TESIS DOCTORAL

SINESTESIA Y EMOCIONES.
REACCIONES AFECTIVAS ANTE LA PERCEPCIÓN
DE ESTÍMULOS SINESTÉSICAMENTE INCONGRUENTES

Synesthesia and emotions.

Affective reactions as a consequence

of synesthetically incongruent stimuli

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ÍNDICE DE FIGURAS, TABLAS Y GRÁFICAS

SINESTESIA. INTRODUCCIÓN[1]

[1] Partes de este capítulo han sido publicadas en:

Callejas, A. y Lupiáñez, J. (en prensa). Los colores de mis letras: sinestesia grafema-color. En M.J. Contreras, J. Botella, R. Cabestrero y B. Gil (Coords.), *Lecturas de Psicología Experimental*. Madrid: UNED.

Callejas, A. y Lupiáñez, J. (2005). El color de las palabras. *Percepnet. Centro de recursos sobre la percepción y ciencias sensoriales*. Revista electrónica. http://www.percepnet.com/

Normalmente vemos los colores, olemos los olores, y oímos los sonidos. Pero, por raro que parezca, esto no es siempre así, como ocurre, al parecer, en el caso de los bebés recién nacidos (Maurer, 1997) o en las personas ya adultas que experimentan el fenómeno de la percepción sinestésica. La sinestesia, del griego “syn” (unión) + “aisthesis” (sensación), consiste en la unión de distintos sentidos. Así, a la percepción de un estímulo sensorial se une la experiencia subjetiva de otra percepción sin referente externo (Cytowic, 1989). Una experiencia es evocada por un estímulo específico que no evocaría dicha experiencia en la mayoría de la población (Ward y Mattingley, 2006). En algunos casos la percepción de una melodía va acompañada de una experimentación de distintos sabores (Beeli, Esslen y Jäncke, 2005), la percepción de distintos sabores va acompañada de una experiencia de tacto (Cytowic, 1993), o cada palabra se experimenta con un sabor particular (Ward y Simner, 2003). En todos estos casos hay un estímulo, perceptual o conceptual, que evoca o dispara una sensación adicional y esa sensación que se experimenta añadida a la propia del estímulo. En la literatura científica se denomina al estímulo evocador *inductor* y a la sensación adicional experimentada *concurrente* (Grossenbacher y Lovelace, 2001).

Aunque el término original de sinestesia hace referencia a la unión de diferentes sentidos, existen casos en los que ésta se produce dentro de una misma modalidad sensorial pero entre dimensiones estimulares distintas como el color y la forma. Así, aunque existen muchos tipos distintos de sinestesia, el más común, y tal vez por ello el más estudiado, es aquel en el que las letras, palabras o números evocan colores (Day, 2005). Este tipo de sinestesia se ha denominado “grafema-color” haciendo referencia al inductor (el grafema) y al concurrente (el color). En segundo lugar están las personas que perciben colores cuando se enfrentan a unidades de tiempo. También es frecuente el caso de ver colores para las palabras habladas, los sonidos en general o las notas musicales. En menor medida se dan casos de personas que ven colores para distintos sabores, sabores o percepciones táctiles para distintos sonidos, sabores para percepciones táctiles y un largo etcétera. Hasta el momento se han documentado casos de casi todas las distintas combinaciones posibles entre los distintos sentidos (Day, 2005; Rich, Bradshaw y Mattingley, 2005).

Es importante distinguir la sinestesia como fenómeno perceptual de otros fenómenos como las asociaciones basadas en memoria o de la sinestesia como figura literaria. En el caso de las asociaciones, un estímulo determinado puede estar asociado con un color particular. Cuando se le pregunta a una persona lo que le sugiere la palabra “plátano” es normal que responda que le sugiere una fruta o el color amarillo. No obstante, no perciben la palabra como si fuera amarilla sino que la ven escrita del color en que realmente está escrita. De igual modo, la sinestesia como figura literaria se utiliza para embellecer el estilo de una composición, para enriquecer la descripción de un fenómeno (ej. “María es una persona muy dulce” “llevaba una camiseta naranja chillón”) pero ello es muy distinto del hecho de que el escritor esté experimentando tales percepciones.

Al contrario, un sinestésico que experimenta colores para las palabras, puede que vea la palabra “plátano” de color amarillo, o tal vez la vea de color azul, pero la ve realmente de ese color aunque esté escrita con tinta negra; tiene una experiencia subjetiva similar a la experimentada ante la percepción real de colores. O puede que un sinestésico realmente experimente un sabor dulce al ver a una persona particular. Los sinestésicos grafema-color perciben las letras y números como si estuvieran escritas con un color determinado. No obstante, son conscientes de que ese no es el color real del estímulo, o al menos, de que no es la única experiencia de color proveniente de ese estímulo sino que experimentan dos colores, real y sinestésico. Es interesante destacar el hecho de que no todos los sinestésicos de esta categoría perciben los colores de igual modo. Algunos de ellos ven el color de las letras proyectado hacia el exterior de manera que se superpone a la letra en sí o flota en el campo visual sin localizarse específicamente en el espacio que ocupa la letra, mientras que otros lo ven “en la mente” (Dixon, Smilek y Merikle, 2004).

1 Antecedentes históricos

El fenómeno de la sinestesia ha sido conocido durante mucho tiempo aunque su estudio científico es relativamente reciente. Ya en el siglo XVIII se encuentran escritos como el de Castel (Castel, 1735) en el que se hace referencia a estudios previos sobre un caso de sinestesia en una persona ciega. Por estas mismas fechas Isaac Newton (1730) intentó encontrar la fórmula matemática para igualar la vibración de las ondas sonoras a la longitud de onda correspondiente para diferentes colores. Con posterioridad, más de un centenar de escritos fueron publicados sobre sinestesia en los que se hacía especial hincapié en la *escucha coloreada* o en las *vocales coloreadas* (véase Marks, 1975 para una revisión de este material).

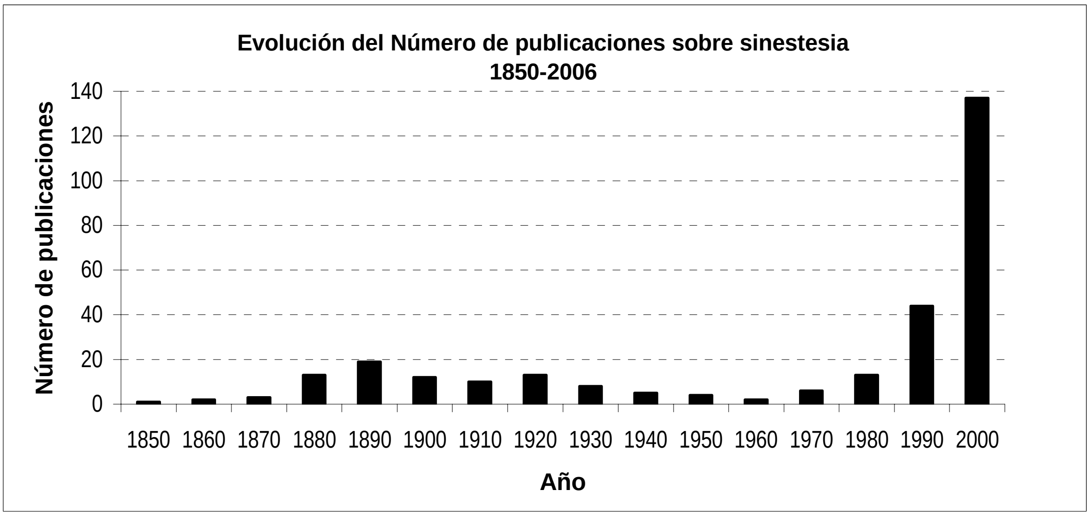
En 1895 Mary W. Calkins publicó el primer artículo científico en el que la palabra sinestesia aparecía en el título y se utilizaba con el significado que le atribuimos actualmente. Un par de años antes realizaría un novedoso estudio con el fin de estimar la frecuencia de dicho fenómeno. Como profesora de psicología del Colegio Wellesley tomó un grupo de 525 alumnas a las que cuestionó en relación a sus percepciones. Un grupo de 35 resultó experimentar lo que en aquel momento Calkins denominó pseudocromatestesia y que más tarde llamaría sinestesia. Por lo tanto el 6.7% parecía experimentar alguna forma de sinestesia. Esta cifra es bastante superior a cualquiera de las estimaciones propuestas actualmente. No obstante, tras examinar las respuestas de las alumnas encontró que la proporción de estudiantes que experimentaba color para las palabras no era superior al 1%. Esta cifra sí es más cercana a otras estimaciones para la sinestesia grafema-color más recientes (véase sección de prevalencia).

Durante esta época también se publicaron diversos libros en los que se discutía la sinestesia en el ámbito del arte, la música, la literatura, la lingüística o la filosofía (Suárez de Mendoza, 1890; Argelander, 1927). En la mayoría de los casos se centraban en la escucha coloreada como la forma más frecuente de sinestesia. En este primer cuarto del siglo XX seguía vivo el interés por la sinestesia y se dieron a conocer numerosos casos de escucha coloreada, así como de música coloreada o de vocales con color. Incluso se intentó explicar la sinestesia desde el punto de vista de la teoría psicoanalítica (Hug-Hellmuth, 1912) o según la estructura fonética de las vocales (Henning, 1923).

En los cincuenta años posteriores, probablemente por la influencia del conductismo y la negación de toda conducta no observable, el interés por la sinestesia pareció decaer, aunque todavía fueron numerosos los estudios realizados, que incluían algunos sobre música coloreada (Karwoski, Odbert y Osgood, 1942; Odbert, Karwoski y Eckerson, 1942), intentos de estudiar las similitudes entre los colores experimentados por las vocales en distintos idiomas (Reichart, Jakobson y Perth, 1949) o informes sobre escucha coloreada inducida por sustancias como la mescalina (Delay, Gérard y Racamier, 1951). Como puede observarse en la Gráfica 1, el número de producciones en esta época descendió considerablemente, comparado con los cincuenta años anteriores.

En la década de los ochenta, Cytowic y Wood (1982) realizaron una serie de observaciones sistematizadas de una persona que experimentaba formas con los sabores y otra que escuchaba colores. Este trabajo puede considerarse el primer estudio experimental, al menos desde el *renacimiento* del interés por el fenómeno de la sinestesia.

A partir de este momento, y gracias al surgimiento gran auge de la psicología y la neurociencia cognitiva, han sido numerosos los estudios interesados por el fenómeno de la sinestesia. Principalmente se han centrado en demostrar que es un fenómeno genuino y no una simple forma de expresarse (Baron-Cohen, Wyke y Binnie, 1987; Mills, Boteler y Oliver, 1999; Dixon, Smilek, Cudahy y Merikle, 2000; Ramachandran y Hubbard, 2001a; Palmeri y cols., 2002; Lupiáñez y Callejas, 2006) aunque también ha habido un gran interés por la posibilidad de que la sinestesia sea hereditaria (Baron-Cohen et al., 1996; Ward y Simner, 2005) y en los mecanismos cerebrales implicados en este fenómeno (Aleman y cols, 2001; Hubbard, Arman, Ramachandran y Boynton, 2005; Nunn y cols., 2002; Paulesu y cols., 1995; Weiss y cols., 2001).



Gráfica 1. Evolución del número de publicaciones sobre sinestesia en los últimos 150 años. Datos procedentes de Marks (1975), Harrison (2001) y de las bases de datos de Science Citation Index y Social Sciences Citation Index (búsqueda "synesthesia or synaesthesia")

Una vez asentada la premisa de que la sinestesia es un fenómeno real, cuantificable y sujeto a estudio empírico, se ha comenzado a diversificar el interés de la comunidad científica para centrarse en otros tipos de sinestesia menos conocidos, aunque también relativamente frecuentes, como pueden ser las líneas numéricas (Seron y cols., 1992), la música coloreada (Ward, Huckstep y Tsakanikos, 2006), la sinestesia léxico-gustativa (Ward y Simner, 2003), la música saboreada (Beeli y otros, 2005), la sinestesia crono-espacial (Smilek, Callejas, Dixon y Merikle, en prensa), etc.

Actualmente el fenómeno de la sinestesia parece estar de nuevo en auge y la evolución en los últimos años ha sido espectacular. No sólo hay más laboratorios interesados en desentrañar las peculiaridades de esta forma de percibir, y de cómo puede ayudarnos a conocer más a fondo el funcionamiento y las bases neurales de los procesos perceptuales y de integración multisensorial en personas no sinestésicas, sino que también ha crecido la conciencia social del fenómeno que se encontraba en el nivel de lo paranormal o anecdótico. Numerosos libros se han publicado en los últimos veinte años, tanto a nivel divulgativo (Cytowic, 1993; Harrison, 2001, Duffy, 2001) como a nivel científico (Cytowic, 1989/2002; Baron-Cohen y Harrison, 1997; Robertson y Savig, 2005). Se ha creado una asociación de sinestesia en Estados Unidos (American Synesthesia Association) y otra paralela en el Reino Unido (UK Synaesthesia Association) y se celebran congresos anuales en ambos paises en los que la comunidad científica interesada en la sinestesia, así como personas con sinestesia, se reúnen y ponen en común los avances científicos junto con los informes subjetivos de los sinestésicos. En el ámbito puramente científico también se ha plasmado el interés creciente en el tema con un simposium especial sobre sinestesia en el XIV congreso de la Sociedad Europea de Psicología Cognitiva (European Society of Cognitive Psychology) y una edición especial de la revista Cortex dedicada exclusivamente al tema de la sinestesia.

2 Características de la sinestesia

Aunque hay cierto debate sobre algunas de las afirmaciones siguientes, las características más importantes de la sinestesia como fenómeno neurocognitivo son las siguientes (Cytowic, 1995). La sinestesia es un fenómeno estable, de carácter perceptual e idiosincrásico. Ocurre de manera automática y es una experiencia genérica memorable. Es unidireccional y tiene un marcado carácter emocional. A continuación se describen cada uno de estos aspectos.

2.1 Estabilidad

La sinestesia es un fenómeno *estable en el tiempo*. Esto es algo que lo distingue de las asociaciones de memoria. Antes de que la sinestesia se empezara a estudiar científicamente, se solían minusvalorar las informaciones proporcionadas por los sinestésicos sobre la base de que sus informes no estaban indicando fenómenos reales sino meras asociaciones aprendidas a lo largo de la vida. Así, algunos argumentaban que las personas con sinestesia simplemente habían aprendido a leer y escribir utilizando un método en el que se asociaba un color a cada letra. Aunque esto pueda ser el desencadenante de los colores particulares (Witthoft y Winawer, 2006) que una persona experimenta, el hecho de que los experimente no está basado en tales factores. Estudios realizados posteriormente han demostrado que ésta no es la razón de tales experiencias y que no se clasifican como asociaciones de conceptos sino como percepciones. Cuando se pregunta a una persona con sinestesia sobre los colores que ve para un conjunto de estímulos, la respuesta que se obtiene es mucho más estable que la que se pueda obtener preguntando a un grupo de personas sin sinestesia. Esto es así incluso cuando el intervalo entre test y retest, en los no sinestesicos, es de días y en los sinestésicos de meses (Baron-Cohen, Wyke y Binnie (1987). La constancia en los colores percibidos por las personas sinestésicas es sorprendente, ya que de 100 palabras, letras o números que se les presenten, responden seleccionando el mismo matiz de una paleta de colores para más de 90 de ellas. Es más, aquellas en las que no responden con el mismo color, el escogido suele ser uno del mismo grupo (ej. un azul más claro o más oscuro).

