, since it is supposed to arise as a consequence of the "vital energy" of the person. In contrast, for synaesthetes a photographic portrait normally triggers photisms in a similar way as if the person was present (Milán et al., 2007). Finally, auric vision, unlike synaesthesia, is a technique which may be learnt by following appropriate training techniques.

Table 2: Differential characteristics of the people-color synaesthesia and the auric experience.

"Aura" synaesthesia	**Auric vision**
Different observers (synaesthetes) report seeing different "aura" colors for the same inducer (person).	Clairvoyants and sensitives typically agree on the colors present in the aura of a given person.
Synaesthetic experience can be induced by a photograph.	The aura cannot be seen in a photograph; it is supposed to reflect the vital force that emanates from the subject per se.
The "aura" photisms are linked to emotions and subjective impressions experienced by the synaesthete (Cytowic, 1989; Milán et al., 2007; Ward, 2004). Color-emotion associations are idiosyncratic.	Specific colors are believed to reflect the character of a person being observed, her/his momentary state of mind and physical condition. The colors of the aura are interpreted following a system defined in esoteric and New Age literature.
People-color synaesthesia involves seeing a photism in one's mind's eye (the three cases reported here) or a photism projected externally (Riggs & Karwoski, 1934; Ward, 2004).	The aura is seen by the clairvoyant as a silhouette or a halo around the person being observed.
Synaesthetic "aura" usually contains a single color hue.	The human aura is believed to have seven layers; typically several colors are present.
Synaesthesia is a life-long "condition" which is most probably congenital (e.g., Barnett et al., in press).	It is a "technique" that may be learnt by anybody who receives appropriate training and guidance.
Synaesthesia is triggered automatically and does not require conscious intention in order to experience it (e.g., see Hochel & Milán, in press).	Typically requires some degree of concentration and appropriate conditions (e.g., dim lightning).
Synaesthesia is most easily triggered when the inducer is in the centre of the visual field (Ramachandran & Hubbard, 2001).	The use of peripheral vision facilitates seeing the aura.

In summary, synaesthetes' phenomenological experience seems to be qualitatively different from that of sensitives and clairvoyants. Even though it is not our goal to undermine the theoretical claims held by people who employ auric techniques in alternative medicine, it should be noted that there is a series of alternative explanations offered by the main stream science. Duerden (2004b) shows how phenomena which arise as a consequence of the normal functioning of the human visual system can explain the purported direct experiences of the aura. For instance, the complementary color effect, which results from a temporary "exhaust" of the color sensitive cells in the retina, could account for the presence of auric colors seen by a sensitive when staring at a person. On the other hand, staring at a darker object (a human figure) against a bright background may induce the perception of a bright "halo" around the object. This is due to a contrast amplification mechanism, "built-in" the human visual system, which allows for an efficient detection of edges. (See the original paper by Duerden, 2004b, for a detailed description of this and other optical illusions.) In any case, independently of the plausibility of these scientific explanations of the aura, it seems obvious that the synaesthesia and the (esoteric) aura are phenomenologically dissimilar phenomena which most probably have different neurocognitive backgrounds.

References

Anodea, J. (1996). *Eastern Body, Western Mind: Psychology And The Chakra System As A Path To The Self*. Berkeley: Celestial Arts Publishing.

Arraiza, J. (2005). *Aura*. Madrid: Editorial LIBSA.

Ashby, R. H. (1972). Glossary of terms. In *The guidebook for the study of psychical research and parapsychology* (pp. 144-157). London: Rider.

Barnett, K. J., Finucane, C., Asher, J. E., Bargary, G., Corvin, A. P., Newell, F. N., et al. (in press). Familial patterns and the origins of individual differences in synaesthesia. *Cognition*.

Collins, M. (1929). A case of synaesthesia. *Journal of General Psychology, 2*, 12–27.

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses*. New York: Springer.

Day, S. A. (2006). Types of synaesthesia. Retrieved 12 December, 2006, from http://home.comcast.net/%7Esean.day/Types.htm

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive, Affective, & Behavioral Neuroscience, 4*(3), 335-343.

Duerden, T. (2004a). An aura of confusion Part 2: the aided eye--`imaging the aura?' *Complementary Therapies in Nursing and Midwifery, 10*(2), 116-123.

Duerden, T. (2004b). An aura of confusion: seeing auras--vital energy or human physiology? Part 1 of a three part series. *Complementary Therapies in Nursing and Midwifery, 10*(1), 22-29.

Eagleman, D. M., Kagan, A. D., Sagaram, D., & Sarma, A. K. (2007). A standardized test battery for the study of Synesthesia. *Journal of Neuroscience Methods, 159*(1), 139-145.

Farrar, J., & Farrar, S. (1981). *A witches' bible: The complete handbook*. Blasne,WA: Phoenix Publishing.

Hochel, M., & Milán, E. G. (in press). Synaesthesia: the existing state of affairs. *Cognitive Neuropsychology*.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *The International Affective Picture System. Technical Manual and Affective Ratings*. Gainesville, Florida: The Center for Research in Psychophysiology, University of Florida.

Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., et al. (2007). Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75-95.

Moss, T. (1979). *The body electric: a personal journey into the mysteries of parapsychological research, Bioenergy and Kirlian photography*. Los Angeles: J.P Tarcher.

Ramachandran, V. S., & Hubbard, E. M. (2001). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London, 268*, 979–983.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2006). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition, 1*(98), 53-84.

Riggs, L. A., & Karwoski, T. (1934). Synaesthesia. *British Journal of Psychology, 25*, 29–41.

Snellgrove, B. (1996). *The unseen self: the mysteries of Kirlian photography explained*. Saffron Walden: CW Daniel.

Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.

Thesis Overview

Short summary of studies included in the thesis

Part I (Chapters I and II): Synaesthesia: the Existing State of Affairs

In synaesthesia one type of stimulation evokes the sensation of another, such as when hearing a sound produces photisms, i.e. mental percepts of colors. In the past, the idiosyncrasy of this phenomenon, as well as the natural mistrust of scientists towards the subjective, consigned synaesthesia to the periphery of scientific interest. However, the landscape has changed radically in the last two decades. The labor of many researchers, inside as well as outside of cognitive neuroscience, has transformed synaesthesia into a scientific reality whose existence can be demonstrated and studied empirically. The present paper summarizes and reflects on our current knowledge concerning synaesthesia in all its aspects (cognition, behavior, neurology, genetics and demographics).

Part II: Synaesthesia and Emotion

Chapter 3: Experimental Study of Phantom Colors in a Color Blind Synaesthete.

R is a 20 year old color blind subject who, in addition to the relatively common grapheme-color synaesthesia, presents a rarely reported cross modal perception in which a variety of visual stimuli elicit aura-like percepts of color. In R, photisms seem to be closely related to the affective valence of stimuli and typically bring out a consistent pattern of emotional responses. The present case study suggests that colors might be an intrinsic category of the human brain. We developed an empirical methodology that allowed us to study the subject's otherwise inaccessible phenomenological experience. First, we found that R showed a sequential Stroop effect (delayed response due to interference) elicited by photisms despite the fact that he did not show a regular Stroop with real colors. Secondly, by manipulating the color context we confirmed that colors could alter R's emotional evaluation of visual stimuli. Furthermore, we demonstrated that R's auras might actually lead to a partially inverted emotional spectrum where certain stimuli bring out emotional reactions opposite to the normal ones. These findings can only be accounted for by considering R's subjective color experience or qualia. Therefore the present paper defends the view that the qualia represent a useful scientific concept that can be approached and studied by experimental methods.

Chapter 4: Do Colors Really Matter? Emotional and Physiological Impact of Colors in Chromatic Synaesthesia.

Anecdotal reports suggest that chromatic synaesthetes often show pronounced emotional reactions to colors. Moreover, it is generally believed that colors are linked with emotions, e.g. red is often considered exciting and erotic. Given its subjective significance, it seems surprising that very few experimental studies have examined people's physiological responses to color; the corresponding results are, at best, inconclusive. Experimental series described here explores physiological reactivity to colors in R, a subject with a rare, emotionally conditioned synaesthesia. Although we did not find any interpretable pattern of physiological reactions to colors in a control group of non-synaesthetes, the synaesthete's physiological responses were determined by his emotional perception of the colors presented. Colors perceived as pleasant attenuated the subject's startle reaction to sudden noise, while colors perceived as unpleasant enhanced it. The discovery of such emotional modulation is possibly the first strong evidence in favor of the purported neural hyperconnectivity between the limbic system and the cortical color-processing areas in synaesthesia.