La estabilidad de las percepciones se ha convertido en un prerrequisito para la sinestesia y, aunque algunos autores proponen entenderlo como una característica asociada más que como una característica definitoria (Ward y Mattingley, 2006), cualquier estudio sobre sinestesia publicado en la actualidad presenta medidas de estabilidad test re-test como forma de demostrar a priori que los participantes tienen de hecho sinestesia. Tanto es así que ha sido desarrollado un Test de Autenticidad de la sinestesia (Testo of Genuineness) (Baron-Cohen y cols, 1987; Asher y cols., 2006). Un conjunto de fichas con distintos colores se presentan a los participantes para que elijan el color que más se parece a su percepción para determinados estímulos (palabras o sonidos). En una segunda ocasión se presentan los mismos estímulos y, con un sistema de puntuación determinado, se estima cómo de similares son los colores elegidos para el mismo estímulo en dos ocasiones diferentes. Normalmente esta prueba se realiza con un intervalo entre test-retest de meses o años y sus autores encuentran que las personas con sinestesia escogen el mismo color o uno muy parecido en la mayoría de los casos mientras que participantes no sinestésicos no recuerdan más del 30% de los colores elegidos incluso cuando el intervalo entre test-retest no es mayor de unas cuantas semanas. En la Figura 1 puede observarse el color elegido por una persona con sinestesia, evaluada en nuestro laboratorio, cuando se le pidió que escogiera un color para cada letra y número de entre los 40 colores de la paleta presente en Microsoft Excel. Como puede observarse, la consistencia entre distintos momentos es muy alta y, sólo en algunos casos, se encuentran diferencias en el color elegido, aunque siempre dentro del mismo matiz. En estos casos la participante informó que ninguna de las opciones de color ofrecidas era la adecuada y, por eso, presentó una mayor variabilidad en la elección del mismo. También se presentan los datos de un retest llevado a cabo tras tres años con un sistema mucho más exhaustivo que daba opción a elegir entre más de 92.000 colores.

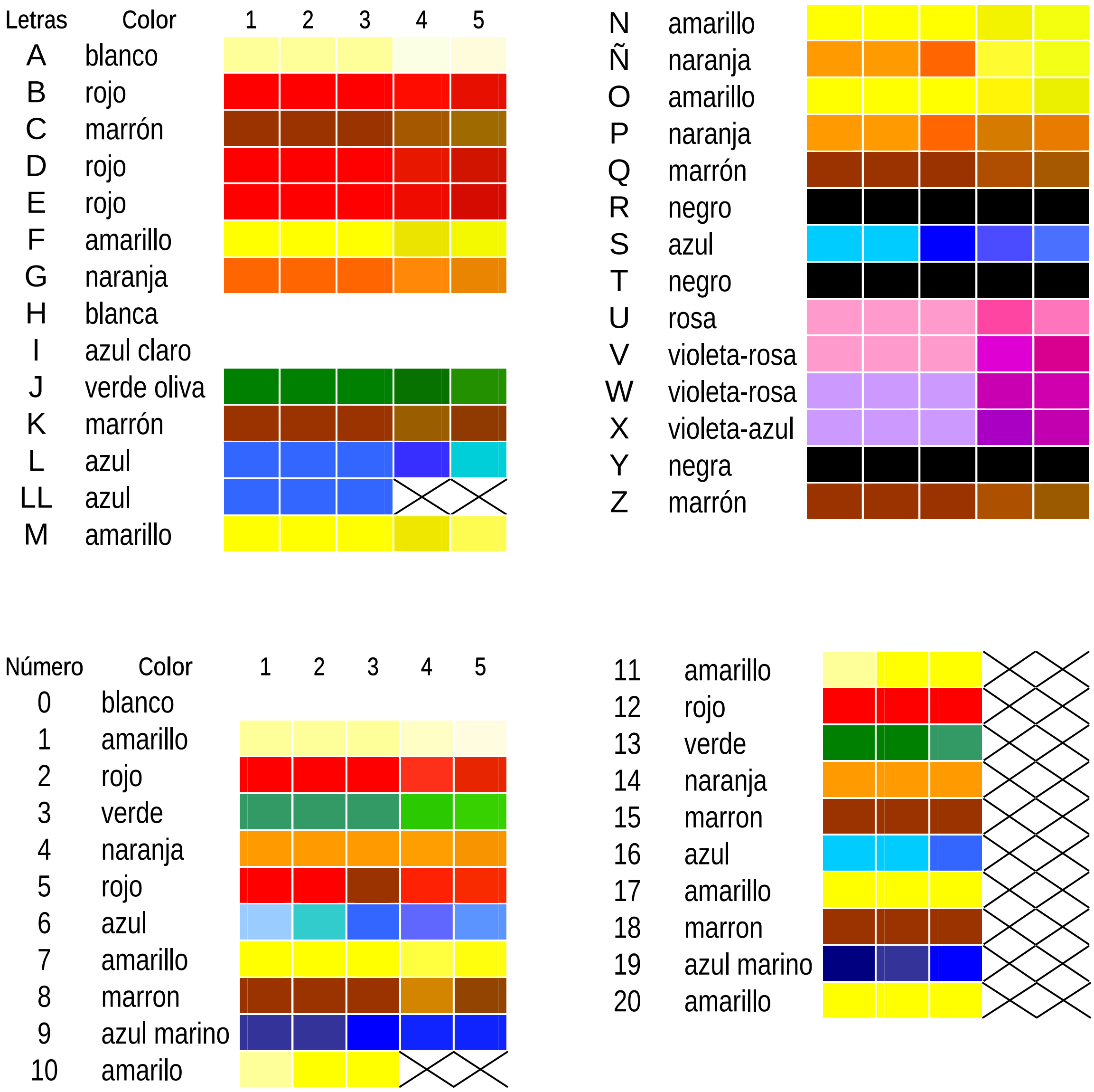


Figura 1. Ejemplo de consistencia en el color elegido por MA para cada letra y número en cinco ocasiones distintas: las tres primeras columnas se rellenaron con la paleta de color (40 colores) de Microsoft Excel. 1: inmediatamente después de decir la etiqueta verbal, 2: a los cinco minutos y 3: a la semana. Las dos últimas columnas corresponden a un retest 3 años más tarde. Los colores se eligieron de una muestra de más de 92000 colores en dos momentos consecutivos (4: primera pasada, 5: segunda pasada).

No obstante, estudios recientes apuntan a que la sinestesia no es un fenómeno tan estable como se había pensado. En un análisis de un cuestionario, cumplimentado por más de 300 personas con sinestesia de habla inglesa, se encontró que un 30% de los sinestésicos informaban de que sus experiencias sinestésicas se habían modificado a lo largo del tiempo (Callejas, Smilek, Dixon & Merikle, 2004). De este subgrupo un 32% informó de que el concurrente experimentado había cambiado en intensidad y otro 24% de que había cambiado cualitativamente. Por lo tanto, la ausencia de estabilidad test-retest, cuando el intervalo de tiempo es suficientemente amplio, no debería de tomarse como prueba de ausencia de la condición.

Para evitar este problema otros laboratorios han desarrollado métodos con los que se puede diferenciar claramente a las personas con sinestesia del resto de forma muy rápida. Con una aplicación informática Smilek, Dixon y Merikle (2005b, www.synaesthesia.uwaterloo.ca/participation.htm) presentan a los participantes una matriz de color en la que el número de posibles colores supera los 92000 y, tras asignar un color a cada letra y número, vuelven a presentar todos los estímulos en un orden aleatorio distinto. Con este método son capaces de distinguir, de forma clara, las personas con sinestesia de aquellas que informan no percibir colores para letras o números.

En nuestro laboratorio hemos adaptado el sistema de Smilek y cols. (2005b) al alfabeto español (inclusión de la letra "ñ") y estamos recogiendo datos de multitud de personas con sinestesia de habla hispana (www.ugr.es/~sinestes/). Los participantes asignan un color de una amplia gama a cada letra o número presentados de forma aleatoria. Inmediatamente después de responder a los 37 estímulos, estos son presentados de nuevo en otro orden aleatorio. Para evitar que los participantes puedan obtener una consistencia mayor mediante la memorización de las coordenadas espaciales en las que se encuentra cada color, una vez terminada la primera fase se modifica el espacio de color presentado para que ningún color se encuentre en la misma pareja de coordenadas x,y. Una vez terminada la segunda fase, los participantes informan sobre el nivel de exactitud con que encontraron el color experimentado para cada estímulo. En la actualidad estamos desarrollando un sistema similar para evaluar la consistencia de los colores asociados a palabras.

Dando un paso más, Eagleman (www.synesthete.org) ha desarrollado un sistema, puesto al servicio de la comunidad científica, en el que combina el método de Smilek y cols (2005b) con un test comportamental. En un primer momento el participante elige el color más adecuado para cada letra y número, en tres ocasiones sucesivas; a continuación cada letra o número es presentado en la pantalla del ordenador en un color determinado y el participante debe responder, a la mayor brevedad, si el color presentado es el elegido por él en la fase anterior (el color *correcto*) o un color distinto (*color incorrecto*). Aunque una persona, con muy buena memoria o utilizando distintas estrategias, podría llegar a puntuar de manera similar a un sinestésico en el test de consistencia, los tiempos de reacción necesarios para decidir si el color presentado es el correcto o no distinguen claramente a ambos grupos.

2.2 Carácter perceptual

Las sensaciones sinestésicas son *de carácter perceptual* y no basadas en memoria. En un intervalo de meses, tanto Ramachandran y Hubbard (2001a) como Smilek, Dixon, Cudahy y Merikle (2001) demostraron, en dos variantes de una tarea de búsqueda visual, que en sinestésicos que perciben grafemas con colores particulares, estos colores son percibidos y procesados de una forma muy similar a aquella en la que los procesarían si estuvieran, de hecho, presentes en el papel o la pantalla del ordenador.

Ramachandran y Hubbard (2001a) presentaron un conjunto de letras a su participante sinestésico JC y a un grupo de controles. Entre las letras, presentadas de manera aleatoria en la pantalla, se escondía una figura geométrica cuyo contorno estaba formado por una de las tres letras presentes. Las otras dos se utilizaban como distractores. Teniendo en cuenta que los participantes sabían en cada bloque la identidad de la letra cuya distribución formaba la figura geométrica, la persona con sinestesia era más exacta al identificarla cuando el conjunto estimular se presentaba durante 1s, en comparación al grupo control.

Smilek y cols. (2001) realizaron una tarea incluso más exhaustiva en la que presentaron, durante 32 ms, un grafema enmascarado a su sinestésica C y a un grupo de controles. La tarea de los participantes era identificar el grafema enmascarado. La manipulación crítica consistió en variar el color del fondo en que se presentaban los estímulos, para que pudiera ser igual o distinto al fotismo evocado por dicho estímulo. La lógica experimental era que, si los fotismos se perciben en el espacio externo, de manera automática y como si fueran colores reales, cuando el color del fondo igualara al del fotismo evocado por el grafema presentado en gris oscuro, la participante sinestésica tendría más dificultad para identificarlo que cuando el fondo no era del mismo color. Esto fue lo que, de hecho, encontraron. C identificaba los objetivos con más facilidad cuando el fondo en el que se presentaban no correspondía con el color evocado. Los participantes no sinestésicos, no solo no presentaron una diferencia entre ensayos, con fondo congruente e incongruente, sino que tuvieron una ejecución general peor que la de C.

En un estudio posterior, además, demostraron además que el efecto de sustitución de objeto (Enns y Di Lollo, 1997) desaparecía para C cuando el fotismo evocado por el objetivo era distinto al evocado por los distractores. Este efecto ocurre a nivel conceptual cuando los recursos atencionales están distribuidos y la máscara permanece en la pantalla durante un tiempo suficiente tras la presentación del objetivo (Di Lollo, Enns y Rensink, 2000). Con esto demostraron que, aunque el efecto de sustitución de objeto elimina el reconocimiento consciente de grafemas en los participantes no sinestésicos, no eliminaba la experiencia de color en C. Aunque la atención focalizada parece ser necesaria para el reconocimiento de los grafemas, el color se suele considerar una característica básica que no requiere del mecanismo de binding (Treisman y Gelade, 1980).

2.3 Carácter idiosincrásico

Las percepciones sinestésicas son *idiosincrásicas*. Aunque los colores que un sinestésico percibe para un conjunto de letras y números permanece estable a lo largo del tiempo, su conjunto de colores es totalmente distinto al de otro sinestésico que también vea colores para letras y números. En la Figura 2 se muestran los colores asociados a letras y números por distintas personas con sinestesia.

Figura 2. Ejemplo de colores para tres personas con sinestesia grafema-color. Como puede observarse, uno de los casos solo percibe color para las vocales.

Los primeros estudios llevados a cabo en la “era moderna” del estudio de la sinestesia enfatizaban que los colores asociados con letras o números no seguían un patrón observable y no estaban determinados por la experiencia previa. Así, era muy normal encontrar la afirmación de que *la sinestesia no estaba causada por juegos de imanes de la infancia* (es común en algunos países encontrar juegos para que los niños aprendan el alfabeto, que consisten en imanes para pegar en el frigorífico con las letras de distintos colores). Con esto se pretendía enfatizar el hecho de que la sinestesia no es una asociación de conceptos sino una experiencia perceptual.

No obstante, algunos estudios, comparando las asociaciones de un gran número de personas con sinestesia, han encontrado tendencias de que ciertos grafemas están más asociados a unos colores que a otros (Simner y cols., 2005, Simner, Glover y Mowat, 2006). Así, por ejemplo, en países de habla inglesa se ha encontrado que el color más probable para la letra “A” es el rojo, ya que está fuertemente asociada a “manzana” (*apple*), mientras que la “B” es muy probable que sea percibida en azul, ya que dicho color empieza por esta letra en inglés (*blue*). Estudios recientes han documentado un caso en el que los colores de una persona con sinestesia estaban en su mayoría determinados por un juego de imanes que la participante tenía en su niñez (Witthoft y Winawer, 2006).

Una de las participantes sinestésicas estudiada en nuestro laboratorio sostiene que los colores de sus letras están determinados por los colores en que se presentaban en el libro con el que aprendió a leer (Micho). Tras realizar numerosos estudios experimentales, que se describen a continuación, conseguimos recuperar un ejemplar de dicho método de aprendizaje de la lectura. En la Figura 3 se comparan los colores utilizados en la cartilla con los experimentados por MA.

Puesto que el método de aprendizaje utiliza el criterio fonético para colorear las letras, puede observarse que letras con el mismo fonema (ej. “c” y “k” producen el fonema /k/) tienen el mismo color y que otras letras (ej. “g”) tienen distinto color en función del sonido que producen. También es interesante ver que ninguna de las vocales se presenta en color (excepto la “u” cuando unida con la “g” da lugar al sonido /g/). Por lo tanto, de 27 letras, sólo en 11 coincide el color de la cartilla Micho y el esquema de percepción sinestésica de MA.

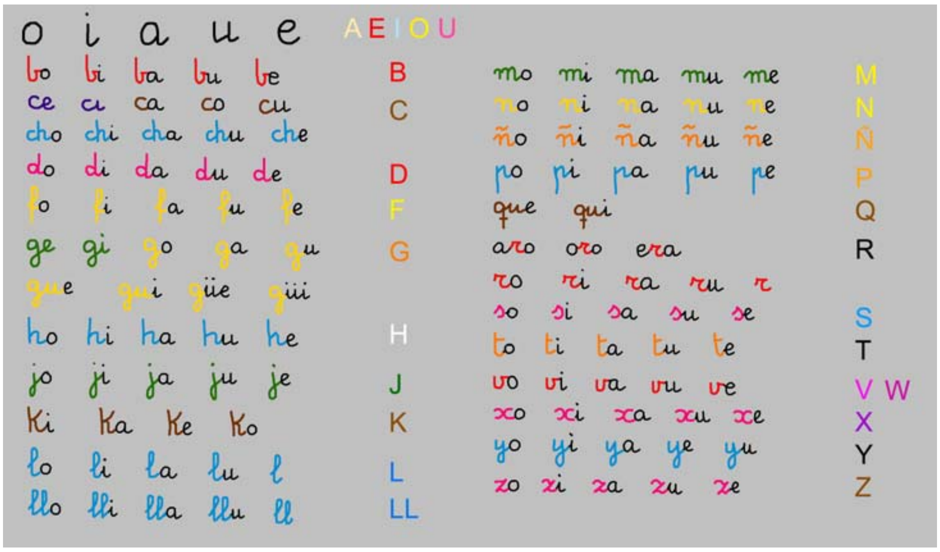


Figura 3. Comparación de los colores utilizados en un método de aprendizaje de lectura (Cartilla Micho), presentados a la izquierda, con los colores asociados a las letras por la participante sinestésica MA, presentados a la derecha.

Como se discutirá más adelante, el hecho de que la sinestesia sea un fenómeno perceptual, automático e involuntario no está reñido con que se conozcan los orígenes de las asociaciones entre grafemas y colores. Puesto que los humanos no nacen con conocimiento de los grafemas y sistemas de escritura, es necesario que tenga lugar el aprendizaje de los mismos para que pueda producirse la sinestesia. Por lo tanto, aquello que distingue a sinestésicos de los que no lo son sería simplemente la predisposición a enlazar información aparentemente independiente y experimentarla de manera vívida e involuntaria. Es posible que los libros utilizados para aprender un lenguaje o los juegos con los que se interacciona en la infancia sean los determinantes de las asociaciones específicas de cada persona sinestésica pero no del hecho de que lo sean.

2.4 Automaticidad

Las percepciones sinestésicas son *automáticas, involuntarias* y *difíciles de suprimir*. Esto es, la persona que tiene estas experiencias no puede reprimirlas. Simplemente ocurren. Como antes se mencionó, numerosas investigaciones se han llevado a cabo en este ámbito, principalmente con distintas variantes del paradigma Stroop, para demostrar que las percepciones sinestésicas ocurren de forma automática (Dixon y cols., 2002; Elias, Saucier, Hardie y Sarty, 2003; Lupiáñez y Callejas, 2006 -Capítulo 1-; Mattingley, Rich, Yelland y Bradshaw, 2001; Mills y cols., 1999, 2002; Odgaard, Flowers y Bradman, 1999; Wollen y Ruggiero, 1983, entre otros). En la versión estándar del paradigma Stroop (1935) se presentan nombres que designan colores en un color de tinta que puede ser congruente o incongruente con el color designado por la palabra (ej. ROJO presentado en color rojo-congruente- o en color azul-incongruente-). Las respuestas en la condición incongruente cuando la tarea del participante es nombrar el color en que se presenta la palabra suelen ser más lentas que en la condición congruente. Como la tarea a realizar no está relacionada con la lectura de la palabra pero incluso así ésta ocurre, se concluye que la lectura de la palabra es automática (MacLeod, 1991).

En la extensión del paradigma al estudio de la sinestesia, la manera más común de proceder ha sido la de presentar un conjunto de letras o números en un color determinado y pedir a los participantes que indiquen el color en que se encuentra el estímulo. La manipulación clave, incluida en los estudios de sinestesia consiste en presentar cada estímulo con el color en el que el sinestésico ha informado previamente que lo percibe (condición congruente) o con un color distinto (condición incongruente). Así una “J” presentada en *rojo* podría ser congruente para un sinestésico mientras que si se presenta en *azul* sería incongruente. Del mismo modo, para otra persona con sinestesia ambos colores serían incongruentes y el *verde* sería el congruente. En cualquier caso, lo que para una persona sin sinestesia sería una tarea carente de dificultad (nombrar el color en que se presenta una “h” o una “j”), para una persona con sinestesia debería de ser más fácil o más difícil en función de la letra escrita. Es decir, en función de que el color evocado por la letra (el fotismo) coincida o no con el color en el que ésta se presenta y por lo tanto, el color que hay que nombrar. Esto es precisamente lo que se encuentra en una gran variedad de estudios. Las personas con sinestesia son mucho más rápidas cuando color real y fotismo coinciden (condición congruente) que cuando no lo hacen (condición incongruente).

Otro enfoque al estudio de la automaticidad de la sinestesia ha sido el de comparar la interferencia producida por el fotismo con la interferencia producida por el color real presentado al participante (Dixon y cols., 2004; Lupiáñez y Callejas, 2006 -Capítulo 1-). Dixon y cols pidieron a diferentes personas con distinto tipo de sinestésia (asociativa o de proyección; ver más abajo) que realizaran ambas tareas; nombrar el color y nombrar el fotismo. Encontraron que, en el caso de la sinestesia asociativa, la interferencia producida por el color real, cuando la tarea consistía en nombrar el fotismo, era mayor que la interferencia producida por el fotismo cuando la tarea era nombrar el color real del estímulo. Además, eran más rápidos nombrando el color real que nombrando el fotismo. Para la sinestesia de proyección encontraron que la interferencia del color real sobre el fotismo era menor y se tardaba menos tiempo en nombrar el color del fotismo que el color percibido visualmente. Si estos estudios se generalizan a otros grupos de personas con sinestesia, la tarea de nombrar el color vs. nombrar el fotismo podría pasar a ser un elemento objetivo para diferenciar ambos grupos de sinestésicos.

Finalmente, también se ha estudiado el grado en que experiencias sinestésicas se pueden inhibir mediante el paradigma de Priming Negativo (Odgaard y cols, 1999; Lupiáñez y Callejas, 2006; Capítulo 1).

2.5 Percepción genérica

Las percepciones sinestésicas son *genéricas*. Es decir, cuando una palabra da lugar a una percepción de color, ésta es simple, se trata de un color o un pequeño conjunto de ellos, no de una percepción elaborada. De igual modo, cuando un sinestésico, por ejemplo, experimenta formas al probar distintos sabores, estas formas son muy generales, como líneas o espirales o texturas suaves o rugosas. No experimentan la sensación de estar tocando una vaca o viendo un castillo (Cytowic, 1993).

Aunque al describir sus experiencias una persona con sinestesia comente que el sabor del pollo es como tocar una columna de mármol, eso es sólo una analogía que hace referencia a un objeto familiar y ayuda en la descripción. No obstante, si se insiste en una descripción basada en sensaciones discretas, las personas con sinestesia admiten que no es eso lo que perciben sino sensaciones primarias, la sensación de ausencia de rugosidad, la temperatura baja, superficie vertical, etc.

2.6 Carácter memorable de las percepciones

Otra característica de la sinestesia es que las percepciones son *memorables.* Es común encontrar que las personas sinestésicas recuerden la percepción secundaria o sinestésica de forma más vívida que la primaria (aquella que evoca la sensación sinestésica) (Mills y cols., 2006; Smilek, Dixon, Cudahy y Merikle, 2002). Así, hay casos en los que no recuerdan un número de teléfono o el nombre de una persona, pero saben que el número empezaba por azul, o que el nombre era verde.

Quizás el caso más famoso de capacidades de memoria excepcionales sea el descrito por Luria (1968). S era un experto en mnemotecnia que podía memorizar cincuenta dígitos en tres minutos y recordarlos sin ningún error de manera inmediata y años después. S era, además, sinestésico y Luria especuló que sus habilidades mnemotécnicas podrían ser un resultado de su sinestesia. No obstante, Luria no proporcionó ninguna evidencia empírica de que fuera de hecho la sinestesia lo que mejoraba su memoria.

Smilek y cols. (2002) realizaron un experimento en el que abordaron el estudio empírico de esta cuestión. Para ello, presentaron a una participante sinestésica matrices de números para su memorización. Para comprobar que el fotismo evocado por cada número ayudaba a la memorización de los mismos, manipularon el color en que presentaban la matriz a recordar. En un caso (línea base) la presentaron en negro y en otras dos ocasiones en color (en un caso congruente con sus fotismos y en otro incongruente con los mismos). En este estudio encontraron que, cuando los dígitos estaban presentados en color incongruente, su participante sinestésica C era incapaz de recordarlos, mientras que, cuando se presentaban en negro o en color congruente, su recuerdo era mejor que el de la mayoría de los controles. Para demostrar que este efecto no se debía a una buena memoria general realizaron otro experimento en el que los estímulos a recordar eran caracteres que no evocaban ningún fotismo para C. En este caso encontraron que su recuerdo no era mejor que el de los controles. Es más, en una prueba sorpresa, 48 horas tras la fase de estudio, encontraron que el recuerdo de los controles para los dígitos y los caracteres decaía drásticamente. Del mismo modo decaía el recuerdo de C, pero sólo para la matriz de caracteres que no evocaban ningún fotismo. La matriz de dígitos era recordada con la misma exactitud que en la fase de prueba realizada tras el estudio.

Recientemente Azoulai, Hubbard y Ramachandran (2005) estudiaron el caso de un joven británico con capacidades mnemótécnicas excepcionales. En la actualidad ostenta el record europeo de decimales del número “pi” recordados (22.515). DT es, además, sinestésico y sostiene que su sinestesia le ayuda en el recuerdo. Para él, cada número del 0 al 10.000 tiene una forma particular y eso le ayuda a recordarlos y a realizar operaciones matemáticas de manera asombrosamente fácil. Además, cada número tiene un tamaño específico (6 es el más pequeño de todos y 9 el mayor). Azoulai y cols. (2005) presentaron a DT una matriz de 100 números para su memorización. Con Siguiendo una manipulación similar a la llevada a cabo por Smilek y cols. (2002), le presentaron a DT una matriz de números en la que el tamaño de cada número era igual (línea base), y un par de matrices en las que cada número tenía un tamaño. En una matriz los tamaños relativos de los números eran congruentes con lo informado por DT y en otra los tamaños eran incongruentes. Tras cinco minutos de estudio, DT recordaba el 68% de los dígitos cuando éstos aparecían en la condición de línea de base y el 50% cuando aparecían en condición congruente. Sin embargo, sólo recordaba el 16% cuando aparecían con un tamaño incongruente. Lo más sorprendente fue que, en un re-test realizado tras un día y en otro realizado tras tres días, DT recordaba todos los dígitos que había recuperado en la primera prueba para las dos primeras condiciones (línea base y congruente). No obstante, en el caso de los dígitos con tamaño incongruente, a las 24 horas sólo recordó el 4%, y a las 72 horas no fue capaz de recordar uno solo número. Azoulai y colaboradores concluyeron que las características sinestésicas asociadas a cada número ayudaban a DT a memorizarlas, pero cuando las características reales del estímulo interferían con su percepción interna, ésta ya no era efectiva en la mejora de su capacidad de memoria.

2.7 Unidireccionalidad

Tradicionalmente se ha pensado que la sinestesia es unidireccional (Mills y cols., 1999) y que un inductor evoca un concurrente; pero, a su vez, dicho concurrente no evoca el inductor. Esta afirmación, generalmente aceptada, ha sido cuestionada recientemente por dos grupos (Brugger y Della Betta, 2000; Brugger, Knoch, Mohr y Gianotti, 2004; Cohen-Kadosh y cols., 2005; Cohen-Kadosh y Henik, 2006; Knoch, Gianotti, Mohr y Brugger, 2005;).

Cohen-Kadosh y cols. (2005) utilizaron una variante del paradigma de congruencia de tamaño para estudiar si la sinestesia grafema-color es de hecho unidireccional. En el paradigma de congruencia de tamaño se presenta un par de números y el participante debe informar sobre el carácter numérico de ellos (ej. indicar cuál es mayor). Si el dígito, que es numéricamente mayor, es también mayor en tamaño físico, la tarea se ve facilitada en contraposición con el caso en el que el dígito, que es numéricamente más pequeño, es el que aparece en un tamaño físico mayor. Este resultado se interpreta haciendo referencia al hecho de que el tamaño físico es procesado automáticamente y, por ello, afecta la ejecución (Henik y Tzelgov, 1982).

Este paradigma de congruencia de tamaño se puede modificar para convertirlo en un paradigma de congruencia de color. No obstante, eso sólo es posible si el color lleva asociado un significado (en este caso, el número que lo induce). Para comprobar si el color evoca el número con el que está asociado se presentan números coloreados con el color que le corresponde o con el color correspondiente a otros números que están más separados ordinalmente o menos separados ordinalmente que los presentados. De esta manera se puede inducir un efecto de congruencia similar pero sólo si el color es efectivo para activar la representación semántica del número con el que se asocia. Es decir, sólo si el concurrente activa a su inductor. Siguiendo esta lógica Cohen-Kadosh y cols. (2005) presentaron un conjunto de pares de números que podían tener una distancia numérica pequeña (ej. 4 y 5) o una distancia numérica grande (ej. 2 y 7). En ambos casos los números aparecían en su color correspondiente (condición congruente) o en un color asociado con dígitos con distinta distancia numérica. En el caso del 4 y el 5, podían aparecer con el color del 2 y el 7; y en el caso del 2 y el 7, podían aparecer con el color del 4 y el 5. Con estas condiciones encontraron que, cuando el color en que se presentaban los dígitos era el evocado por dígitos con mayor distancia numérica, los participantes con sinestesia eran más rápidos en indicar cuál de los dos dígitos era mayor que cuando aparecían en su color correspondiente. No obstante, el efecto contrario no se encontró (la discriminación de dígitos con distancia numérica grande no empeoró cuando estaban coloreados con el color correspondiente a dígitos con pequeña distancia numérica). Los autores concluyeron que, en el primer caso, el procesamiento del color activaba el concepto numérico correspondiente y ayudaba a la ejecución. En el último caso, explican la ausencia de efecto basándose en la diferencia relativa en la velocidad con que se procesan las dos dimensiones del estímulo. Una distancia numérica grande se procesaría de forma rápida y el procesamiento del color que, a su vez, activaría el concepto numérico no sería llevado a cabo con suficiente rapidez como para influir en la respuesta.

2.8 Carácter emocional

Por último, la sinestesia tiene un carácter *emocional.* La experiencia sinestésica va asociada a una sensación de certidumbre y convicción de que lo experimentado es real y válido (Cytowic, 1993; 1989/2002). Debido al hecho de que la percepción sinestésica ocurre de forma involuntaria y es difícil de suprimir, hace que se experimente indistintamente de las características del inductor. Así, una “J” que lleva asociada la experiencia del color verde, seguirá induciendo dicho color independientemente de que esté escrita en negro, verde o amarillo. Esta presencia o ausencia de coincidencia entre las características preceptuales del inductor y del concurrente experimentado lleva a crear situaciones de congruencia o incongruencia entre ambas dimensiones, que inducen ciertas reacciones emocionales en las personas sinestésicas, bien de carácter positivo o negativo. Muchas personas con sinestesia informan de que la percepción de algo inconsistente, con su experiencia subjetiva, es desagradable y les causa malestar. Ramachandran y Hubbard (2001b) comentaron brevemente este aspecto de la sinestesia e incluso especularon con la posibilidad de que la presencia de conexiones cruzadas en el cerebro de las personas con sinestesia no se viera reducida a la zona que procesa la forma y el color sino que estuviera presente en toda la arquitectura cerebral, incluidas zonas del sistema límbico. Esto explicaría la experiencia de dichas reacciones afectivas. Esta característica de la sinestesia es una de las menos estudiadas hasta el momento y es, precisamente, en la que se centra el presente trabajo de investigación.

3 Prevalencia y carácter hereditario

Ya en el siglo XIX, Galton (1883) advirtió que el tipo de sinestesia más común era la *escucha coloreada* y que era mucho más común entre miembros de una misma familia de lo que lo era en la población general. Poco tiempo más tarde, en 1893 Calkins estimó a partir de una muestra de más de 500 personas, que el 6.7% de los entrevistados experimentaban sinestesia (entonces la llamó pseudo cromatoestesia). De este grupo, sólo el 1% informó percibir color para todas las palabras. Baron-Cohen y colaboradores (1996) realizaron un estudio que ha influido enormemente en la investigación posterior, tanto por sus afirmaciones sobre la prevalencia de la sinestesia, como sobre el posible componente hereditario de la misma y el porcentaje de hombres y mujeres que la experimentan. Tras anunciar su investigación en un periódico local, un grupo de personas con sinestesia se pusieron en contacto con su laboratorio. Basándose en las estadísticas del número potencial de lectores y en el número de personas que se pusieron en contacto con ellos para comunicar su sinestesia, llegaron a la estimación de que 1 de cada 2000 personas experimenta sinestesia (0.05%). También encontraron una proporción mayor de mujeres que de hombres (de 6:1 a 3:1 en función de que el estudio se realizara con habitantes de la ciudad de Cambridge o con estudiantes de dicha universidad). En ambos casos encontraron además, al igual que Galton, que en torno al 25-30% de ellos informaban tener alguien en su familia que también experimentaba sinestesia.

Basándose en este estudio, Baron-Cohen y cols. (1996; Bailey y Jonson, 1997) concluyeron que el patrón de transmisión genética, que más se ajustaba a tales características, era la transmisión ligada al sexo con letalidad. Propusieron que un solo gen ligado al cromosoma X podría ser el responsable del patrón encontrado y que la mayor cantidad de mujeres que de hombres podría deberse a la concurrencia de letalidad. Es decir, de los varones engendrados y portadores del *gen de la sinestesia*, la mitad no llegarían a término (darían lugar a abortos espontáneos).