Chapter 5: Congruence or Coherence? Emotional and Physiological Responses to Colors in Synaesthesia.

Anecdotal data suggest that synaesthetes are particularly sensitive to inconsistencies between their synaesthetic percepts and the real world, e.g. it can be annoying and unpleasant for them to see a letter printed in a color different than the respective photism color. For R, a synaesthete subject who participated in this study, photisms possess specific emotional values (a red photism is pleasing and attractive, green is repulsive and unpleasant, etc.). In contrast to the anecdotal data, R does not always find the color-photism incongruence disturbing. More importantly, he states that it is the emotional *coherence* between the stimulus and the corresponding photism that matters. In a series of experiments, we studied this new concept (of emotional coherence) on three levels - subjective (self-report), behavioral and physiological, corroborating R’s introspective statements. Besides the implications of the concept of coherence itself, the results presented here suggest that even highly subjective cognitive constructs can be approached and measured experimentally, uncovering the workings of the underlying psychophysiological mechanisms.

Chapter 6: Emotional Interplay between Colors and Photisms in Chromatic Synaesthesia: a Single Case Study.

Present paper is a continuation of our earlier study presented in Chapter 5. It further explores the role of emotional coherence of colors in R’s synaesthesia and confirms the fact that the perceived presence or absence of coherence may modulate R’s physiological responses. The data obtained in this study are in line with a recent theory on synaesthesia suggesting existence of hyperconnectivity between the limbic system and the brain areas responsible for color processing.

Part III: Creativity in Synaesthesia

Chapter 7: Are Synaesthetes More Creative than Non-synaesthetes?

Synaesthesia has often been associated with artistic creativity. A series of authors speculated that synaesthesia may lead to an above-average creative potential. The present paper explores this hypothesis by examining three components of creativity (cognitive fluency, flexibility and originality) in synaesthetes and non-synaesthete subjects. The subjects’ creative potential was assessed by means of standardized psychometric measures as well as a non-standard creative imagery task.

Part IV: Beyond Synaesthesia

Chapter 8: Auric Phenomena in Mysticism and Synaesthesia. Related or Different?

One of the relatively infrequent varieties of synaesthesia is the one where photisms are triggered by affect laden stimuli such as emotional words, photographs, human figures and known people's faces. For instance, for F.J., a synaesthete who participated in this study, seeing a familiar person automatically triggers a mental image of "a human silhouette filled with color." Subjective descriptions of synaesthetic experiences, induced by the visual perception of people's figures and faces, show certain similarities with the reports of persons who claim to possess the ability to see the human *aura*. It has been proposed that the purported auric perception may in fact be easily explained by the presence of a specific subtype of cross-modal perception. In the present study we systematically analyzed subjective phenomenological reports of three synaesthetes who experience colors in response to human faces and figures. These reports are contrasted with descriptions of alleged auric phenomena found in folk psychology literature and with claims made by an expert in esoteric disciplines. Contrary to the abovementioned hypothesis, we believe that there are a number of important discrepancies suggesting that the two phenomena are not alike; they are phenomenologically dissimilar and most probably have different neurocognitive backgrounds.

Overview of main findings and conclusions

Experiments included in Part II are aimed at examining the role of emotions in R, a subject who shows a rarely reported modality of synaesthesia where photisms are triggered by a large variety of visual stimuli such as human figures and faces, complex visual scenes (e.g., landscapes), photographs of people and objects, etc. A summary of main findings follows:

- By using a set of emotional photographs (International Affective Picture System, IAPS) we demonstrated that the colors of R's photisms were closely related to the emotional response elicited by the triggering stimulus. E.g., photographs of physically attractive people as well as aesthetically pleasing pictures normally induced red color photisms and images which were perceived as disgusting or "sick" were synaesthetically perceived as green.
- We demonstrated that R's "auras" could interfere with behavioral performance in a color naming task, prolonging R's reaction time when there was incongruence between the real color and the photism color.
- R's emotional perception of colors was not limited to his photisms but also played a role in his perception of colored stimuli. By using colored frames along with affect-laden photographs from IAPS, we showed that real colors could modulate R's emotional assessment of the photographs. E.g., an emotionally positive picture of an attractive woman was perceived as less pleasing when presented in an emotionally negative green frame.
- We examined the possible influence of colors on physiological variables in R and a group of control subjects through application of a startle reflex modulation paradigm. While control subjects did not show any interpretable pattern of

physiological reactions to colors, in R we found that a combination of photisms (triggered by number stimuli) with congruently colored frames lead to a modulation of the startle response to sudden noise. Namely, colors perceived as positive by R weakened the blinking reflex as well as attenuated his cardiac startle response.

- Perceived incongruence between synaesthetic colors and real colors (e.g., a grapheme which triggers yellow photism printed in color blue) often leads to feelings of discomfort in synaesthetes. In contrast to earlier studies, we found that R did not always find the color-photism incongruence to be disturbing. More importantly, what determined R's assessment of a given stimulus was the perceived emotional coherence between the stimulus and the corresponding photism. In this way, when a stimulus triggered a subjectively positive synaesthetic color (e.g., yellow) and it was depicted in a different color which was also perceived as emotionally positive (e.g., red), such combination was evaluated as “coherent” and pleasing for R despite the fact that the colors did not match. We demonstrated that the principle of emotional coherence worked not only on a subjective level, but also influenced R's reaction times in a behavioral task as well as modulated his physiological variables in response to a sudden white noise. Namely, emotionally coherent stimuli typically attenuated R's startle reaction while incoherent stimuli enhanced it.

In part III we examine the hypothesis put forward by a series of authors who proposed that synaesthesia may lead to an above-average creative potential. Synaesthetes are often considered to be more creative than the general population. By investigating three components of creativity (cognitive fluency, flexibility and originality) in synaesthetes and a control group of non-synaesthetes, we show that the purported differences between synaesthetes and normal population in terms of creative abilities do not seem to be significant.

In the final chapter we look at the relationship between synaesthesia and the so-called auric phenomena, described in esoteric literature. It has been hypothesized that the alleged ability of certain individuals to perceive the human aura could be explained in terms of synaesthesia. By comparing subjective phenomenological reports of people-color synaesthetes to descriptions of alleged aura phenomena, we show that there are a series of important discrepancies suggesting that the two phenomena are not alike.

As a final point, we would like to sketch a possible follow-up of the experimental series included in this thesis. Concerning the role of emotion in synaesthesia, it would be interesting to see whether the mechanisms observed in R are entirely idiosyncratic or they are also present in other synaesthetes. Namely, a future research could extend the present study by examining possible behavioural and physiological effects triggered by photisms and real colors in a larger sample of synaesthetes. The modulation of the startle reflex by colors and photisms observed in R is in line with the hypothesis which advocates the role of the amygdale in synaesthesia. Prospective studies making use of neuroimaging techniques could definitively confirm or refute this proposal.

Relating to the role of emotional coherence, it should be noted that for R, the concept of coherence extends to the field of aesthetic judgments. Simply put, he generally likes artworks that he perceives as coherent and he hates those where the use of color is “arbitrary and incoherent”. If these (or similar) mechanisms were found in other synaesthetes and possibly non-synaesthetes, it could indicate a novel way of investigating the perception of aesthetics, which goes beyond phenomenological reports.

According to our psychometric study of creativity in synaesthesia, there seem to be no evidence in favour of the purported above-average creative abilities of synaesthetes. However, the present study has a series of limitations that shall be overcome by prospective studies. First, the sample was relatively small which inevitably lead to a diminished power of the corresponding statistical test. Even though this inconvenience was in part avoided by using standardized psychometric tools (allowing a comparison with respect to the population of reference), we believe that a larger scale investigation will be necessary in order to definitively confirm our hypothesis. Secondly, all synaesthetes who participated in this research were of the "associator" type. In theory it is possible that only the "projector" kind of synaesthesia correlates with higher creative potential. The existence of these and other inter-individual differences raises the question whether all the diverse categories of synaesthesia may or not be put "into the same basket". Ideally, future studies on creativity will include samples stratified according to specific subtypes of synaesthesia.