La predicción clara de esta propuesta es que las madres con sinestesia tendrían más hijas que hijos y un mayor número de abortos espontáneos que la población general. Aunque la primera afirmación parecía estar apoyada por los datos de Baron-Cohen y cols. (1996), la segunda no ha sido comprobada hasta recientemente. Ward y Simner (2005), recientemente, realizaron un estudio con 85 familias y concluyeron que, aunque sus resultados eran básicamente consistentes con la hipótesis de una herencia ligada al cromosoma X, en su muestra no había evidencia de letalidad en los varones, ya que encontraron un número de hijos similar al de hijas de personas con sinestesia.

Un par de artículos recientes plantean cierto conflicto con el punto de vista de que la sinestesia se puede explicar con un patrón de herencia dominante ligada al cromosoma X. Smilek y cols. (2002) documentaron un caso de una pareja de gemelas monocigóticas discordantes para sinestesia. Un análisis genotípico demostró que su carga genética era idéntica. No obstante, pruebas objetivas, así como sus propios informes subjetivos, demostraron que sólo una de ellas era sinestésica. Los autores propusieron como posible explicación de dicha discordancia el hecho de que en cada una de las gemelas se hubiera desactivado un cromosoma X distinto. No obstante, recientemente, informaron de un caso que es más difícil de conciliar con el punto de vista mayoritario sobre el modo de herencia de la sinestesia. (Smilek, Dixon y Merikle (2005b). Han documentado un caso en el que dos hermanos gemelos monocigóticos son discordantes para la sinestesia. Puesto que en los varones sólo hay un cromosma X, la hipótesis de la desactivación no puede explicar este caso. Aunque una posible explicación hace referencia a la relativa penetración del gen, los autores se decantan por cuestionar el hecho de que la sinestesia sea hereditaria. Basándose en estudios recientes, que demuestran una mayor prevalencia de la sinestesia que lo anteriormente pensado, (Stephan, 2005; Simner y cols., en prensa), los autores cuestionan que, realmente, sea más común encontrar a distintas personas con sinestesia dentro de una familia que en la población general.

Tres laboratorios están intentando descifrar el posible gen responsable de la sinestesia y su modo de actuación (Asher, Lamb, Baron-Cohen y Monaco en Cambridge, Reino Unido; Eagleman, Kagan, Sarma y Nelson en Houston, Estados Unidos y Mitchell, Bargary, Barnett y Newell en Irlanda). El primer grupo se decanta por la idea de que la sinestesia está ligada a más de un cromosoma (Asher, Lamb, Baron-Cohen y Monaco, 2006) y no predice un mecanismo de acción particular de los mismos. El segundo grupo se decanta por la posibilidad de que la acción del gen ligado a la sinestesia sea la de producir una arquitectura cerebral distinta de la de personas no sinestésicas (Eagleman, Kagan, Sarma y Nelson, 2006; ver hipótesis de la activación cruzada más abajo). Por último el tercer grupo se centra en la posibilidad de que el gen ligado a la sinestesia tenga implicaciones funcionales (Mitchell, Bargary, Barnett y Newell, 2006; ver hipótesis de la retroalimentación desinhibida más abajo).

Igualmente, en lo referente al sesgo encontrado entre el número de mujeres y hombres con sinestesia, existe un cierto debate sobre la exactitud y la interpretación de estas afirmaciones. Aunque estudios recientes encuentran unas estimaciones muy similares (Rich y cols., 2005), es importante tener en cuenta que ambos estudios (Baron-Cohen y cols., 1996 y Rich y cols., 2005) se basaron en muestras auto-referidas. Una información publicada en un periódico local, en un caso, y nacional en el otro, sirvieron de reclamo para que todo aquel interesado contactara con los investigadores. Las características de este método tienen inherente un problema relacionado con la propensión de distintos subtipos de población a responder más que otros. En particular, la diferencia encontrada entre el número de hombres y mujeres, que contestaron al reclamo, podría deberse al hecho de que los hombres sean menos propensos a ofrecer información sobre sus peculiaridades que las mujeres, y no tanto a una mayor prevalencia de la sinestesia entre las mujeres. Rich y colaboradores (2005) mantienen que el hecho de que la proporción de personas con sinestesia en Australia sea 6.1:1 (extremadamente parecida al 6.3:1 de Baron-Cohen y cols, 1996, en Cambridge, Reino Unido) no puede explicarse sólo sobre la base de un sesgo de género en la propensión a ofrecer información de este tipo. Day (2005) encuentra una proporción similar con los datos obtenidos mayoritariamente con población estadounidense.

No obstante, las razones encontradas en otros estudios difieren significativamente de estas. Recientemente Simner y cols. (en prensa) realizaron dos estudios a gran escala en los que las muestras no eran auto-referidas. En ambos casos se realizaron pruebas objetivas y subjetivas para determinar la ocurrencia de la sinestesia *grafema-color* o de cualquier otro tipo de sinestesia. En el primer estudio realizaron una pequeña prueba a más de mil visitantes del Museo de la Ciencia de Londres, en una exposición interactiva. A cada participante le presentaron todas las letras y números de manera individual y se le pidió que le asignaran el color que mejor combinara con dicho estímulo. Una vez terminada la prueba se le volvió a presentar el mismo conjunto de estímulos y se infirió de ambas puntuaciones una medida de consistencia. Por último preguntaron a los visitantes si pensaban que ellos experimentaban sinestesia. De los 1190 visitantes, que realizaron las pruebas, el 1.1% fue identificado con sinestesia *grafema-color*. Una prueba similar se llevó a cabo con 500 estudiantes universitarios escoceses y, de nuevo, el porcentaje de personas con sinestesia *grafema-color* era del 1.4%. Aún más interesante fue el hecho de que el mismo número de hombres que de mujeres fueron identificados en estas muestras. Estos datos suponen el primer intento de estudio de la prevalencia de la sinestesia en una muestra más aleatoria de la población. En este sentido, es importante señalar que, aun cuando en este estudio el participante no era el agente activo que debía informar de su percepción, la muestra también estaba sesgada en cierta manera, pues sólo determinados grupos de población están interesados en visitar un museo de ciencia y, obviamente, la muestra universitaria es sólo representativa de ese subgrupo de la población). Datos similares, en cuanto a la prevalencia de la sinestesia, provienen del estudio de Mulvenna, Hubbard, Ramachandran y Pollick (2004).

4 Tipos de sinestesia

Ya en 2001 Ramachandran y Hubbard propusieron que podría haber dos subgrupos de gente con sinestesia, dentro de la sinestesia grafema-color. Los denominaron sinestésicos de “alto nivel” y de “bajo nivel” y lanzaron la hipótesis de que el “locus” de la activación cruzada estaría localizado en diferentes áreas cerebrales en ambos grupos (ver teoría de la activación cruzada más abajo). Ambos grupos se diferenciarían, en la práctica, por el nivel de procesamiento del inductor, en el que se produciría la activación del concurrente. Mientras que en los sinestésicos de “bajo nivel” la forma del grafema sería el desencadenante del color, en los de “alto nivel” serían las características ordinales de los estímulos (el orden de las letras en el abecedario o de los números o días de la semana). El inductor respondería, por lo tanto, a un nivel más conceptual del mismo estímulo.

De forma casi paralela Smilek y Dixon (2002) propusieron una distinción en función de los informes subjetivos de las personas sinestésicas con las que habían interaccionado. Al describir sus experiencias, un gran número de sinestésicos hacían referencia al lugar espacial en el que percibían los fotismos. Mientras unos informaban que el color aparecía proyectado en el espacio, normalmente encima del estímulo que lo inducía, otros aseguraban que el color no lo veían proyectado, sino en la mente. Estos informes llevaron a los autores a proponer dos tipos de sinestesia grafema-color, la sinestesia “de proyección” y la sinestesia “de asociación”. Postularon que la primera estaría caracterizada por una mayor automaticidad en la percepción del fotismo que la segunda.

No obstante, algunos investigadores (Edquist, Rich, Brinkman y Mattingley, 2006; Mattingley y cols., 2001; Rich y Mattingley, 2005) obvian la posibilidad de que haya diferentes subgrupos de sinestesia grafema-color y agrupan a personas con sinestesia en sus análisis sin evaluar la posibilidad de que sus experiencias se puedan catalogar bien en uno de los grupos descritos por Ramachandran y Hubbard (2001b), bien o en uno de los descritos por Dixon y Smilek (2005).

Recientemente Dixon y cols. (2004) han demostrado empíricamente que las personas con sinestesia de proyección tienen un patrón de comportamiento distinto a las personas con sinestesia de asociación. Al tomar un grupo de personas, que explicaban sus experiencias sinestésicas haciendo referencia a que el color aparecía en la mente, y otro grupo, que hacía referencia al color como proyectado en el espacio, realizaron un experimento Stroop con dos variantes. En un caso, pedían a los participantes nombrar el color en que aparecía el estímulo e ignorar su fotismo y, en otro, pedían nombrar el fotismo e ignorar el color presente en la pantalla del ordenador. La interferencia causada por el color *real* al nombrar el fotismo fue mayor en el grupo de sinestesia de asociación, mientras que la interferencia causada por el fotismo al nombrar el color *real* fue mayor en el grupo de sinestesia de proyección. Los autores concluyeron que la sinestesia de proyección tenía un carácter más perceptual que la de asociación y, por ello, los últimos tenían más interferencia del color *real* al nombrar el fotismo experimentado en la mente.

Si bien es cierto que muchas personas con sinestesia no se ven identificadas con ninguna de estas dos categorías, eso no es motivo suficiente para obviarlas, ya que dan lugar a patrones comportamentales distintos. En lugar de obviar las diferencias, sería conveniente que seguir profundizando en las características de este tipo de sinestesia, ya que puede haber otros tipos intermedios o simplemente tratarse de un continuo de viveza con la que se experimenta el fotismo. En cualquier caso, la diferenciación de los diferentes subtipos de sinestesia es importante, ya que nos permitirá un mejor conocimiento de la sinestesia y probablemente de los diferentes mecanismos cognitivos y cerebrales que la sustentan.

5 Bases cerebrales

El número de estudios con imagen cerebral llevados a cabo en la investigación de las bases neuronales de la sinestesia va en aumento, y de forma especial, en los últimos años. En un primer estudio, Paulesu y cols. (1995) utilizaron PET para estudiar la sinestesia palabra-color. Compararon la actividad cerebral de personas con sinestesia y participantes control al escuchar tonos puros o palabras habladas. Las personas sinestésicas que estudiaron percibían colores para el lenguaje hablado pero no para los tonos puros. Comparando la activación entre en ambas condiciones, en personas con sinestesia encontraron activación en áreas del cortex temporal posterior-inferior y en zonas de la unión parieto-occipital, pero ninguna diferencia en zonas de procesamiento visual primario como V1, V2 o V4. Ninguna de estas zonas estaba activa en controles no sinestésicos.

En un estudio posterior Nunn y cols. (2002) estudiaron de nuevo sinestésicos, para los que la escucha de nombres evocaba color, pero con técnicas de resonancia magnética funcional. En este caso encontraron activación diferencial en la zona del cerebro relacionada con el procesamiento del color (V4/V8), pero no en zonas de procesamiento visual más tempranas (V1 o V2,) siempre que las personas con sinestesia escuchaban nombres pero no cuando escuchaban sonidos puros. De nuevo ninguna de estas activaciones estaba presente en los participantes del grupo control.

Otros estudios posteriores de caso único también han encontrado patrones de actividad inconsistentes. Mientras que Weiss y cols. (2001) encontraron activación cerca de V4, pero no en V1, en una persona con sinestesia, para la que los nombres de persona evocaban colores, en un estudio más reciente no encontraron actividad en estas zonas cerebrales sino en zonas del surco intraparietal (Weiss, Zilles y Fink, 2005) que se han relacionado con la unión de color y forma (Robertson, 2003). Por último Aleman y cols. (2001) encontraron activación en V1 pero no en V4. Según Hubbard y Ramachandran (2005) esta discrepancia en cuanto a las zonas activadas podría deberse a diferencias metodológicas o al tipo de sinestesia de las personas estudiadas.

Para evaluar la contribución relativa de estas dos posibles variables contaminantes, Hubbard y cols. (2005) combinaron un conjunto de pruebas psicofísicas con un estudio de imagen cerebral y un par de tareas secundarias, a fin de determinar anatómicamente las áreas visuales en cada uno de los participantes sinestésicos y sus respectivos controles. Mediante la utilización de técnicas de estimulación de la retina como cuñas blancas y negras en rotación o anillos expandiéndose (Engel, Rumelharth, Wandell y Lee, 1994; Sereno y cols., 1995), identificaron las áreas visuales primarias de cada participante que están organizadas de forma retinotópica con un margen de error de 2 a 4mm (Engel, Zhang y Wandell, 1997). Hubbard y cols. (2005) encontraron que V4 (pero no áreas anteriores en el procesamiento visual: V1, V2) estaba más activado, en personas con sinestesia, cuando percibían grafemas que evocaban color que cuando percibían caracteres gráficos sin significado (y por lo tanto sin color). Es interesante comentar que la activación encontrada en estas zonas correlacionaba con la mejoría encontrada en las tareas psicofísicas en relación con los controles. Por lo tanto, parece ser que las diferencias individuales en ejecución entre distintas personas con sinestesia van acompañadas de cambios cuantitativos en la actividad cerebral de las áreas de procesamiento del concurrente.

Otro estudio reciente también comparó la actividad de personas sinestésicas con controles delimitando las zonas visuales para cada uno de los participantes (Sperling y cols., 2006). De nuevo encontraron que la activación de V4 era mayor en sinestésicos cuando se le presentaban grafemas para los que tenían una experiencia sinestésica de color que para aquellos que no la producían.

Por lo tanto, los estudios más recientes, que realizan un mapa retinotópico para cada uno de los participantes, parecen coincidir en el hecho de que V4 está más activada cuando personas con sinestesia experimentan un color que cuando no lo hacen.

Aunque estos estudios informan de actividad en V4, la baja resolución temporal de las técnicas de imagen cerebral no ofrece información sobre el momento temporal en que dicha activación se produce y, por lo tanto, no ayudan a discernir si tal actividad es concurrente a la del procesamiento de la forma o posterior. Estudios de electrofisiología son necesarios para discernir este punto.

En este sentido sólo un estudio se ha llevado a cabo hasta el momento sobre el curso temporal de las percepciones sinestésicas (Schiltz y cols., 1999). Un conjunto de 17 personas con sinestesia y otros tantos controles realizaron una tarea, típica del paradigma de odd-ball, en la que había que detectar un objetivo infrecuente entremezclado con distractores. Ambos, objetivo y distractor, podían ser letras o números. Los resultados del estudio demostraron que el grupo de sinestésicos comenzaba a diferenciarse de los controles alrededor de los 150ms post aparición del objetivo y en electrodos frontales y centrales, pero no en los parietales. Los autores interpretaron los datos haciendo referencia a las demandas de la tarea en la que las personas con sinestesia tenían que ignorar el color evocado por el estímulo para centrarse en su identidad y así poder realizar la tarea correctamente, tal y como habían propuesto anteriormente Paulesu y cols. (1995) para explicar cierta actividad encontrada en su estudio de PET en áreas prefrontales derechas.

No cabe duda de que son necesarios más estudios electrofisiológicos para llegar a un mejor entendimiento del curso temporal de las experiencias subjetivas asociadas a la sinestesia.

6 Teorías Explicativas

Han sido numerosas las teorías propuestas para explicar el fenómeno de la sinestesia, tanto desde un punto de vista psicológico como neurocognitivo. También han sido múltiples los modos de clasificar dichas teorías, en función del énfasis dado a ciertas características de unas teorías frente a otras (Harrison y Baron-Cohen, 1997; Harrison, 2001; Cytowic, 2002; Marks y Odgaard, 2005; Hubbard y Ramachandran, 2005). La estructura con la que se enuncian a continuación utiliza como criterio el ámbito en que se plantea la teoría, ya sea psicológico o neurocognitivo y la relación que postulan entre las personas no sinestésicas y las sinestésicas. Como podrá observarse, las teorías estrictamente psicológicas pertenecen a los estudios clásicos de principios del s.XIX y las neuropsicológicas a los estudios actuales.

6.1 Teorías Psicológicas

Dos teorías se pueden diferenciar en este campo. Ambas hacen referencia a asociaciones creadas entre el inductor y el concurrente que explican la experiencia subjetiva de uno al percibir el otro. Así la sinestesia sería el producto de una cadena de asociaciones mentales en la que algunos de los pasos intermedios podrían haber dejado de ser conscientes. La diferencia entre ambas teorías radica en el mecanismo postulado para la aparición de dichas asociaciones.

La *Teoría de las asociaciones* (Langfield, 1926: Wheeler y Cutsforth, 1922) explica la sinestesia haciendo referencia a asociaciones azarosas de manera que si A sugiere B, entonces A y B deben haber sido experimentadas de manera simultánea en algún momento del pasado. Esta teoría tiene problemas para explicar el hecho de que, en la misma familia, distintos miembros experimenten asociaciones distintas entre, por ejemplo, letras y colores.

La *Teoría del tono emocional* (Calkins, 1895, Smith, 1905) propone una explicación similar, pero haciendo referencia al significado connotativo de los estímulos implicados. Propone que el inductor y el concurrente comparten un trasfondo emocional que es el causante de la asociación entre ellos. Tal y como Cytowic (2002) plantea, esto llevaría a postular que un sonido estaría, no sólo asociado a un color con el que comparte la misma base emocional, sino también a un sabor, un olor, etc.

En la actualidad estas teorías han recibido poco apoyo ya que los estudios comportamentales y de neuroimagen parecen dejar patente que los mecanismos implicados en la sinestesia tienen una base neural. En cualquier caso, el hecho de que las nuevas teorías neurocognitivas puedan explicar de un modo más preciso los mecanismos responsables de la sinestesia en sí, teorías psicológicas parecidas a estas podrían ser adecuadas para explicar la génesis de las asociaciones específicas de cada sinestésico.

6.2 Teorías Neurocognitivas

Desde la Neurociencia Cognitiva, el área de conocimiento más dedicada en la actualidad al estudio de la sinestesia, se han propuesto diferentes teorías en las que se combinan mecanismos cognitivos y cerebrales para la explicación del fenómeno. Estas teorías recogen los datos sobre áreas cerebrales implicadas en la sinestesia provenientes de distintas técnicas de neuroimagen (ver sección anterior) y plantean distintos modos en los que las zonas encargadas del procesamiento del concurrente se verían activadas cuando se procesa el inductor, dando así lugar a la experiencia subjetiva de sinestesia. Además, también plantean si los mecanismos que hacen posible esta comunicación están presentes en todos los humanos y, por alguna razón, sólo activos en las personas con sinestesia o si no son compartidos por todos. Aunque algunos autores (Hubbard y Ramachandran, 2005) plantean que estas dos dimensiones son independientes, no todas las posibilidades han sido propuestas. La mayor parte de las teorías se han basado en estudios de sinestesia grafema-color aunque también hay alguna que se centra en otros tipos de sinestesia como la sinestesia gustativo-táctil (Cytowic, 1993).

Teoría de la activación cruzada local (Ramachandran y Hubbard)

La hipótesis de que la sinestesia pudiera deberse a una activación cruzada entre áreas encargadas del procesamiento de la forma y procesamiento del color fue propuesta hace más de un siglo y retomada posteriormente por otros investigadores (Harrison y Baron-Cohen, 1997; Marks, 1975; Grossenbacher, 1997). No obstante, no ha sido hasta recientemente cuando se ha presentado de modo elaborado y comprensible. Ramachandran y Hubbard (2001) la retomaron y ampliaron para proponer un "locus" específico de dicha activación cruzada. Basándose en estudios previos sobre el Área de la Forma Visual de las Palabras (Cohen y Dehaene, 2004) y el homólogo humano a V4, que procesa el color (Wade y otros, 2002), propusieron que en esta zona de la corteza fusiforme podría estar produciéndose la activación cruzada que daría lugar a la experiencia subjetiva de color, cuando se procesara visualmente un grafema. Además, para dar cuenta de las diferencias entre distintos tipos de sinestésicos, añadieron que la activación cruzada también podría ocurrir en niveles superiores del procesamiento de la forma y del color, en el giro angular izquierdo. Esta zona se ha implicado en los cálculos numéricos abstractos (Dehaene, 1997). Cerca del giro angular está el giro temporal superior que se ha relacionado con el siguiente estadío en el procesamiento del color (Zeki y Marini, 1998). Por lo tanto, la teoría propone que al percibir un grafema, la información llega a zonas de la corteza estriada y extraestriada y posteriormente es enviada a la zona del área de la forma visual de la palabra y de ahí a la corteza angular. En uno de estos pasos se produce una activación cruzada de zonas cerebrales adyacentes que procesan el color y dicha activación da lugar a la experiencia subjetiva de color que acompaña a la experiencia del estímulo visual que se está percibiendo. En la Figura 4 se esquematiza esta teoría y los posibles estadíos del procesamiento en los que se produciría la activación cruzada entre zonas adyacentes. Esta activación cruzada lleva a la experiencia reproducible, involuntaria y sistemática de percepciones sinestésicas (Hubbard y Ramachandran, 2003). Aunque la teoría fue propuesta dentro del marco de la sinestesia grafema-color, los autores proponen que podría extenderse a otros tipos de sinestesia en los que las zonas cerebrales encargadas de procesar el inductor y el concurrente se encuentran próximas dentro de la geografía cerebral.

Respecto al origen de estas conexiones cruzadas entre zonas adyacentes del cerebro, Ramachandran y Hubbard (2001b; Hubbard y Ramachandran, 2005) proponen que son debidas a una deficiente poda neural en las etapas tempranas del desarrollo cerebral. Aunque no descartan la posibilidad de que dichas conexiones estén presentes en la población adulta y sólo sean funcionales en las personas con sinestesia (tal vez por encontrarse desinhibidos), se decantan por la posibilidad de que una mutación genética dé lugar a un exceso de conexiones que en condiciones normales no se vería. Esta hipótesis la apoyan en el hecho de que en fetos de macaco existe un 70%-90% de conexiones de áreas superiores con V4, mientras que las mismas conexiones no superan el 20%-30% en el macaco adulto no superan el 20%-30%. (Kennedy, Batardiere, Dehay y Barone, 1997). Si a causa de una mutación genética estas conexiones continúan presentes en el adulto, podrían llevar a la experiencia de color cuando se visualizan letras o números. Por lo tanto, aunque las zonas encargadas del procesamiento del color y de la forma estén adyacentes, el mecanismo determinante de que exista la activación cruzada no sería esa proximidad espacial sino el hecho de que las conexiones existentes en el período perinatal no se poden. En trabajos más recientes Hubbard y Ramachandran (2005) admiten la idea de que el mecanismo causante de la sinestesia pueda ser común a todos los adultos pero esté presente, en mayor grado, en las personas con sinestesia. Ese mecanismo compartido sería el causante de las correspondencias entre algunos mapas cross-sensoriales, como la intensidad luminosa y la sonora (Ward y cols., 2006) o entre las figuras onduladas o puntiagudas y sonidos como “bouba” o “kiki” (Ramachandran y Hubbard, 2001b).

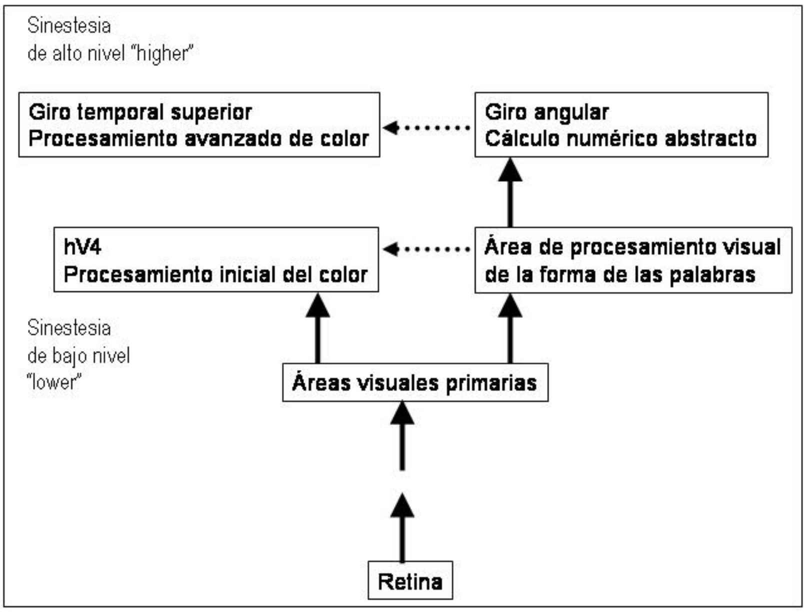


Figura 4. Representación esquemática de la teoría de la activación cruzada de Ramachandran y Hubbard, 2001

Esta teoría recibe un fuerte apoyo experimental de las investigaciones de Maurer (1997, Maurer y Mondloch, 2005) que propone que todos los humanos somos sinestésicos durante los dos o tres primeros meses de vida. En sus estudios con recién nacidos encontró que bebés habituados a una intensidad luminosa particular no respondían de modo especial a un estímulo sonoro de igual intensidad pero sí a uno de intensidad diferente. Maurer propone dos variantes de la hipótesis para explicar sus resultados. La hipótesis fuerte propone que los recién nacidos se parecen a los adultos sinestésicos, para los que la estimulación de una modalidad sensorial evoca el precepto de esa modalidad, y, además un precepto en una modalidad secundaria. Por lo tanto el recién nacido tendría percepciones sinestésicas porque algunas de las conexiones transitorias estarían activas. En la forma débil de su hipótesis (Maurer y Mondloch, 1996) propone que los bebés no diferencian estímulos de distintas modalidades a causa de la inmadurez de su corteza cerebral. Por lo tanto, estarían respondiendo a la cantidad total de energía sumada a través de todas las modalidades sensoriales. Esto implica que serían conscientes de los cambios en el patrón de energía y capaces de reconocer algunos patrones experimentados con anterioridad, pero serían incapaces de diferenciar qué modalidad fue la que produjo el patrón de energía.

Teoría de retroalimentación desinhibida (Grossenbacher y Lovelace)

Esta teoría se basa en el hecho de que las conexiones que unen regiones sensoriales con zonas superiores de procesamiento (conexiones de abajo hacia arriba) se ven completadas con conexiones de retroalimentación (de arriba hacia abajo) que informan a regiones inferiores de procesamiento sensorial de lo procesado en estadíos posteriores (Cynader y cols., 1988). Estas conexiones de retroalimentación pueden ser de suma importancia cuando la percepción de un estímulo sensorial va precedida por una expectación del mismo (modulación de arriba hacia abajo).

Grossenbacher (1997, Grossenbacher y Lovelace, 2001) proponen que las conexiones de retroalimentación son una alternativa a los modelos de activación cruzada. Según este modelo el procesamiento del inductor es llevado a cabo de modo rutinario y, en un momento dado, en un nexo multimodal, la información procedente del procesamiento del inductor activaría vías de retroalimentación en la ruta normal de procesamiento del concurrente, dando como resultado el inicio de un procesamiento del concurrente sin estimulación directa. Por lo tanto, las señales hacia delante en la vía de reprocesamiento del inductor activarían neuronas en una zona cerebral donde la vía de procesamiento de éste y del concurrente convergen. Las señales de retroalimentación de este área se propagarían hacia abajo en la vía de procesamiento del concurrente, activando así su representación. En la Figura 5 se esquematiza esta teoría.

En la mayoría de las personas estas vías de retroalimentación de arriba hacia abajo están inhibidas y por lo tanto no experimentan inducción sinestética. En cambio, en las personas con sinestesia estas vías de retroalimentación estarían desinhibidas y la información que entra en las zonas de convergencia se propaga por la vía de procesamiento del concurrente. Por lo tanto, esta teoría propone que la arquitectura cerebral de sinestésicos y no sinestésicos es equivalente y la diferencia en percepción subjetiva de ambos grupos se debería a la desinhibición de algunas de las vías compartidas por todos.

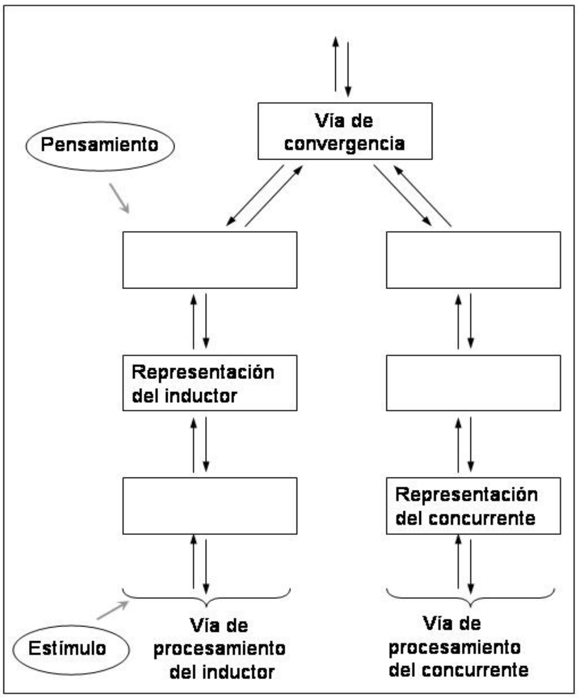


Figura 5. Representación esquemática de la teoría de la retroalimentación desinhibida de Grossenbacher y Lovelace (2001).

Esta teoría también es defendida por Cytowic (2002). En un principio propuso la mediación de estructuras límbicas en la sinestesia y la supresión de actividad cortical (Cytowic, 1993). Dicha hipótesis estaba basada en estudios de actividad cerebral llevados a cabo con xenon-133 en los que encontró que una persona con sinestesia, en la que sabores eran experimentados con cierta forma, la actividad cerebral descendía hasta niveles asombrosos cuando experimentaba sinestesia. Esto, añadido al hecho de que Cytowic considera de suma importancia el afecto asociado a la experiencia sinestésica, así como la capacidad memorística aumentada, lo llevó a concluir que unas partes del cerebro se desconectan de otras haciendo que los procesos normales del sistema límbico se disparen y salgan a conciencia, siendo experimentados como sinestesia. No obstante, en publicaciones más recientes (Cytowic, 2002) admite que la retroalimentación de arriba hacia abajo desde zonas transmodales a zonas unimodales explica de manera simple tanto el carácter memorable como el afecto asociado a la sinestesia, ya que uno de los enlaces transmodales es el complejo hipocampal-entorinal. Cytowic favorece esta teoría en detrimento de la teoría de la activación cruzada local ya que con los parámetros de este enfoque se puede explicar cualquier tipo de sinestesia y las sensaciones asociadas a ésta y no solo la sinestesia grafema-color.

Una variante de esta teoría fue propuesta por Smilek (Smilek, Dixon, Cudahy y Merikle, 2001) específicamente para explicar la sinestesia grafema-color. La denominaron *teoría del procesamiento reentrante* y propusieron que la sinestesia grafema-color está causada por retroalimentación desde zonas del giro fusiforme anterior, donde se accede al significado de los dígitos (Allison y cols, 1994). La retroalimentación de estas zonas hacia las zonas que procesan el color (hV4) haría cambiar la percepción del dígito presentado externamente. Según esta hipótesis, el nexo multimodal, en el que se llevaría a cabo el proceso de retroalimentación a otras zonas, estaría en el giro fusiforme anterior La Figura 6 muestra una comparativa de esta teoría explicativa de la sinestesia grafema-color y de la teoría de la activación cruzada local (Ramachandran y Hubbard, 2001b).

Una serie de estudios posteriores (Myles, Dixon, Smilek y Merikle, 2003: Dixon y cols., 2004; Smilek, Dixon y Merikle, 2005a; Dixon, Smilek, Duffy, Zanna y Merikle, 2006) han mostrado que, incluso en personas con sinestesia de muy bajo nivel, una misma forma física puede evocar un color u otro en función del significado que se le asigne. Así, un estímulo ambiguo, que puede identificarse como una letra S o el número 5, puede evocar el color asociado con la letra o el asociado con el número, en función del contexto en que se presenta. Estos autores mantienen que las propuestas de activación cruzada, entre zonas que procesan la forma y el color, no pueden explicar estos resultados y, por lo tanto, postulan que es el significado y no la forma física el que evoca el fotismo experimentado.