Afterword

A few months ago, the director of our research group received the following email from a person who claimed to be "interested in synaesthesia":

"Since I was fourteen I have been seeing a kind of colored light around people, animals and sometimes around objects as well. It looks like a shining glow which can be violet, blue, green, turquoise... Sometimes it is only a thin white contour around a person or an object, but quite often there are more layers of different colors. Am I a synaesthete? Is there a remedy?"

After exchanging a few emails with Carola, the author of this text, it turned out that her "visions" were an integral part of her everyday life. However, she has never attributed any particular value to this unusual perception; she has not associated it either with particular situations, emotions nor esoteric qualities. The only reason for contacting "experts in the field" was her hoping that we would be able to examine and put a label on her "condition". When she responded to a series of our questions aimed at exploring more thoroughly certain aspects of her unusual sensory experience, we could only arrive to one simple conclusion. She was not a synaesthete. At least not in the sense determined by the current scientific knowledge of synaesthesia.

Even though this story may sound almost like one of those cheap, "mysterious cases" printed in sensationalist newspapers, only some decades ago synaesthetes were often causing similar impression and a lot of disbelief among medical and scientific community. Many physicians, psychiatrists and psychologists must have thought: Are these people extravagant, trying to attract interest, or is it a symptom of psychotic disorder? Fortunately, there were a small number of open-minded professionals who asked themselves a completely different type of questions. Questions motivated by a desire to venture into the unknown and to unravel a fascinating enigma. Thanks to their spontaneous scientific curiosity as well as thanks to those who have later followed this line of research, at the present time we know that rather than a condition, synaesthesia is a neuronal toy of nature which may be inspiring to those who posses it. We also know that it is a hereditary treat that is most probably caused by a gene (or genes) which boost neuronal connectivity in synaesthetes' brains. Interestingly, synaesthesia is not an "all-or-nothing" condition: there are genuine "projector" synaesthetes who perceive "phantom" colors, tastes, textures or smells as if they were present "out there" in the "real" world; there are "associators" whose brains automatically recreate synaesthetic percepts in the mind's eye; there are also "minor" synaesthetes who use "color labels" for numbers, days of the weeks but also for people or places; and finally there is a synaesthete inside all of us when we say things such as

“I feel blue”, “I am high” or when we see that a “bouba” sound “feels rounded” while “kiki” “sounds jagged”. Through synaesthesia research, we have also learnt that a good cognitive science often involves listening to your experimental subjects, without a blind disregard towards “subjective reports.” (By the way, why “subjective report” is so often used as a synonym of “absolutely untrustworthy”?) Moreover, the phenomenon of synaesthesia is confirming the idea that the study of infrequent and rare phenomena may often lead to inspiring insights on a more global level; for instance, synaesthesia is helping us to understand some of the most mysterious mechanisms of the human mind, such as abstract thinking or metaphoric language. Despite the fact that these days synaesthesia is “just another neuropsychological phenomenon” which is no more causing any particular excitement in the scientific community, the progress in the understanding of synaesthesia is allowing us to reveal new pieces of the enormous puzzle called the human brain.

Those who feel sorry for having lost the thrill of the early stages of synaesthesia research will certainly soon find a new challenging puzzle, such as the one mentioned in the beginning of this text. By now, the aforementioned story has no ending and we have no idea what Carola is seeing and why. Is she just trying to attract attention? Does she suffer from a rare visual impairment? Or maybe should we pay more attention to those “weird people” claiming to be able to perceive human *auras*, whatever they are supposed to be? Hopefully there will be an open, curious mind willing to study it.

In Granada, February 6, 2008

APPENDIX

Resumen de la tesis doctoral en español

Introducción

La presente tesis doctoral explora varios aspectos de un fenómeno neuropsicológico de muy baja incidencia – la sinestesia. En personas sinestésticas la estimulación de un canal sensorial lleva de manera automática a una experiencia perceptiva concurrente a través de otra modalidad sensorial. Por ejemplo, la escucha de una melodía musical puede llevar a la percepción de colores y/o formas visuales. La primera parte de la tesis (capítulos 1 y 2) constituye una revisión teórica exhaustiva que recoge el conocimiento científico actual sobre la sinestesia. Las partes 2 y 3 incluyen artículos (algunos de ellos publicados o aceptados) que se centran en dos aspectos relacionados con el fenómeno sinestésico: los matices emocionales de la sinestesia (2ª parte) y la relación entre la sinestesia y la creatividad (3ª parte).

Primera parte (Capítulos 1 y 2)

En la primera parte de la presente tesis se presenta una extensa revisión de la literatura científica dedicada al tema de la sinestesia.

La palabra sinestesia proviene del término griego aesthesis, percepción, y literalmente significa "percepción unida" (syn = "unido", "junto"). En los sinéstetas, la estimulación de un sentido conlleva una percepción en otra modalidad sensorial añadida. Así, por ejemplo, para un sinésteta musical los tonos de una melodía adquieren matices de colores específicos. En algunos casos, la experiencia sinestésica implica la "transducción" de una categoría semántica aprendida (grafemas, números, caras humanas, días de la semana) en una experiencia sensorial (por ejemplo, la percepción de un color "fantasma"). La primera referencia a la sinestesia se remonta al año 1812, cuando el médico Sachs (citado en Dann, 1998; Krohn, 1892) menciona algunos aspectos de esta condición observados en él mismo y en su hermana. Sin embargo, dentro de la comunidad científica no se habla de "sinestesia" hasta finales del siglo XIX., cuando la mezcla de sentidos es descrita por Francis Galton (1880/1997). El interés inicial por el fenómeno decae más tarde debido en parte a la falta de herramientas para estudiar la experiencia subjetiva y también debido a la creciente influencia del conductismo. Hasta hace pocas décadas la sinestesia era considerada mera curiosidad y fue relegada a la periferia del interés científico. La situación cambió gracias a una serie de estudios pioneros (p.ej., Cytowic, 1989; Marks, 1978); el fenómeno se ha convertido en un hecho científico cuya existencia puede ser demostrada y estudiada empíricamente. Incluso se han llegado a proponer "criterios diagnósticos" (Véase Cytowic, 1996) para facilitar el reconocimiento de la sinestesia y diferenciarla de algunas condiciones patológicas (como las alucinaciones) o de estados inducidos por sustancias psicotrópicas que pueden guardar un parecido superficial con la sinestesia. No obstante, la sinestesia es un fenómeno muy heterogéneo (las asociaciones sinestésicas y la fenomenología subjetiva cambia de un sinésteta a otro). Este hecho unido a la baja frecuencia de la sinestesia en la población general, hacen que el estudio científico de la sinestesia con frecuencia tenga que ceñirse a diseños de caso único. Pese a esta dificultad, el abanico de conocimientos disponibles ha ido creciendo rápidamente en las últimas dos décadas. Las investigaciones científicas han demostrado que la sinestesia es una condición duradera (normalmente se adquiere en la infancia y persiste de por vida), automática (la experiencia sinestésica está fuera del control voluntario del sujeto) y consistente (las asociaciones sinestésicas no cambian en un mismo individuo). Además, según sugieren los estudios de prevalencia, la sinestesia tiende a aparecer más a menudo entre parientes y, por lo tanto, muy probablemente se trata de una condición hereditaria. Por otra parte, la investigación neuropsicológica ha demostrado que el cerebro de los sinéstetas reacciona de una manera diferencial a la estimulación sensorial en aquella modalidad que induce la experiencia sinestésica (p.ej., Hubbard & Ramachandran, 2005). Este último aspecto de la sinestesia, en conjunción con los datos referentes a la fenomenología de la experiencia sinestésica, sugiere que la sinestesia se debe a una hiperconectividad que se da en regiones específicas del cerebro. Sin embargo, en el presente no sabemos con seguridad si esta hiperconectividad es causada por una deshinhibición de vías neuronales (bloqueadas en un cerebro normal) o se debe a la existencia de unas conexiones anormales. En cualquier caso, todos los modelos vigentes de la sinestesia apuntan en la existencia de dicha hiperconectividad.