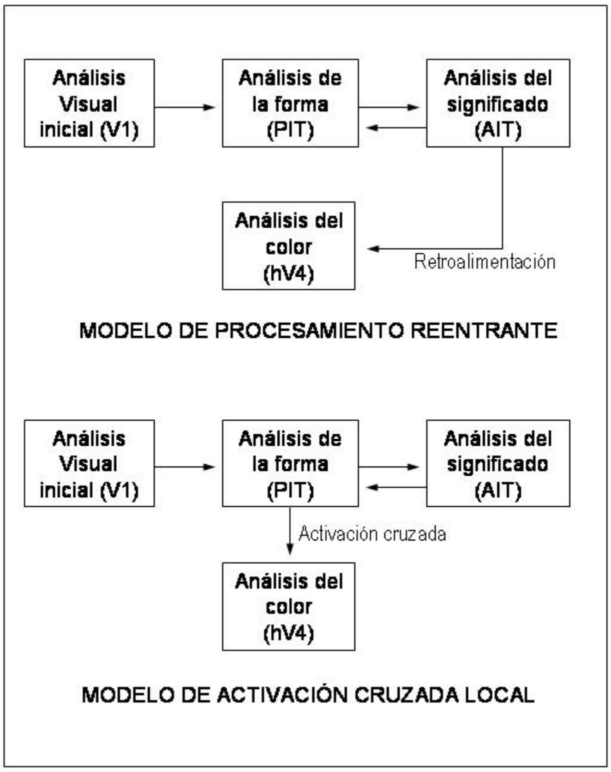


Figura 6. Representación esquemática de la teoría del procesamiento reentrante de Smilek, Dixon y Merikle (2001) y comparación con la teoría de activación cruzada de Ramachandran y Hubbard (2001b).

No está claro, a partir de lo presentado por los autores, si las vías de retroalimentación postuladas estarían presentes en todas las personas, y sólo activas en los sinestésicos, o si serían causa de una arquitectura cerebral diferente. No obstante, el uso de términos como aberrante o anormal para referirse a las conexiones de retroalimentación hace pensar que los autores se decantan más por una base neural diferenciada en las personas con sinestesia.

Los datos de los que actualmente se dispone no son suficientemente finos como para poder distinguir entre una teoría y otra. Smilek et al. (2005a; Dixon et al., 2006) sostienen que los datos provenientes de experimentos en los que una misma forma evoca distintos grafemas en función del contexto en que se encuentre son evidencia a favor de que la forma, junto con el significado son necesarios para la experiencia sinestésica. A su vez, esta modulación contextual de la sinestesia la toman como evidencia a favor de su teoría ya que la información debe ser procesada hasta niveles de significado antes de que pueda experimentarse el color sinestésico. No obstante, Hubbard y Ramachandran (2005) argumentan que las conexiones de retroalimentación normales existentes entre distintas áreas cerebrales son suficientes para explicar los efectos de contexto desde su teoría. En la Figura 6 se ve cómo ellos proponen que la información procedente de las zonas de procesamiento del significado llegaría a V4 a través de el área de Análisis de la forma en vez de directamente como proponen Smilek et al. (2001).

Es probable que los resultados de estudios genéticos o de las nuevas técnicas de imagen cerebral de conexiones entre áreas sean capaces de discriminar entre una teoría u otra. Los primeros informarán de si realmente la sinestesia tiene un componente genético y, si así es, de la función del gen o genes relacionados con la misma. Los segundos podrán informar de las conexiones presentes en distintos tipos de sinestesia y de si también lo están en la población general. No obstante, también es posible que ambas teorías sean complementarias o que cada una de ellas explique el mecanismo subyacente a la sinestesia en distintos grupos de sinestésicos.

7 Conclusiones

La evolución del estudio de la sinestesia en las últimas dos décadas ha sido espectacular y una vez superada la fase de demostración de la realidad de este fenómeno, se están comenzando a abordar interrogantes de gran calado teórico y a desarrollar estrategias adecuadas para su estudio.

El campo de estudio se ha extendido desde la sinestesia grafema-color hasta otras variantes hasta hace poco inexploradas: sabores evocados por música (Beeli y cols., 2005), sabores evocados por las palabras (Ward y Simner, 2003), estructuras espaciales evocadas por unidades de tiempo (Smilek y cols., en prensa), colores evocados por la música (Ward y cols., 2006), etc.

Todo este nuevo conocimiento ayuda a definir globalmente el fenómeno de la sinestesia al comparar las similitudes de los distintos tipos y así entender si tienen un origen común o se deben a procesos diferenciados cuyas características observables parecen similares. El creciente aumento del conocimiento a cerca de este fenómeno también está facilitando el estudiar su relación con procesos de percepción e integración crossmodal y el grado en que percepción crosmodal en personas no sinestésicas y sinestesia comparten mecanismos (Sagiv y Ward, en prensa).

Iniciativas serias de estudio de los componentes genéticos de la sinestesia se han puesto en marcha y un optimismo generalizado aguarda los resultados de dichas investigaciones con la esperanza de que proporcionen información útil para distinguir entre distintas teorías explicativas y categorizar los distintos tipos de sinestesia y aquellos otros fenómenos con características similares pero orígenes distintos.

Por último, cabe mencionar que uno de los temas que menos atención ha recibido ha sido el del carácter emocional de la sinestesia. Aunque ha sido repetidamente descrito en la literatura científica, su estudio empírico aún no ha sido abordado. Este es precisamente el objetivo del presente trabajo de investigación: iniciar el estudio de las reacciones emocionales asociadas a la percepción sinestésica desde un punto de vista empírico para comprobar su existencia, estudiar sus características y evaluar si comparte peculiaridades con las reacciones afectivas experimentadas por personas no sinestésicas.

MOTIVATION OF THIS RESEARCH

The aim of this thesis was to acquire a better understanding of the processes underlying synesthesia in general and the affective reactions experienced as a side effect of synesthesia in particular.

A large body of research claims that synesthesia occurs pre-attentively (Smilek, Dixon, Cudahy & Merikle, 2001; Palmeri et al., 2002; Ramchandran & Hubbard, 2001a) and a similar amount of research points in the opposite direction (Sagiv & Robertson, 2005; Rich & Mattingley, 2003). We wanted to test these alternative theories and check whether we could shed some light to this debate. In order to study this issue we investigated three main questions:

How automatic is synesthesia?
Can synesthesia be suppressed?
Is synesthesia preattentional?

On the other hand, Synesthesia has been characterized as emotional (Cytowic, 1993). Other researchers have also reported that synesthetes inform of a pleasant feeling when a stimulus they perceive match their internal perception for it and an unpleasant feeling when it does not match (Ramachandran & Hubbard, 2001b). Thus, this affective reaction could be though of as a side effect of the synesthesia experience itself. The second, and more important, aim of our research was to empirically test for the reality of this affective reaction that has been informally reported, but never empirically tested, and to study its nature and functioning. Specifically we aimed at answering the following questions:

Are affective reactions associated to the perception of a synesthetic incongruence real?
Are they automatic? Can they be ignored? Can they be modified and what factors influence them?
Are they a ubiquitous phenomenon?
Are they strong enough as to condition co-occurring events?

These two main issues, the role of attention and automaticity on synesthetic perception and the emotional reactions associated to it, were thoroughly investigated on two series of experiments, which are reported in the present thesis in two different sections.

OVERVIEW OF THE RESEARCH

In the First Section we carried out a set of experiments in our synesthete MA to test the attentional features of her synesthesia. In order to test how automatic her synesthesia was, in Chapter 1 we carried out a set of Stroop experiments (Stroop, 1935) where we studied the automaticity of her normal perception of colors and how they influence the naming of her internal photisms and the automaticity of her synesthetic perception and how it influences the naming of the presented colors. By comparing the interference produced by each type of perception we tried to deduce how automatic color perception and photism perception were. These procedures were extended to another synesthete (PSV) in Chapter 4.

In order to test whether synesthesia could be suppressed we went back to the experiments carried out in Chapter 1 because they were designed so that we could also measure Negative Priming. We were then able to test how efficient our synesthete is to inhibit real colors as compared to photisms. In Chapter 2 we also studied this issue by carrying out another color naming task where stimuli were hierarchical figures. By asking her to ignore one dimension and focus on the other we tested whether she could also ignore the photism elicited by the unattended dimension so that it would not interfere in her performance.

Last, to test whether synesthesia is pre-attentional we carried out a series of visual search experiments in Chapter 2. The orientation of a shape made out of letters, embedded on a full matrix of different letters, has to be searched for discriminated. By manipulating the perceptual and synesthetic features of the letter making the target shape we aimed at testing the relative influence of each dimension on the searching task and the conditions under which the synesthetic features would aid in the search of the target stimulus.

In the Second Section of this dissertation we turned our interest to the affective reactions reported to be elicited by synesthesia. Five series of experiments were carried out.

In order to answer the first question and check whether the usual reports of synesthetes regarding synesthetically elicited affective reactions informed of a true phenomenon we carried out a valence rating experiment (Chapter 3) where we manipulated the color in which a set of words with semantic positive, neutral and negative valence were presented. By presenting the words in a congruent color (the same color that a synesthete experiences for a given stimulus) and an incongruent color (we used the color-wheel opposite to the congruent one) we checked whether the emotional valence rating was modulated by synesthesic congruence.

We acknowledged that if we found a modulation of synesthesic congruence we had to check that it was due to the influence of the affective reaction that it produced. In order to test this and whether the affective reaction was automatic, we conducted a categorization experiment with a speeded response where again, semantically emotional words were presented in a congruent and an incongruent color. If an affective reaction was elicited by the incongruence and it was automatic, we predicted that it would influence the valence categorization times in a different way for positive and negative words, leading to an interaction between the two sources of emotional information: that of the semantic information of the emotion related words, and that of the affective reaction elicited by the color-photism congruence.

In Chapter 4 we aimed at answering the question about the generalization of the results we found. We tested three more synesthetes with widely different backgrounds with the same procedures to check whether the results previously found were due to our synesthete's idiosyncrasies or to a feature of synesthesia shared by others. Two of the synesthetes showed similar effects to those shown by MA (although not as pronounced), whereas another synesthete (PSV) reported strong aversive reactions but showed no behavioral sign of them. A further two experiments were carried out to test the possible reasons explaining the lack of correspondence between PSV´s self report of aversive reactions elicited by color-photism incongruence and the absence of behavioral effects.

In Chapter 5 we tested some factors that could influence the affective reactions found in previous experiments. We checked whether some colors were more incongruent than others. Also we checked whether the context in which a color was presented could influence the perception of that color as incongruent. Last we checked the effect of the subjective perception of a color when wave length was kept constant on how incongruent it was perceived. All these variables were tested with a valence rating design similar to the one used in Chapter 3.

In order to check whether the affective reaction would be of a sufficient strength as to condition co-occurring events we carried out a classical conditioning experiment in Chapter 6 with a newly developed implicit learning paradigm (Olson & Fazio, 2001) in which we checked whether the inconsistency between the photism elicited by the number signaling the position of a stimulus and the color of the stimulus presented in that position would elicit a strong affective reaction that would in turn condition attitudes towards that stimulus.

Last, we checked whether non-synesthetes would also show a modulation of performance by the implicit inconsistency between their color preferences and the presented stimuli. Specifically we tested whether non-synesthetes are influenced by their color preferences when performing tasks for which color is an irrelevant dimension. Although color preference is somewhat different than preference for a match between color and photism for a given stimulus, a positive result could lead us to think that the processes involved in the effect of affective reactions elicited by synesthetic incongruence could be related to those giving rise to preference effects in non-synesthetes influencing their performance. Again we used a valence categorization task where non-synesthetes had to categorize words colored either congruently or incongruently with their color preferences.

The results of the seven experimental chapters are briefly summarized and discussed in the General Discussion.

SECTION 1:
SYNESTHESIA AND ATTENTION

CHAPTER 1

AUTOMATIC PERCEPTION AND SYNAESTHESIA: EVIDENCE FROM COLOUR AND PHOTISM NAMING IN A STROOP-NEGATIVE PRIMING TASK[1]

[1] Published in a special issue on synesthesia in Cortex as Lupiáñez & Callejas (2006), 42, 204-212

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ABSTRACT

It is widely assumed that synaesthetic perception is highly automatic, as shown by Stroop tests. Furthermore, it has been shown that, although automatic, it can be suppressed leading to Negative Priming. However, these assumptions have not been consistently investigated, as not many papers have measured Stroop in synaesthesia, and only one used a Negative Priming procedure. Two experiments were carried out in a female synaesthete (MA), and 13 control participants, in which numbers and letters were displayed in colours either congruent or incongruent with MA's photisms. In contrast to control participants, MA showed significant Stroop effects both when naming the colours and when naming the photisms (slower RT when naming a colour or photism that was incongruently coloured versus congruently coloured). For comparison, we also report a control experiment in which the first letters of colour names were displayed in either congruent (e.g., B in blue) or incongruent (e.g., B in red) colours. Significant Stroop and Negative Priming effects were found when a control group named the displayed colour of these letters. The synaesthesic Stroop effect shown by MA was greater than that observed in the control experiment when MA was to name the displayed colour, but smaller when she was to name the photism of the stimuli. Regarding Negative Priming, MA showed an effect similar to that observed in the control experiment, but only when she was to name the photisms of the stimuli. Altogether, these results show that synaesthetic perception is highly automatic and difficult to inhibit.

INTRODUCTION

Synaesthesia is the experience of an atypical dual perception where a particular stimulus elicits a normal sensory percept together with another percept which is not the one usually produced by such stimuli. This additional perception can be categorized as belonging to the same sensory modality or to a different one (i.e. grapheme-colour synaesthesia or music-colour synaesthesia respectively). In fact, the most common type of synaesthesia is the one linking graphemes and colours (Day, 2003) and it is usually referred to as grapheme-colour synaesthesia. Here the additional perception is called a *photism*.

Synaesthesia is not a learned association between colours and specific graphemes. Recent studies have demonstrated that it is a sensory/perceptual phenomenon and not a memory based effect (Ramachandran and Hubbard, 2001a).

Synaesthesia is involuntary in the sense that it automatically happens when the eliciting stimulus is present and it cannot be dismissed at will. Although the eliciting stimulus is usually physical, it has also been shown that synaesthesia can be caused by a conceptual stimulus (i.e., by mentally activating a number concept, Dixon, Smilek et al., 2000).

Although Cytowic (1995) defined synaesthesic percepts as being projected sensations (e.g., the photism is perceived as an overlay on top of the grapheme in the case of grapheme-colour synaesthesia), for some synaesthetes these percepts are experienced in the mind’s eye (Smilek, Dixon et al., 2002). Synaesthesia is also durable, meaning that for any particular synaesthete, the synaesthetic associations do not change over time, they are consistent, and it is also generic as opposed to elaborated. Specifically, synaesthetes see blobs, lines, spirals and the like but not elaborated percepts. Synaesthesia is memorable; it is remembered much easier than the stimulus that elicited it. It is also emotional in the sense of certitude and conviction that what is perceived is really experienced. Some of these features of synaesthesia have been used as diagnostic criteria (Cytowic, 1995), in order to differentiate real synaesthesia from mere crossmodal or unimodal memory associations.

When synaesthesia became of interest to cognitive psychologists, the basic studies that were carried out tried to show whether it was an automatic phenomenon or alternatively whether it could be controlled by people’s will. Stroop type studies were devised to test this automaticity of synaesthetic perception. However, most studies up to date were carried out with a methodology that did not allow for the analysis of single responses (i.e. presenting stimuli on cards, and recording RTs with a stopwatch) which made it difficult to draw some conclusions from them (Mills, Boteler et al., 1999; Mills, Viguers et al., 2002; Odgaard, Flowers et al., 1999; Wollen and Ruggiero, 1983). More recent studies, however, have been carried out using more fine-grained methods to assess this issue (Dixon, Smilek et al., 2002; Elias, Saucier et al., 2003; Mattingley, Rich et al., 2001) and the common finding points to a large Stroop effect on synaesthetic perception. Synaesthetes take longer to name the colours of digits or letters when they are different from the photism perceived for such stimuli. Therefore, several studies have already shown Stroop effects in synaesthetic perception. A conclusion drawn from these studies is that photisms are automatically elicited and can disrupt performance when they are incongruent with the task at hand.

However, it is not clear to what extent photisms’ activation can be inhibited by a synaesthete. In this sense, only Odgaard and colleagues (1999) have shown Negative

Priming (NP, Tipper, 1985) in synaesthetic perception. The NP paradigm is used to study the capacity of the attentional system to inhibit information that is not relevant for the task being performed (Tipper, 2001). This is done by measuring the effect on subject's performance of previously inhibited information that is now relevant (i.e. a previous distracter is now used as target stimulus). In their study, Odgaard, Flowers et al. (1999) asked a synaesthete to name the colour in which a set of numbers were presented ignoring the photism that such numbers elicited. When the list was ordered so that the photism of the previous stimulus (which had to be ignored) was now the colour of the current stimulus, the synaesthete took longer to respond than in those cases where the target colour had not been previously suppressed. To our knowledge, this is the only study that showed NP from previously ignored photisms. Furthermore, in this study a blocked design was used. Therefore, it is still to be shown that ignoring a photism leads to NP in the following trial, when the effect is measured with the standard trial by trial procedure.

The above findings suggest that the perception of photisms is highly automatic although it can be efficiently suppressed when it is detrimental to the task at hand. The automatic nature of synaesthetic perception seems to be quite a robust finding. However, the extent to which it can be controlled by the synaesthete is less clear since it has not been consistently tested. This was one of the aims of the research reported in this paper.

The general aim of the present study was to explore automaticity of synaesthetic perception, and the degree of control that synaesthetes are able to exert over it. In order to do so, two strategies were followed. On the one hand, Stroop and Negative Priming effects were measured with a trial by trial procedure, in a female synaesthete, MA, and 13 control participants. One of 12 possible letters or digits was displayed in each trial, in one of four colours. Participants were required to name the colour in which the presented letter/digit was displayed, which could be either congruent or incongruent with MA's photism (allowing us to assess a Stroop effect), and could be the same or different from the previously ignored photism (allowing us to assess Negative Priming). On the other hand, MA's performance in the colour-naming task was compared to her performance in a photism-naming task, in order to compare the automaticity of response activation from external colours vs. internal photisms.

The effects observed in these two experiments were compared to those observed in a control experiment where non-synaesthetes were to name the displayed colour in which the letters presented were the first letters of colour names (henceforth referred to as “colour initials”). The purpose of this experiment was twofold: on the one hand, we wanted to reproduce standard Stroop and NP effects in order to ensure the appropriateness of the procedure being used. On the other hand, the control experiment had the goal to serve as a baseline condition with stimuli as similar as possible to those used with MA.

If synaesthetic perception is highly automatic, as previously shown in the literature, MA should show a Stroop effect in the colour-naming task of our trial by trial procedure. Furthermore if, despite of being automatic, photism synaesthetic perception can be easily suppressed when it interferes with the task at hand, MA should similarly show a Negative Priming effect, as previously reported by Odgaard et al (1999), in a blocked design. Finally, by comparing MA’s photism-naming performance with her colour-naming performance, a much stronger test of photism automatic perception will be shown. If, in spite of being automatic, photism perception is less automatic that colour perception, then a weaker Stroop effect will be observed in the colour-naming task, where photism interference is measured, than in the photism-naming task, where colour interference is measured.

EXPERIMENT 1. CONTROL EXPERIMENT

A standard Stroop colour-naming task was adapted for comparison with the critical experiments in which MA’s synaesthesia was investigated. Hence, instead of presenting the whole colour name, participants were shown the first letters of one of four colour names displayed in any of the four associated colours, leading to the Congruent and Incongruent standard conditions of the Stroop procedure.

As mentioned above, the aim of this experiment was twofold. First, we wanted to make sure that the specific procedure that was used for measuring synaesthetic Stroop and NP effects in MA was appropriate for measuring the standard Stroop and NP effects. Second, we intended the experiment to serve as a baseline condition for comparison with synaesthetic effects.

Furthermore, in order to study the implementation of online control processes to overcome the interference, apart from NP, the effect of the congruency context was investigated. Note that this can only be investigated when congruency is manipulated on a trial by trial basis. Thus, the Stroop effect observed when the previous trial was congruent was compared to that observed when the previous trial was incongruent. If control processes are dynamically applied depending on online task demands, the Stroop effect should be bigger after congruent trials, a situation in which the system is behaving in a less controlled manner (Carter, Macdonald et al., 2000).

METHOD

Participants

Ten control participants voluntarily participated in the experiment for course credit. They were female psychology students from the University of Granada, and all of them had normal colour vision.

Stimuli and apparatus

The initials of four colour words were used as stimuli (R, Ro, RO, for “rojo” *–red* in Spanish-; V, Ve, VE, for “verde” *–green*-; Az, AZ, az, for “azul” *–blue*-; and Am, AM, am, for “amarillo” *–yellow*-). Each stimulus was displayed in any of the four different colours in different trials.

An IBM 14” screen controlled by a 486 computer running MEL software (Schneider, 1988) was used to present the stimuli. Participants sat at about 50 cm in front of the computer screen. A microphone connected to a voice-key was used to record the onsets of the naming responses of the participants. The computer keyboard was used to record accuracy.

Procedure

Participants were required to name the colour of the stimulus displayed on each trial. A trial started with a black fixation cross ("+") displayed at the centre of the computer screen, over a light grey background. After 1000 ms, one of the 12 colour initials was presented, also at the centre of the screen. The stimuli were pseudorandomly presented so that neither the same colour nor the same initials were presented on two consecutive trials.

Participants were instructed to name the colour of the stimulus, while ignoring the letters. The stimulus was present until participant’s colour-naming response was emitted. Then, the experimenter recorded, via a key press, the response given, for measuring accuracy. Spurious responses due to hesitations or any other misleading activation of the voice-key were also coded, so that they could be discarded from the analyses.

The experiment consisted of a block of practice trials and 5 blocks of 36 experimental trials each. Participants were prompted to rest between blocks.

Design

For the analysis of the Stroop effect, responses were coded as a function of the congruency between the colour in which the stimulus was displayed and the initials being presented. Congruent trials were those in which the colour of the stimulus was the one designated by the initials being displayed (e.g., RO displayed in red –“rojo” in Spanish-). Incongruent trials were those in which the stimulus was presented in a colour different from the one the initials designated (e.g., RO displayed in blue –“azul” in Spanish-). Additionally, trials were coded according to the congruency of the previous trial (N-1). Thus, the design had two within-participant factors: N-Congruency (N-Congruent, N-Incongruent) and N-1 Congruency (N-1 Congruent, N-1Incongruent).

For the analysis of the Negative Priming effect, responses were coded as a function of the relationship between the colour of the current stimulus (target) and the initials presented in the preceding trial (distractor). Ignored Repetition trials were those in which the initials of the preceding trial designated the colour of the current stimulus (e.g., RO displayed in blue –“azul” in Spanish-, preceded by AZ displayed in yellow –“amarillo” in Spanish). Control trials were those in which both the target (colour) and the distractor dimension (initials) were different from the target and distractor of the previous trial (e.g., RO displayed in blue –“azul” in Spanish-, preceded by VE displayed in yellow –“amarillo” in Spanish). Thus, the design had only one within-participant factor: Repetition (Ignored Repetition, Control). Given our restrictions in the colour and stimuli selection procedure (i.e., no repetition of either the target-colour or the distractor colour-initials in consecutive trials), the ignored repetition condition was always incongruent and was also preceded by an incongruent trial (otherwise, either the target or the distractor would repeat in consecutive trials). Therefore, to have a suitable condition to compare the results with, only incongruent trials preceded by incongruent trials were selected for the control condition.

RESULTS

The first trial of each block was eliminated from all the analyses. Furthermore, trials with either incorrect or spurious responses (1.71% and 0%, respectively), together with correct response trials with RT either faster than 200 ms or slower than 1700 ms (0.06% and 0.86%, respectively) were excluded from the RT analyses. Mean RTs for each experimental condition were computed, after exclusions, and were introduced into specific ANOVAs for the appropriate analyses (see Table I). As usual in the NP literature, the analysis was performed taking participants as the random factor. Additionally, an item analysis was carried out in order to be able to compare performance in this experiment with MA's performance in the following experiments.

Table I. Mean RTs (in ms) and error percentages (in parenthesis) for each experimental condition of the Control Experiment.

N-1 Congruent		N-1 Incongruent		
N-Congruent	N-Incongruent	N-Congruent	N-Incongruent	N-Incongruent
Control	Control	Control	Control	Ignored Repetition
608 (1.1%)	773 (3.3%)	629 (1.0%)	742 (1.9%)	767 (2.2%)

Analysis of Stroop effect

A 2 (N-Congruency) x 2 (N-1 Congruency) repeated measures ANOVA was performed on the mean RTs of the control conditions. The analysis showed a highly significant Stroop effect, as revealed by the main effect of N-Congruency, $F_{(1, 9)}$= 61.46, p< .0001 [$F_{(1, 11)}$= 61.38, p< .0001, in the items analysis], showing that RT was 139 ms faster in the N Congruent condition (the target colour and the initials were congruent) than in the Incongruent one. It is worth noting that the Stroop effect was modulated by the congruency of the previous trial, as revealed by the interaction between N-Congruency and N-1 Congruency, $F_{(1, 9)}$= 7.53, p< .05 [$F_{(1, 11)}$= 3.92, p= .073, in the items analysis]. The 165 ms Stroop effect observed when the previous trial was congruent was reduced to 113 ms when the previous trial was incongruent.

No effect was significant in the analysis of errors. However, as can be observed in Table I, the pattern of errors mirrored the pattern of the RT data indicating that there were no speed-accuracy tradeoffs.

Analysis of the Negative Priming effect

A repeated measures ANOVA was performed with Repetition (Control, Ignored Repetition) as the single factor. A standard NP effect was observed: RT was 25 ms slower in the Ignored Repetition than in the Control condition. The effect was significant in the participants analysis, $F_{(1, 9)} = 9.94$, $p < .05$, and marginally significant in the items analysis, $F_{(1, 11)} = 3.81$, $p = .077$. Again, the effect was not significant in the analysis of errors, although error patterns mirrored the patterns observed for RTs (see Table I).

DISCUSSION

The present experiment fulfilled the main goals for which it was planned. Significant Stroop and NP effects were obtained in both analyses, taking participants and items as the random factor. Furthermore, the Stroop effect depended on the congruency of the previous trials, as has been observed in previous studies (Carter, Macdonald et al., 2000; Cohen, Dunbar et al., 1990; Kerns, Cohen et al., 2004). Therefore, the present experiment seems to be appropriate for measuring both Stroop and NP effects, and the online modulation of Stroop by contextual factors (congruency of the previous trial) that modulate the relative control with which the task is confronted.

EXPERIMENTS 2a AND 2b. SYNAESTHESIA EXPERIMENTS

In the following section we report data from two experiments in which the procedure used in the previous experiment was adapted to measure Stroop and NP priming effects in MA, a grapheme-colour synaesthete, and a group of 13 new non-synaesthete control participants. In this case, the measured interference will not reflect the competition between the colour to be named and the initials of such colours because those stimuli were purposely excluded. Instead, we used letters and numbers that elicited in MA's mind one of the four colours used in the previous experiment (red, green, blue or yellow). This way, the Stroop and NP effects would reflect the competition between the responses elicited by the colour in which the stimuli were presented and the photism triggered by the graphemes.

MA participated in two different experiments. In a colour-naming experiment she was to name the colours in which the stimuli were presented, whereas in a photism-naming experiment she was to name their photisms. Her performance was compared to that of a group of non-synaesthete participants. The control group only performed the colour-naming experiment, since they have no photisms to name.

As stated above, if synaesthetic perception is highly automatic, MA should show Stroop effects. Furthermore, if photism perception, although automatic, can be suppressed when it interferes with the task at hand, MA should similarly show a Negative Priming effect. Both effects are expected to be absent in the control group, for which no photisms are perceived.

More importantly, we will be able to compare the relative automaticity of photism and colour naming activation by comparing MA's performance in the colour-naming and photism-naming experiment. The stronger and more automatic a dimension is activated, the more interference will produce in responding to the other dimension. Therefore, if photism perception is less automatic than colour perception, weaker Stroop effects will be observed in the colour-naming task than in the photism-naming task.

METHOD

Participants

A female synaesthete, MA, voluntarily took part in the study. MA is a psychology student at the University of Granada, who was 21 years old at the time of testing. Thirteen female psychology students from the University of Granada volunteered to take part in the same colour-naming experiment as MA, as a control group in exchange for course credits. All participants had normal colour vision.

Stimuli and apparatus

Instead of presenting the initials of the different colours used as in the previous control experiment, seven letters and five numbers were presented. None of them were the first letter of any of the four colours used in the experiment. The selection of stimuli was made taking into consideration MA's photisms so that three of the stimuli were synaesthetically perceived as red (*E*, *D* and *2*), three were perceived as green (*J*, *3*, *13*), three as blue (L, S, 6), and the remaining three were perceived as yellow (*F*, *M*, *7*). Everything else was the same as in the previous experiment.

Procedure

The colour-naming task that both control participants and MA performed required them to name on each trial the colour in which the stimulus was displayed, while ignoring the grapheme. Similarly, in the photism-naming task MA was required to name the photism (i.e., the synaesthetic colour that she perceives), while ignoring its displayed video colour.

Control participants took part in one single colour-naming session (a block of 36 practice trials and 5 blocks of 36 experimental trials). MA took part in four experimental sessions: In the first one she performed the colour-naming task. In the second session she was required to name the photism instead of naming the colour of the stimuli. In the remaining two sessions MA repeated the same tasks, but in the reversed order (photism-naming in the third session, and colour-naming in the last one).

Design

The design of both colour-naming and photism-naming tasks was the same as that of the Control Experiment, both for the Stroop and the NP analysis, although in this case congruency and repetition effects did not refer to the relation between displayed colour and initials of colour words, but to the colour-photism relationship. Thus, *Congruent* trials were those in which the stimulus being displayed was coloured according to MA's synaesthetic colours (e.g., *D* displayed in red or *L* displayed in blue). *Incongruent* trials were those where the video colour of the stimulus was different from MA's photism (e.g., *D* displayed either in green, blue or yellow). For the NP analysis, as in the Control Experiment, *Ignored Repetition* and *Control* trials were always incongruent.

In both the colour naming and photism naming tasks, *Control* trials were those in which both the photism and the displayed colour were different from the photism and displayed colour of the previous trial. *Ignored repetition* trials were those in which the target (the displayed colour in the colour-naming experiment, or the photism in the photism-naming experiment) was the same as the distractor of the previous trials (the photism in the colour-naming experiment, or the displayed colour in the photism-naming experiment) (e.g., a *D* (red photism) displayed in blue, preceded by *L* (blue photism) presented in yellow, for the colour-naming experiment, or *D* (red photism) displayed in blue, preceded by *J* (green photism) presented in red, for the photism-naming experiment). An item analysis was carried out in order to be able compare MA's performance to that of the control group, where stimuli were taken as the random factor.

In short, the design of the Stroop analysis had two within-item factors: *N-Congruency* (N-Congruent, N-Incongruent) and *N-1 Congruency* (N-1 Congruent, N-1Incongruent). The design of the Negative Priming analysis had only one within-participant factor: *Repetition* (Ignored Repetition, Control).

An additional within-item factor was introduced into the analysis, in order to compare MA's performance in the colour-naming and photism-naming tasks to that of the control group in the colour-naming task. This factor is called *Experiment*: Control-Group (Colour-Naming), MA (Colour-Naming) and MA (Photism-Naming.