Finalmente, hay que resaltar que el avance en el estudio de la sinestesia también está abriendo puertas hacia la explicación de algunos enigmas neuropsicológicos más globales, como por ejemplo, los aspectos metafóricos y abstractos del lenguaje humano. La presencia de "efectos sinestésicos" en la población normal (no-sinésteta) sugiere que la sinestesia no es un fenómeno de todo o nada. (Por ejemplo, las personas normalmente asocian sonidos agudos con colores claros y sonidos bajos con colores oscuros.) De este modo, la sinestesia en un sentido más amplio podría abarcar una gran variedad de fenómenos, desde la sinestesia idiopática propiamente dicha, pasando por sinestesias inducidas conceptualmente, hasta quizás el talento para utilizar la expresión artística multimodal y el lenguaje marcado por asociaciones sinestésicas presentes tanto en la literatura como en el lenguaje común. De ahí que el estudio de la sinestesia nos permite a su vez profundizar en la comprensión de ciertos aspectos del funcionamiento neurocognitivo normal.

Segunda parte (Capítulos 3 – 6)

La segunda parte del trabajo doctoral está enfocada en la relación entre sinestesia y emoción. A continuación se presenta el resumen y los resultados principales de los estudios experimentales incluidos.

Capítulo 3: Un estudio de caso único de sinestesia cromática emocional

R, el sujeto de este estudio, presenta múltiples variantes de sinestesia. Además de la sinestesia grafema-color, R experimenta colores sinestésicos como respuesta ante estímulos visuales complejos como figuras humanas o escenas visuales (paisajes, fotogramas de películas, obras de arte visual, etc.). Estos fotismos no son proyectado externamente, sino que se parecen más a una imaginería visual, involuntaria y automática. Esta modalidad de sinestesia presente en R parece estar íntimamente relacionada con la valencia emocional del inductor sinestésico. Por ejemplo, personas alegres inducen fotismos amarillos, personas aburridas o poco interesantes fotismos marrones, personas enfermas o repugnantes fotismos verdes, etc. Asimismo, un examen minucioso de la capacidad de discriminación de colores reveló que R sufría de una variedad leve de la ceguera al color (daltonismo dicromático) y no presentaba efecto de interferencia Stroop en el Test de Colores y Palabras.

Para examinar el patrón de asociaciones sinestésicas en R utilizamos un set de imágenes emocionales IAPS (Vila et al., 2001) para inducir fotismos y determinar su relación con el contenido emocional de las fotografías. Para evaluar las respuestas emocionales de R ante los estímulos inductores, le hemos pedido que puntúe cada fotografía según las dimensiones del cuestionario SAM. R evaluó las imágenes IAPS en una escala de *valencia* emocional (desde muy agradable a muy desagradable), así como en una escala de *arousal* (desde muy excitado a muy relajado). El resultado principal fue que los fotismos de R obedecían al siguiente esquema general: los fotismos rojos y púrpura estaban asociados con emociones positivas, los verdes con emociones negativas y los azules y los marrones indicaban neutralidad o falta de interés. Además, un segundo experimento reveló que los colores reales podían influir la valoración emocional que R hacía de las imágenes IAPS. Al presentar los mismos fotogramas enmarcados en colores congruentes o incongruentes con el fotismo asociado descubrimos que los colores reales podían modular la valoración emocional de R en dirección consistente con los sentimientos subjetivos asociados a cada color. Por ejemplo, un marco incongruente de color rojo hacía que una imagen fuese percibida como más positiva mientras que un marco verde llevaba a una evaluación emocional más negativa.

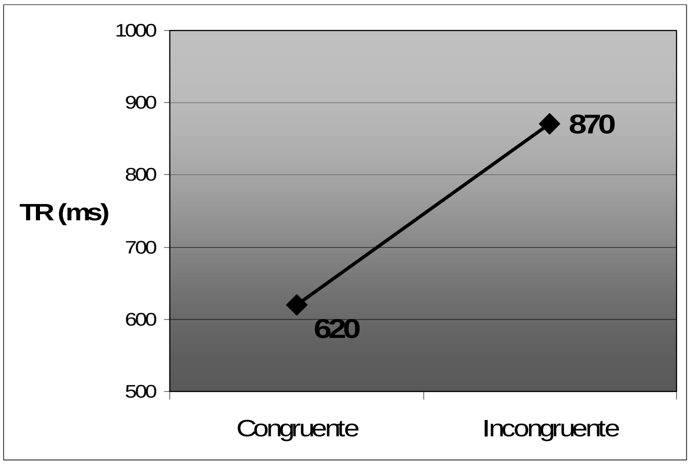


Figura 1: Efecto Aura Stroop: La percepción de "auras" sinestésicas interfiere con la discriminación de colores reales.

Finalmente, para examinar el impacto de los fotismos sobre la percepción de colores reales, R fue sometido a un experimento tipo Stroop (Stroop, 1935). En cada ensayo se le presentó una imagen IAPS durante 3 segundos, seguida inmediatamente de un cuadrado de color bien congruente o bien incongruente con el color del fotismo asociado al la imagen anterior. Su tarea consistía en identificar el color del cuadrado; la variable dependiente fue el tiempo de reacción medido en milisegundos. El resultado reveló un claro efecto de interferencia tipo Stroop (Véase la Figura 1.), causada por la incongruencia entre el color del fotismo y el color real.

El artículo en su conjunto, además de proporcionar una descripción experimental de un caso único de sinestesia emocional en un sujeto daltónico, demuestra la importancia del estudio de la experiencia subjetiva. Los efectos de modulación emocional por colores sólo pueden ser explicados atendiendo a la experiencia fenomenológica del sujeto.

Capítulo 4: Impacto emocional y fisiológico de colores y fotismos en la sinestesia cromática

Estudios anecdóticos sugieren que los sinéstetas a menudo presentan respuestas emocionales que acompañan la experiencia de fotismos (p.ej., Cytowic, 1989). Por otra parte, entre la población normal existe una creencia generalizada de que los colores están de algún modo relacionados con las emociones. Por ejemplo, el color rojo suele ser considerado excitante y erótico. Sin embargo, pese a esta significancia emocional subjetiva de los colores, ha habido muy pocos estudios experimentales dedicados al examen del impacto fisiológico del color. La serie experimental presentada en este artículo explora la posibilidad de reactividad fisiológica ante colores en R, un sujeto que presenta una modalidad poco frecuente de sinestesia cromática condicionada emocionalmente. Según demostramos en un estudio anterior (Véase el resumen del capítulo 3.), R experimenta fotismos que pueden ser categorizados según la valencia emocional del estímulo inductor.

En el Experimento 1 pedimos a R y un grupo de sujetos controles que evaluasen una serie de colores según su valor emocional. Tanto en los controles como en R los tonos saturados (en comparación con los desaturados) llevaron a una valoración emocional más positiva; los colores saturados también fueron evaluados como más excitantes. Además R presentaba un patrón de valencia emocional determinado por el matiz: los tonos rojos y naranjas eran percibidos como positivos, los azules como neutrales y los verdes como negativos.

El segundo experimento examinaba el posible impacto fisiológico de diferentes colores, observando el efecto de modulación emocional del reflejo de sobresalto inducido por un sonido desagradable presentado al azar. El reflejo de sobresalto implica un patrón de respuestas fisiológicas y motoras que se da como reacción ante la presentación inesperada de un estímulo saliente (p.ej., un ruido o un destello de luz). La modulación emocional de este reflejo (su potenciación con estímulos aversivos y la atenuación del mismo con estímulos apetitivos o agradables) es uno de los fenómenos más estudiados en el campo de la psicología de la emoción (p.ej., Bradley, Cuthbert, & Lang, 1991).

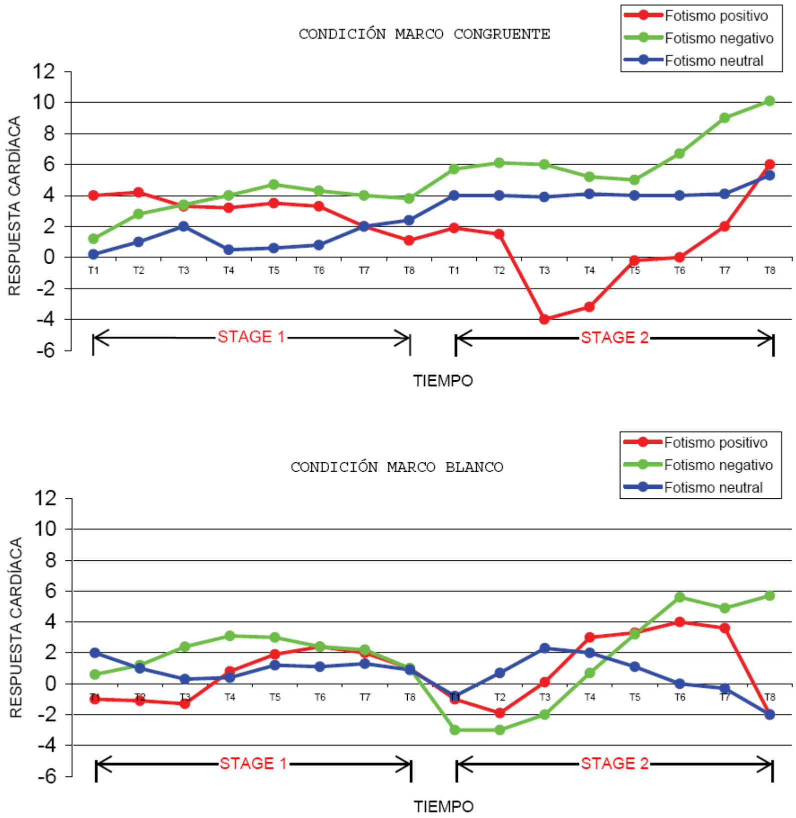


Figura 2: El patrón de cambio cardiaco observado en R en el Experimento 3. Los colores positivos llevaron a una atenuación de la respuesta cardiaca de sobresalto, mientras que los colores negativos la potenciaron. Esta modulación no se daba en la condición donde los números fueron presentados con un marco blanco.

De acuerdo con los estudios anteriores, la influencia del color sobre variables fisiológicas no presentan un patrón claro – los efectos observados cambian de un individuo a otro y su dirección no suele concordar con la valoración emocional subjetiva de los colores presentados (p.ej., Abbas, Kumar, & Mclachlan, 2005). En el experimento 2 aplicamos una metodología nueva en el campo de la psicología del color (la modulación del reflejo de sobresalto). Los colores utilizados en el Experimento 1 fueron presentados durante 6 segundos en una pantalla de ordenador. En el intervalo de 2.5 a 4.5 segundos se presentaba al azar un ruido blanco de 50 milisegundos que causaba una respuesta de sobresalto. La variable dependiente fue la magnitud de la respuesta cardiaca de sobresalto. Los resultados concuerdan con los de los estudios anteriores. Sólo uno de los tres controles presentaba un efecto de modulación por categoría del color (rojo, azul o verde). El sinésteta también presentaba dicho efecto, pero la dirección del mismo (potenciación o inhibición del sobresalto) fue diferente que en el sujeto control y además no concordaba con su propia valoración subjetiva de los colores. (Por ejemplo, los tonos verdes – negativos para R – inhibían la respuesta cardiaca de sobresalto en lugar de potenciarla.)

Finalmente, en el Experimento 3 se estudió la posibilidad de modulación emocional del reflejo de sobresalto por fotismos y por la combinación de fotismos y colores reales. Manteniendo la lógica del experimento anterior, utilizamos como estímulos las cifras numéricas inductoras de fotismos que fueron presentadas con un marco blanco o con marcos del mismo color que el fotismo asociado (condición marco congruente). Los resultados revelaron que mientras que los fotismos de por sí no ejercían una función moduladora sobre la respuesta cardiaca de sobresalto (condición marco blanco), la combinación de fotismos con colores reales (condición marco congruente) llevaba a una modulación de dicha respuesta. Además, la dirección de la modulación observada concordaba con el valor emocional subjetivo de los colores y fotismos. (Véase la Figura 2.) Es decir, los marcos de colores positivos atenuaban la respuesta cardiaca de sobresalto mientras que los marcos negativos la potenciaban. El mismo resultado fue obtenido al utilizar como variable dependiente otra medida – el reflejo de parpadeo (electromiografía del músculo orbicular del ojo izquierdo).

En resumen, los datos de los experimentos 1 y 2 confirman los estudios anteriores realizados con sujetos normales: el color no parece tener un efecto claro sobre variables fisiológicas. No obstante, según demostró el experimento 3, en el sujeto sinésteta la modulación emocional de la respuesta de sobresalto sí se da en la condición dónde se presentan inductores de fotismos (números) acompañados de colores reales congruentes.

Capítulo 5: El efecto de coherencia emocional de colores en la sinestesia léxica-cromática

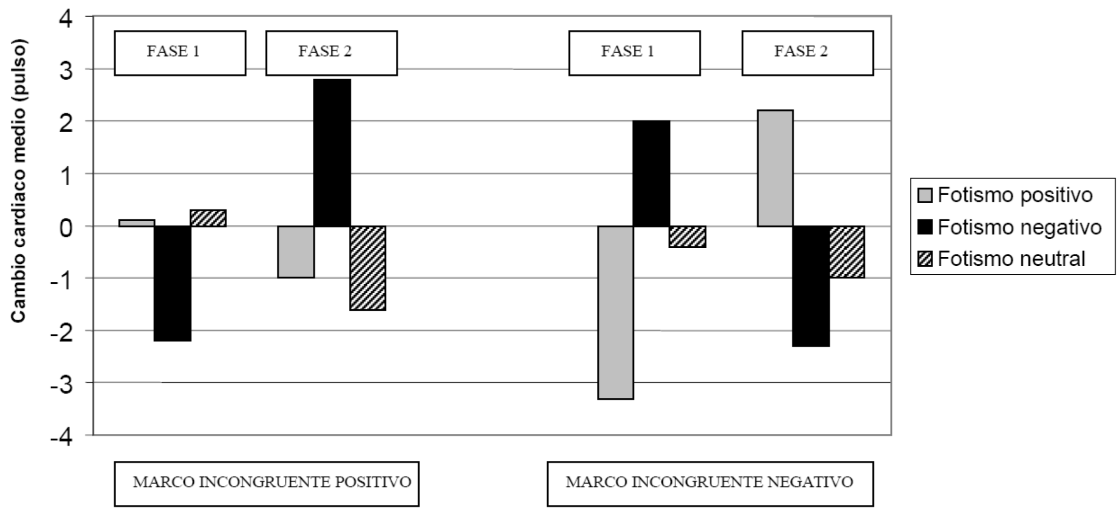
La sinestesia léxica-cromática es una condición en la cual letras y/o palabras inducen fotismos, es decir, una percepción de colores mentales. Datos anecdóticos sugieren que los sinéstetas son sensibles a la inconsistencia entre su percepción sinestésica y el mundo real. Por ejemplo, les puede resultar molesto o desagradable ver una letra escrita en un color que difiere del matiz del fotismo asociado (Callejas, Acosta, & Lupiáñez, 2007). Para R, el sujeto del presente estudio, los fotismos (y también colores reales) poseen valores emocionales específicos (el rojo es agradable y atractivo, el verde es repugnante y desagradable, etc.). En contraste con los datos y estudios anteriores, R no siempre percibe como desagradable la incongruencia entre el fotismo y el color real. Más bien, según afirma R, es la incoherencia emocional de colores y fotismos que puede ser considerada como desagradable. Por ejemplo, el número 3, que induce un fotismo de color positivo (rojo), escrito con un color de tinta naranja o amarillo (también colores positivos), no le resulta desagradable. Por otro lado, si el mismo número está escrito en verde, un color de valencia emocional negativa para R, la incoherencia emocional resultante es percibida como muy desagradable. La serie experimental presentada en este capítulo explora el concepto de incoherencia emocional a tres niveles: subjetivo, conductual y fisiológico.

El Experimento 1 se centra en la valoración emocional subjetiva de colores y fotismos asociados a números. Con esta finalidad primero obtuvimos los colores exactos correspondientes a los fotismos de R y éste categorizó estos colores según su valencia emocional como positivos, negativos o neutros. A continuación le presentamos números de 1 a 9 con un marco que podía ser del mismo color (congruente) que el número asociado o de un color diferente (incongruente). Además, tanto los colores de los marcos como los fotismos podían ser de una valencia positiva, negativa o neutra. La tarea de R consistía en evaluar su percepción emocional de estos números enmarcados en una escala de 1 a 9 (desde muy desagradable/negativo a muy agradable/positivo). Los resultados demostraron que cuando el valor emocional del color del marco era inconsistente con el fotismo, la valoración emocional se inclinada en al dirección del color del marco (p.ej., un marco positivo en combinación con un número de fotismo negativo era evaluado más bien como positivo.) Por otro lado, los estímulos emocionalmente coherentes (valencia emocional consistente entre el fotismo y el marco) tendían a obtener una puntuación emocional neutra.

En el segundo experimento utilizamos los mismos estímulos en una tarea de tiempo de reacción que consistía en decidir si el número era par o impar. En este caso obtuvimos un claro efecto de (in)coherencia emocional. Es decir, los estímulos que para R eran emocionalmente incoherentes (p.ej., un número con fotismo positivo con un marco de color negativo) parecían ralentizar las respuestas del sujeto.

Finamente, en el Experimento 3 empleamos el paradigma del reflejo de sobresalto (p.ej., Bradley et al., 1991) para ver si los estímulos emocionalmente incoherentes podían, o no, tener un impacto fisiológico. Para ello se emplearon los mismos estímulos que en el experimento anterior. En un ensayo dado un número enmarcado fue presentado durante 6 segundos; además, en el intervalo de 2.5 a 4.5 segundos se presentaba un ruido blanco de 50 milisegundos para causar una respuesta de sobresalto. La modulación emocional de este reflejo (su potenciación con estímulos aversivos y la atenuación del mismo con estímulos apetitivos o agradables) es uno de los fenómenos más estudiados en el campo de la psicología de la emoción. Considerando que los estímulos emocionalmente incoherentes eran percibidos como negativos por R, esperamos obtener un efecto de modulación. La variable dependiente fue la respuesta cardiaca diferencial (cambio de pulso con respecto de una línea base obtenida 3 segundos antes de la presentación del estímulo). Los resultados indican un efecto diferencial en la modulación de la respuesta cardiaca de sobresalto, en función de la coherencia o incoherencia emocional del estímulo. (Véase la Figura 3.)

Figura 3. Cambio cardiaco medio (con respecto de línea base), observado en las dos condiciones incongruentes, en respuesta a un sonido que causaba sobresalto. La respuesta cardiaca de sobresalto es atenuada cuando el color del marco y el fotismo asociado tienen la misma valencia emocional, pero está presenta cuando las dos valencias no coinciden. Los fotismos neutros parecen inhibir el sobresalto tanto para la condición de marco negativo como para la del marco positivo.



Los datos presentados confirman que los fotismos pueden tener un valor emocional no sólo a nivel subjetivo, sino también a nivel conductual y fisiológico. En contraste con los datos anecdóticos y estudios anteriores, la respuesta emocional de R parece depender de la coherencia emocional del estímulo, más que de una mera incongruencia entre colores reales y fotismos. Sin embargo, queda por responder a la pregunta si este mecanismo de coherencia es un efecto totalmente idiosincrásico que sólo se da en R, o si ocurre también en otros sinéstetas y posiblemente en personas no-sinéstetas expuestas a colores reales. Esperamos que futuras investigaciones puedan aclarar estas cuestiones.

Capítulo 6: El efecto de coherencia emocional de colores en la sinestesia léxica-cromática: parte II

El capítulo 6 es una continuación del artículo presentado en el capítulo precedente. Aplicando la misma lógica experimental replicamos el efecto de modulación emocional de la respuesta cardiaca de sobresalto observado en el sujeto sinésteta R, utilizando como variable dependiente la respuesta de parpadeo (electromiografía del músculo orbicular del ojo izquierdo). En resumen, la presencia de estímulos emocionalmente coherentes para R llevaba a una atenuación de la respuesta de parpadeo causada por el ruido blanco.

Tercera parte (Capítulo 7)

Capítulo 7: ¿Son los sinéstetas más creativos?

Con frecuencia la sinestesia ha sido relacionada con la creatividad artística. Los datos anecdóticos sugieren que entre la población dedicada a profesiones creativas hay un número relativamente grande de personas con sinestesia. Existe una larga lista de artistas sinestésicos: el escritor Vladimir Nabokov, los compositores Jean Sibelius, Amy Beach, Franz Liszt y Nikolai Rimsky-Korsakov, la leyenda del jazz Miles Davis, los pintores David Hockney, Wassily Kandinsky, etc. Aparte de datos anecdóticos, los estudios demográficos (p.ej., Rich, Bradshaw, & Mattingley, 2006) indican que entre la población sinésteta hay un porcentaje alto de personas que se dedican a profesiones o aficiones creativas. Asimismo, el término sinestesia, aparte de la sinestesia idiomática, también se ha aplicado en el contexto artístico a obras que emplean una mezcla de sentidos o asociaciones intermodales. Considerando esta cara artística de la sinestesia parece extraño que sólo ha habido muy pocas investigaciones centradas en las capacidades creativas de los sinéstetas. Además los resultados de estos estudios (p.ej., Sitton & Pierce, 2004) han sido, en el mejor caso, no concluyentes.

El artículo incluido en el Capítulo 7 examina el potencial creativo de un grupo de tres sujetos sinéstetas, comparándolo con un grupo control de participantes normales. Según el modelo de creatividad propuesto por Guilford (1957), la creatividad es el resultado de la suma de 3 factores cognitivos: la fluidez cognitiva, la flexibilidad cognitiva y la originalidad. La fluidez cognitiva implica la capacidad para producir un número alto de ideas o respuestas significativas ante un problema dado. La flexibilidad cognitiva hace referencia a la habilidad de adaptarse ante una situación nueva y la originalidad implica soluciones novedosas y creativas.

Para poner a prueba la fluidez cognitiva de los sujetos se utilizó la prueba de fluidez semántica y la fluidez fonológica (Tombaugh, Kozak, & Rees, 1999). No hubo diferencias significativas entre el grupo de sinéstetas y el grupo control en la ejecución en estas tareas. La flexibilidad cognitiva de los sujetos fue examinada por medio de tres tests psicológicos que son ampliamente utilizados en la praxis clínica así como en la investigación: Wisconsin Card Sorting Test (WCST, Heaton, Chelune, Talley, Kay, & Curtiss, 1993), Trail Making Test (TMT, Reitan, 1992) y prueba de Palabras y Colores basada en el paradigma Stroop (Golden, 1994). No hubo diferencias significativas entre las medias de ambos grupos en los principales índices del WCST que miden la flexibilidad cognitiva. Tampoco se observaron diferencias entre ambos grupos en la ejecución en el TMT. Finalmente, no fueron detectadas diferencias significativas algunas en el grado de interferencia tipo Stroop medida en el Test de Colores y Palabras. En su totalidad los datos indican que la flexibilidad cognitiva de los sinéstetas no es superior a la del grupo control de sujetos no-sinéstetas.

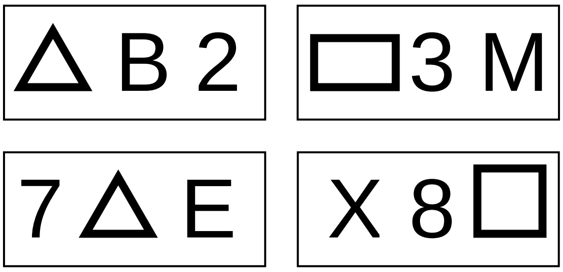


Figura 4: Ejemplos de tripletes utilizados en la prueba de imaginería visual.

Para estudiar el componente de originalidad, utilizamos una versión modificada de la tarea de imaginería visual de Finke (1990). La tarea consiste en combinar mentalmente tres formas geométricas para crear un objeto reconocible. (Véase la Figura 4 con ejemplos de tripletes de objetos a combinar que se utilizaron en la prueba.) El tiempo para realizar un ensayo de este tipo es normalmente limitado; no se puede dibujar durante la realización del ensayo. Una vez que el sujeto invente un objeto, le asigna un nombre y lo dibuja en una hoja de papel. Posteriormente los objetos son evaluados por “jueces” independientes en dos escalas: la escala de correspondencia (entre el nombre y la forma creada por el sujeto; escala 1-5) y la escala de originalidad (1-5). Los resultados indicaron que no había diferencias significativas entre ambos grupos en términos de originalidad de las creaciones y tampoco en la correspondencia. (Véase la Figura 5.)

En su totalidad, los datos referentes a los tres componentes cognitivos de creatividad, propuestos en el modelo de Guilford, sugieren que no existen diferencias significativas en el potencial creativo de personas sinéstetas en comparación con la población no sinésteta. Ahora bien, hay que reconocer que los resultados del presente estudio son limitados en términos del tamaño de la muestra. En teoría es posible que los participantes controles fuesen particularmente creativos, distorsionando por lo tanto el resultado de la comparación. No obstante, al convertir las puntuaciones directas en percentiles (esto sólo fue posible para las pruebas estandarizadas utilizadas para medir los componentes de fluidez y flexibilidad), no observamos que los sinéstetas fuesen particularmente superiores a la población normal de referencia.

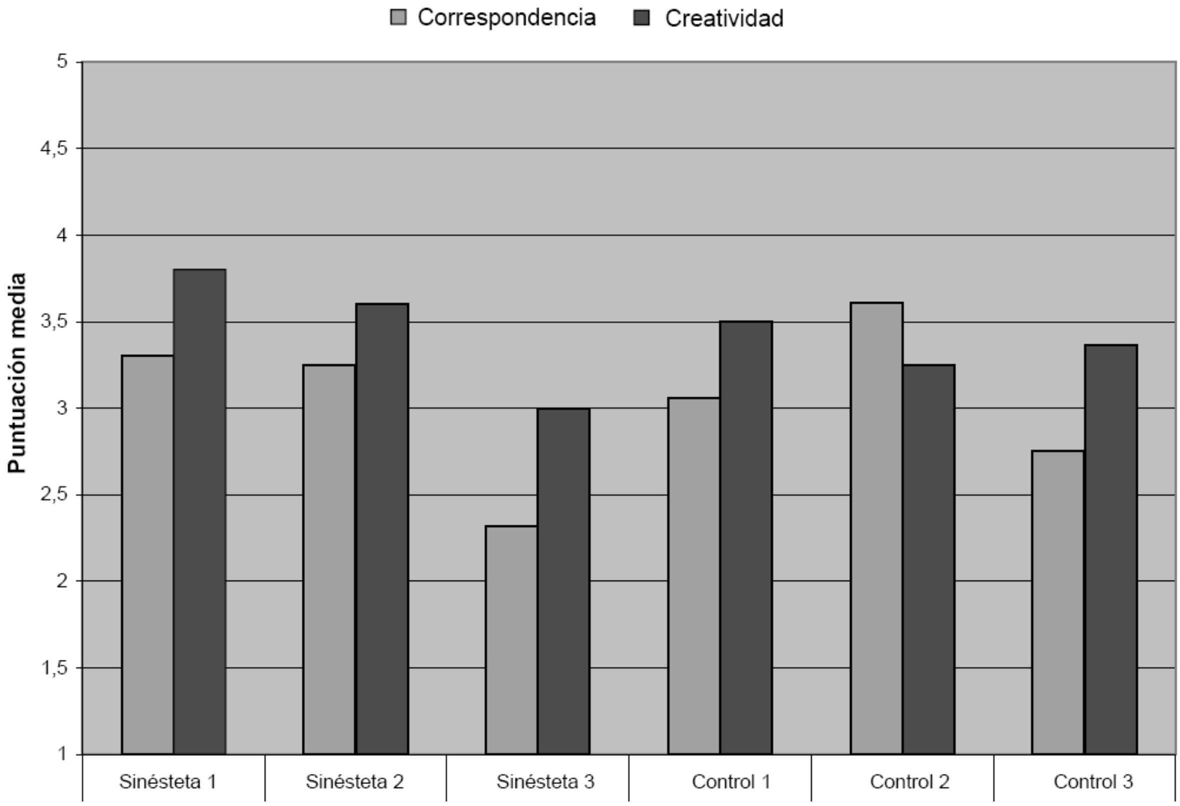


Figura 5: Puntuaciones individuales medias obtenidas por los sinéstetas y por los sujetos controles en la tarea de imaginería visual.

Otra posible limitación reside en el hecho que los tres sinéstetas incluidos en el estudio fueron de tipo “asociador” (que perciben los fotismos en su mente y no como proyectados al exterior). Es posible que sólo en los sinéstetas llamados proyectores (que tienen experiencias sinestésicas proyectadas) exista una capacidad creativa superior a la población normal. Una futura investigación que incluya una muestra más amplia de sujetos sinéstetas, estratificada en función de subtipos concretos sinestesias, podrá responder a estos interrogantes.

Cuarta parte (Capítulo 8)

Capítulo 8: El aura en misticismo y la sinestesia. ¿Fenómenos relacionados o diferentes?

Existen ciertos tipos de sinestesia que presentan un parecido con los llamados fenómenos áuricos descritos en el campo de misticismo y creencias New Age. En la literatura científica ha habido informes de casos de sinestesia emocional en la cual la percepción de caras o figuras humanas induce una percepción concurrente de colores (Milán et al., 2007; Ward, 2004). Algunos autores (p.ej., Ward, 2004) han propuesto que la supuesta capacidad de algunas personas de ver el aura humano se podría explicar como un subtipo de sinestesia cromática emocional. En este trabajo de investigación entrevistamos a tres sinéstetas emocionales que experimentan colores mentales (fotismos) en respuesta a la percepción visual de caras o figuras humanas. La información obtenida es contrastada con las descripciones de la supuesta visión áurica, obtenidas de un experto en medicina alternativa así como de la literatura esotérica. Basándonos en la información disponible sobre ambos fenómenos concluimos que muy probablemente se trata de dos fenómenos diferentes, con desiguales características fenomenológicas y en cuyo origen se encuentran mecanismos neurocognitivos dispares.

Conclusiones

El trabajo de investigación presentado en esta tesis doctoral no empezó con una serie de objetivos claros. Fue motivado por un sinfín de interrogantes que surgieron al conocer a una persona concreta – R, el sinésteta emocional que se ofreció voluntariamente como sujeto de nuestras investigaciones. La búsqueda de respuestas nos llevó a menudo por caminos inesperados, pero no por ello menos interesantes. El haberlos seguido nos permitió descubrir nuevos matices y aspectos de la sinestesia idiopática en general y de la sinestesia emocional en particular.

En primer lugar, probablemente por primera vez fue analizada en profundidad una variante poco frecuente de sinestesia que se caracteriza por la experiencia de fotismos (colores mentales) ante la presencia de estímulos visuales complejos, como caras, figuras humanas, pero también ante paisajes u objetos inanimados. Gracias a las entrevistas iniciales con R, comprendimos que su experiencia sinestésica estaba íntimamente relacionada con su mundo emocional y pusimos al descubierto un patrón de correspondencia entre el color de sus fotismos y su experiencia emocional. Aplicando de un paradigma de tiempo de reacción, confirmamos la autenticidad de la experiencia sinestésica en R, demostrando que los fotismos inducidos por fotografías emocionales podían facilitar o dificultar el reconocimiento de colores reales en función de su congruencia o incongruencia. Además, el empleo de métodos de tiempo de reacción, así como de registros fisiológicos, hizo posible una exploración minuciosa de la sinestesia emocional, descubriendo, por ejemplo, el papel de la coherencia emocional de los colores en esta peculiar variante de sinestesia.

Aparte de los experimentos realizados siguiendo la lógica de caso único, estudiamos la relación entre la sinestesia y la creatividad. Aunque sea verdad que hay un número relativamente alto de artistas de renombre con sinestesia, este hecho de por sí no puede considerarse una prueba empírica a favor de un mayor potencial creativo de los sinéstetas con respecto de la población normal. A pesar de ello, varios estudiosos de la sinestesia llegaron a plantear hipótesis neuropsicológicas sobre las posibles causas de la supuesta mayor creatividad de los sinéstetas (p.ej., Ramachandran & Hubbard, 2001). En nuestra opinión, este último planteamiento es, como mínimo, prematuro. El estudio psicométrico presentado en el capítulo 7 desmitifica el tema de la creatividad en sinestesia, poniendo al descubierto la ausencia de diferencias significativas entre sinéstetas y normales en términos de fluidez cognitiva, flexibilidad mental y originalidad. Una futura continuación de esta línea de investigación permitirá responder de un modo más contundente a la cuestión si la sinestesia funciona o no como un potenciador de la creatividad.

En el último capítulo estudiamos la hipotética relación entre la sinestesia emocional y los llamados fenómenos áuricos, conocidos de la literatura esotérica. A pesar del parecido superficial que pueden guardar ambos fenómenos y en contraste con las conjeturas de algunos autores, demostramos que muy probablemente se trata de fenómenos desiguales en cuyo origen se encuentran mecanismos neurobiológicos diferentes.

Finalmente consideramos importante resaltar la aportación del presente trabajo desde el punto de vista metodológico. Algunos de los procedimientos utilizados en nuestra serie experimental son novedosos en el campo de la investigación de la sinestesia; en particular la aplicación del paradigma de modulación de sobresalto para estudiar el impacto emocional de colores y fotismos. La observación de un efecto fisiológico atribuible a la experiencia sinestésica, es, a nuestro saber, un avance nuevo en este campo.

Para cerrar esta discusión, consideramos oportuno introducir una reflexión sobre la importancia de la sinestesia para el avance de nuestra comprensión de la experiencia subjetiva. El fenómeno sinésteta ha constituido un curioso rompecabezas para la ciencia cognitiva por la sencilla razón de tratarse de una experiencia fenomenológica cuya incidencia es muy baja. A diferencia de patologías psiquiátricas y trastornos resultantes de lesiones cerebrales, la sinestesia es una condición innata, no perturbadora y altamente estable, que se da en individuos por lo demás normales. Lo que llama la atención de laicos y profesionales es el hecho de que los sinéstetas informan de ver “cosas” que las personas “normales” no pueden percibir. Si usted al encontrarse en un cruce de peatones dice que ve “un semáforo en rojo”, ningún científico cognitivo va a empeñarse en aplicarle una tarea Stroop para verificar que usted realmente ve lo que dice ver. Curiosamente, desde el punto de los sinéstetas, los comienzos de la investigación sobre la sinestesia eran precisamente eso – responder a la pregunta: ¿es verdad lo que usted afirma y realmente ve la B acromática en rojo? En otras palabras, la investigación cognitiva invirtió tiempo y esfuerzo para comprobar la autenticidad de una experiencia subjetiva, demostrando lo mismo que los sinéstetas ya nos habían comunicado con sus propias palabras. Si aceptamos por completo los informes verbales de los sinéstetas, aparentemente la ciencia ha hecho un trabajo en vano. Sin embargo, además de demostrar empíricamente la veracidad de la introspección, en nuestra opinión este esfuerzo ha constituido una lección de aprendizaje para la psicología, en relación con la comprensión científica de la experiencia subjetiva.

En la actualidad el estudio de la sinestesia se encuentra en una fase nueva, en la cual ya no es necesario demostrar escrupulosamente la autenticidad de la experiencia sinestésica. En realidad, a menudo es útil dejarnos inspirar por las afirmaciones subjetivas de nuestros sujetos y así revelar posibles caminos nuevos en la investigación experimental. Los experimentos presentados en este trabajo no habrían sido posibles sin una actitud abierta y atenta a los informes verbales de los sinéstetas a la hora de plantear hipótesis, crear diseños y también interpretar los datos obtenidos. En realidad, una buena parte de los resultados experimentales serían indescifrables en absoluto sin hacer referencia a la subjetividad y la idiosincrasia del sujeto. (Por ejemplo, los patrones fisiológicos observados en R sólo se pueden comprender teniendo en cuenta su peculiar percepción emocional de los colores.) Esto nos lleva al controvertido concepto de los *cualia*, es decir, de las experiencias subjetivas intransferibles (Chalmers, 1996). Hay quienes dudan de que este constructo sea útil en absoluto más allá de las fronteras de la filosofía de la mente. Algunos aspectos de la experiencia sinestésica parecen indicar lo contrario. Los sinéstetas pueden presentar respuestas subjetivas que no tienen un correlato directo en la realidad, pero no por ello son imposibles de estudiar o comprender. Hay quienes experimentan fotismos de matices de colores que sólo "existen" en su mente y no los pueden ver en el mundo real. Sin entrar en un debate filosófico, queremos poner énfasis la importancia que ha tenido el estudio de la sinestesia para el progreso de la investigación científica de las experiencias "en primera persona", tanto a nivel teórico como metodológico. En nuestra opinión, el camino a seguir para continuar avanzando en esta dirección implicará compaginar los datos conductuales y neurológicos con los informes subjetivos (Smilek & Dixon, 2002), convirtiendo el punto de vista del sujeto en una parte integral de la investigación neuropsicológica.

Referencias

Abbas, N., Kumar, D., & McIachlan, N. (2005, September 1-4). *The Psychological and Physiological Effects of Light and Colour on Space User.* Paper presented at the Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China.

Bradley, M. M., Cuthbert, B. N., & Lang, P. J. (1991). Startle and emotion: lateral acoustic probes and the bilateral blink. *Psychophysiology, 28*(3), 285-295.

Callejas, A., Acosta, A., & Lupiáñez, J. (2007). Green love is ugly: emotions elicited by synesthetic grapheme-color perceptions. *Brain Research, 1127*(1), 99-107.

Cytowic, R. E. (1989). *Synesthesia: a Union of the Senses*. New York: Springer.

Cytowic, R. E. (1996). Synesthesia: Phenomenology and neuropsychology [Electronic Version]. *Psyche*, *2*. Retrieved 10 january 2007 from http://psyche.cs.monash.edu.au/v2/psyche-2-10-cytowic.html.

Chalmers, D. J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*. New York: Oxford University Press.

Dann, K. T. (1998). *Bright Colors Falsely Seen: Synaesthesia and the Search for Transcendental Knowledge*. New Haven: Yale University Press.

Finke, R. A. (1990). *Creative imagery: Discoveries and inventions in visualization*. Hillsdale, NJ: Erlbaum.

Galton, F. (1880/1997). Colour associations. In S.Baron-Cohen & J.E.Harrison (Eds.), *Synaesthesia: Classic and Contemporary Readings* (pp. 43-48). Oxford: Blackwell.

Golden, C. J. (1994). *Stroop Test de Colores y de Palabras*. Madrid: TEA Ediciones.

Guilford, J. P. (1957). Creative abilities in the arts. *Psychological Review, 64*(2), 110-118.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual: Revised and expanded*. Odessa (FL): Psychological Assessment Resources.

Hubbard, E. M., & Ramachandran, V. S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron, 48*, 509–520.

Krohn, W. O. (1892). Pseudo-chromaesthesia, or The Association of Color with Words, Letters, and Sounds. *American Journal of Psychology, 5*, 20-41.

Marks, L. E. (1978). *The Unity of The Senses: Interrelations Among the Modalities*. New York: Academic Press.

Milán, E. G., Hochel, M., González, A., Tornay, F., McKenney, K., Díaz Caviedes, R., et al. (2007). Experimental study of phantom colors in a color blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75-95.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia: A window into perception, thought and language. *Journal of Consciousness Studies, 8*(12), 3–34.

Reitan, R. M. (1992). *Trail making test. Manual for administration and scoring*. Tucson: Reitan Neuropsychology Laboratory.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2006). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition, 1*(98), 53-84.

Sitton, S. C., & Pierce, E. R. (2004). Synesthesia, creativity and puns. *Psychological reports, 95*(2), 577-580.

Smilek, D., & Dixon, M. J. (2002). Towards a Synergetic Understanding of Synaesthesia: Combining Current Experimental Findings Withs Synaesthetes' Subjective Description [Electronic Version]. *Psyche*, *8*. Retrieved December 12, 2006 from http://psyche.cs.monash.edu.au/v8/psyche-8-01-smilek.html.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Studies of interference in serial verbal reactions, 18*, 643-662.

Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative Data Stratified by Age and Education for Two Measures of Verbal Fluency: FAS and Animal Naming. *Archives of Clinical Neuropsychology, 14*(2), 167-177.

Vila, J., Sánchez, M., Ramírez, I., Fernández, M. C., Cobos, P., Rodríguez, S., et al. (2001). El Sistema Internacional de Imágenes Afectivas (IAPS): Adaptación española. Segunda parte. *Revista de Psicología General y Aplicada, 54*, 635-657.

Ward, J. (2004). Emotionally mediated Synaesthesia. *Cognitive Neuropsychology, 21*(7), 761-772.