RESULTS

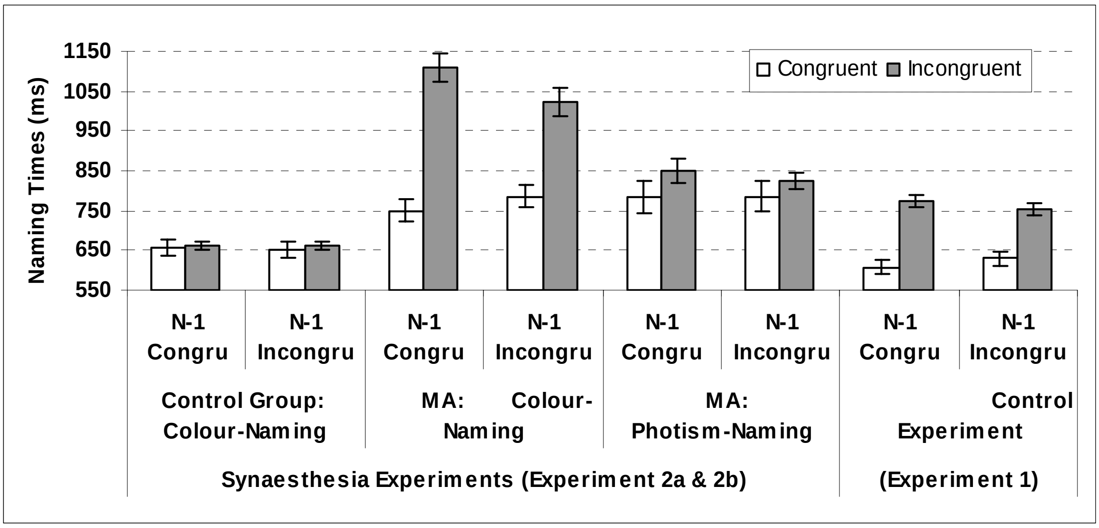
As in the Control Experiment, the first trial of each block was eliminated from all the analyses. Furthermore, trials with either incorrect or spurious responses (0.44% and 0% for the control group, 0.88% and 3.43% for MA colour-naming, and 1.20% and 0.70% for MA photism-naming, respectively), together with correct response trials with RTs faster than 200 ms or slower than 1700 ms (0.04% and 0.13 % for the control group, 0% and 0.04% for MA colour-naming, and 0% and 0% for MA photism-naming, respectively) were excluded from the RT analyses. Mean RTs for each item and experimental condition were computed, after exclusions, and were introduced into specific ANOVAs for the appropriate analyses (see Table II).

Table II. Mean RTs (in ms) and error percentages (in parenthesis) for each experimental condition for the Control Group Colour-Naming Experiment, and for MA Colour-Naming and Photism-Naming Experiments.

	N-1 Congruent		N-1 Incongruent		
	N-Congruent	N-Incongruent	N-Congruent	N-Incongruent	N-Incongruent
	Control	Control	Control	Control	Ignored Repetition
Control Group Colour-Naming	656 (0.3%)	660 (1.1%)	652 (0.5%)	654 (0.2%)	666 (0.3%)
MA Colour-Naming	749 (0.0%)	1108 (0.0%)	786 (0.0%)	1037 (0.0%)	1012 (3.1%)
MA Photism-Naming	784 (0.0%)	848 (2.1%)	786 (1.4%)	797 (1.1%)	852 (0.0%)

Analysis of Stroop effect

A 3 (Experiment) x 2 (N-Congruency) x 2 (N-1 Congruency) repeated measures ANOVA was performed on the mean RTs of the control conditions (i.e., excluding the ignored repetition condition). Apart from the main effect of Experiment, $F_{(2, 22)}$= 82.13, p< .0001, the analysis showed a highly significant Stroop effect, as revealed by the main effect of N-Congruency, $F_{(1, 11)}$= 35.29, p< .0001. However, as expected, the Experiment x N-Congruency interaction was also significant, $F_{(2, 22)}$= 84.23, p< .0001, showing that the Stroop effect was only present in MA's performance (F<1 for the control group). As shown in Graph 1, the Stroop effect that was observed in MA's performance followed the same pattern of that observed in the Control Experiment, with a larger Stroop effect for the congruent context (N-1 congruent) (in fact, the N-Congruency x N-1 Congruency interaction was also significant, $F_{(1, 11)}$= 5.10, p< .05). This contrasts with the Control participants' data where no Stroop effect was observed.



Graph 1: Stroop effects in MA's performance, in the colour-naming and photism-naming experiments, as compared to the control group of non-synaesthetic participants. For comparison, data from the Control Experiment are also provided.

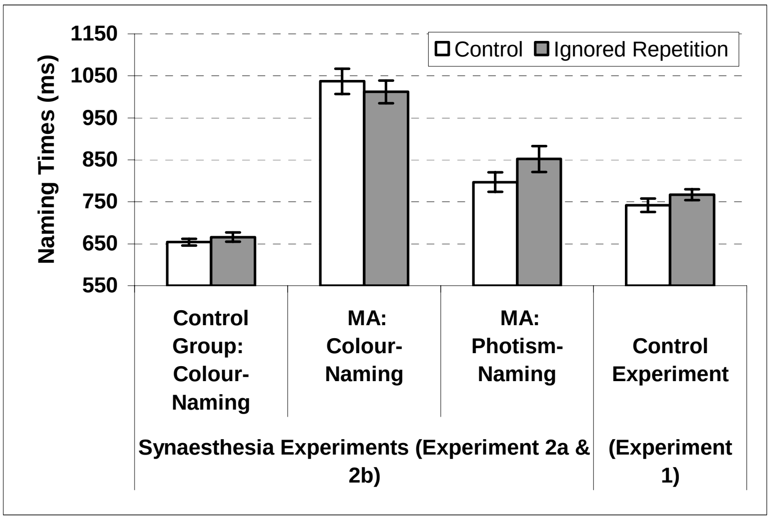
In order to have a closer look to the pattern of Stroop effects observed in MA's performance in comparison to the standard Stroop effects observed in the Control Experiment, a new 3 (Experiment) x 2 (N-Congruency) x 2 (N-1 Congruency) ANOVA was performed. In this case, the three levels of the variable experiment were: Control Experiment, MA/Colour-Naming, and MA/Photism-Naming. The analysis showed that a significant Stroop effect, $F_{(1, 11)}$= 70.76, p< .0001, was different across Experiments, F(2,

$_{22)}$= 55.73, p< .0001. Planned comparisons showed that, compared to the control experiment, the Stroop effect was greater in MA's colour-naming experiment, and smaller in MA's photism-naming experiment (both ps< .001). Furthermore, the Stroop effect was again significantly modulated by the congruency of the previous trial, $F_{(1, 11)}$= 7.86, p< .02. It is important to note that this modulation was similar in the three experiments, as shown by the non significant three-way interaction (F<1) (see Graph 1).

No analysis was performed in the error rates, given that very few errors were made (see Table II).

Analysis of the Negative Priming effect

A 3 (Experiment) x 2 (Repetition) repeated measures ANOVA was performed on the mean RTs. Apart from the main effect of Experiment, which was again significant, $F_{(2, 22)}$= 89.02, p< .0001, the interaction between Experiment and Repetition was marginally significant, $F_{(2, 22)}$= 3.19, p= .061. Planned comparisons showed that the only significant NP effect was that found in MA's photism-naming experiment, $F_{(1, 11)}$= 11.29, p< .01 (p> .25 in any of the other two cases).



Graph 2. Negative Priming effect in MA's performance, in the colour-naming and photism-naming experiments, as compared to the control group of non-synaesthetic participants. For comparison, data from the Control Experiment are also provided.

As we did with the Stroop analysis, a new 3 (Experiment) x 2 (Repetition) ANOVA was performed, now taking Control Experiment, MA/Colour-Naming, and MA/Photism-Naming as the three levels of the variable Experiment. The NP effect was significantly different across experiments, $F_{(2, 22)}$= 3.96, p< .05. As compared to the Control Experiment, MA's RTs showed a smaller NP effect in colour-naming, $F_{(1, 11)}$= 5.81, p< .05, whereas she showed a comparable NP effect in the photism-naming Experiment, $F_{(1, 11)}$= 2.44, p> .10. In fact, as can be observed in Graph 2, the NP effect shown by MA in the photism-naming Experiment was numerically larger than that observed in the Control Experiment; in contrast, MA showed no NP effect in the colour-naming Experiment (in fact she showed a non-significant effect in the opposite direction). Importantly, these effects shown by MA for the two tasks were significantly different from each other, $F_{(1, 11)}$= 4.90, p< .05.

DISCUSSION

As one might expect, participants in the control group did not show any significant difference in their colour-naming performance depending on whether the letters and numbers were displayed in the same colour as MA's photism or in any other colour. In contrast, MA took much longer to name the same colours when the stimuli elicited a photism different from the colour in which it was presented, than in a congruent condition in which photism and colour were the same. This synaesthetic Stroop effect was observed both when MA was required to name the (external) colour and when she was asked to name the (internal) photism elicited by the stimuli. However, the effect was much larger in the former case as MA's responses were especially slow when she had to name the colour of photism-incongruent letters/digits, but not when naming the photism of colour-incongruent letters/digits.

As reasoned in the introduction, these results are the opposite to what one would expect if the activation of the response appropriate to the photism were less automatic than that of the colour being displayed. Consequently, the pattern of data suggests that the activation of a colour-naming response might be more automatic when it is produced by the identification of a letter or number than when it is produced by the processing of a wavelength of light. Therefore, these results add to the literature showing high automaticity in synaesthetic colour perception.

The priming results are in line with this interpretation. MA did not show any sign of Negative Priming in the colour-naming experiment. That is, contrary to what could be expected, she was not slower at naming the colour of an incongruently coloured stimulus when this colour was the same as the photism of the previous stimulus, compared to a control situation in which the previous photism was different from the current to-be-named colour. In fact, she showed some facilitation, although not significant. These results could reflect the difficulties that MA had at inhibiting the response associated to the photism, when required to name the colour (colour-naming task). The fact that MA was slower in naming the colour of incongruently coloured stimuli than in naming the photism of the very same stimuli (see Graph 1) is in agreement with that conclusion. Therefore, MA seems to have special difficulties for suppressing naming responses elicited by her synaesthetic perception of letters and numbers, whereas she seems to have not much difficulty in suppressing colour naming responses when required to name the photism.

At first, these results are at odds with those of Odgaard et al. (1999), since their synaesthete L showed NP in an experiment where she had to name the displayed colour of a set of numbers ordered in a way that the colour of each one was the same as the photism of the previous item. This effect was equivalent to the Stroop effect found for colour names. As already mentioned, we did not find any hint of a NP effect in the colour naming experiment performed by MA. One possible explanation could be that MA's grapheme-colour synaesthesia operates differently than does L's. Whereas MA's synaesthesia seems to be of a high level (Ramachandran and Hubbard, 2001b), we do not have data to conclude whether L's synaesthesia is of low or high level. Alternatively, it might be argued that the absence of NP in the colour naming performance of MA, but not in her photism naming performance, could be due to MA's markedly long RTs in the former condition. However, this is unlikely because in fact NP is usually greater (nor smaller) when accuracy is emphasized, in spite of having longer RTs (Li, 1996; Neill and Westberry, 1987).

Several other differences could explain such inconsistencies in the results. In the first place, the methodologies used in both experiments are considerably different. Whereas we used a trial by trial procedure in which response latencies were measured for each stimulus, Odgaard et al. (1999) measured the time taken to complete a 13-item list. An important consequence of the current procedure was that we were able to manipulate the different conditions within-blocks while they had to manipulate them between-blocks. The blocked manipulation of the two conditions could be boosting the adoption of a more controlled task set that would facilitate the observation of NP effects, even in the colour naming task. In fact, Odgaard (personal communication) used the blocked design in order to maximize the conditions under which a NP effect was likely to be obtained.

A different explanation for the inconsistencies in the results has to do with the emotional state produced by the task. Synaesthetes usually report being disturbed by incongruently coloured stimuli. This disturbance is easily appreciated in MA when she is performing a common Stroop-type task and has been shown to influence her performance on behavioral tasks (Callejas, Acosta & Lupiáñez, submitted, Chapter 3). Such a state of anxiety induced by the task could interfere with inhibitory processes in MA's performance. In fact, MA reported that she did not like doing these kinds of tasks, because they made her anxious. Fox (1994) has reported that Negative Priming can disappear in trait-anxious individuals when they have to ignore threat-related information, as well as non threat-related distracting information. Thus, the anxiety induced by the colour naming task could have caused the lack of NP on MA's performance on this task (interestingly, MA was not distressed by the photism naming task). However, in order to take this hypothesis as a possible explanation for the differences, several things had to be tested. The study carried out by Fox (1994) refers to trait-anxious individuals as opposed to state-anxious individuals. It is not clear whether or not the same results would be found with this "state" measure. Another problem for this interpretation is that we do not know the emotional reactions experienced by L when she underwent the experiments reported by Odgaard et al. (1999).

Alternatively, it could be argued that MA might have a defective control system that would cause a lack of inhibition of irrelevant information, and therefore an absence of NP. Two facts disprove this hypothesis. An incapacity to inhibit irrelevant information would lead to a substantial increase in the percentage of errors for the control condition of the NP analysis. However, MA performed those trials without making one single mistake. More importantly, NP was found on MA's performance on the photism-naming task, thus proving that MA does not have inhibition deficits.

In fact, the NP effect found in the photism-naming experiment is even larger than that shown by control participants in the control experiment. This finding is especially interesting when compared to the effect obtained on the colour-naming task, where a non significant trend towards facilitation was observed instead. This dissociation could be explained on the basis of the relative strength of the activation of the colour responses associated to the wave length vs. the photism. In short, the pattern of results could be explained by arguing that the colour response associated to the photism is either more strongly activated than that associated to the wave length of the stimulus, or has a privileged access to consciousness.

A much stronger activation of the response associated to the photism would account for the pattern of results found in the two experiments. The activation of the response associated to the wave length colour is not so automatic (or has a less privileged access to consciousness). Therefore, this distracting dimension can be easily inhibited on trial N-1 (when the task is to name the photism), thus not interfering with the photism naming response. In fact, its interfering effect was practically eliminated when enough control was exerted, as on trials preceded by incongruent trials (see Graph 1). Consequently, this effective inhibition led to the NP that was found on trial N in these conditions (see Graph 2).

On the contrary, given a strong activation of the photism response (or a privileged access to consciousness), a great deal of inhibition would be necessary to prevent its disrupting influence on the response on trial N-1, when the task is to name the wave length colour. The fact that the Stroop effect observed in these conditions was reduced from 359 to 251 ms when the preceding trial was incongruent might be interpreted as evidence that the control system was acting by inhibiting the disrupting influence of the photism colour response (the distractor in this task). However, a strong Stroop effect (greater than that observed in the control experiment) was still observed in this effective-control situation. This ought to be interpreted as evidence that, in spite of the inhibitory control being applied, the photism colour response could not be effectively inhibited. Consequently, no NP was found from the photism colour of the preceding trial on the wave length colour response to the current trial.

Taken together, the Stroop and NP results consistently point to a high degree of automaticity and strength of synaesthetic perception. The reaction time patterns could suggest that such perception is, either stronger and more automatic than the one related to external visual stimuli or has a privileged access to consciousness

CHAPTER 2
THE ROLE OF ATTENTION IN SYNESTHESIA

ABSTRACT

A currently hot topic in the grapheme-color synesthesia research is the role of attention in the binding of grapheme and color. While some researchers suggest that conscious perception of the inducing stimulus is necessary for the elicited photism to be experienced, others posit that the photism can be experienced even before the inducer is consciously recognized. We present the results from five experiments aimed at testing whether synesthetic photisms aid visual search in our synesthete MA, and whether focusing attention on one dimension of the inducer stimulus can prevent incongruent information from the ignored dimension from affecting performance. Results show that synesthesia does not aid in the search for the target stimulus although it influences performance by varying the relative similarity between target and distracters and among distracters. We also find that ignoring the dimension of a stimulus that elicits an incongruent photism is not sufficient to prevent that incongruence from influencing performance.

INTRODUCTION

An important issue on synesthesia research is the role of attention on synesthetic perception. That is, whether synesthetic percepts are automatically generated or rather attention is necessary for synesthetic percepts to be activated. Furthermore, in any case, a related issue is the degree in which synesthetic perception is subject to the control and intentionality of the synestehete. Several papers have now been published where different positions in the debate about the necessity of attention for synesthesia are defended. While some defend the perceptual reality of photisms (Smilek, Dixon, Cudahy & Merikle, 2001; Palmeri et al., 2002; Ramachandran & Hubbard, 2001a) other groups defend that attention is necessary for synesthetic colors to appear (Mattingley, Rich, Yelland & Bradshaw, 2001; Sagiv & Robertson, 2005). As surprising as it might seem, five years have passed since the first papers proposing one view or the other were first published and a consensus is yet to come. Each laboratory validating their own results and discrediting those pointing in a different direction on the basis of methodological problems, statistical problems, nature of the synesthetic population or rationale used to test individuals or groups, all that has been put forward up to now is more evidence for each point of view from the corresponding lab. Far from aiming at an exhaustive revision of the published data, a brief summary will be given of the data favoring each view.

Binding of grapheme and color is pre-attentive

This idea was first put forward by Ramachandran and Hubbard (2001a) and Smilek et al. (2001). The first group carried out a task where participants had to segregate a shape from a background of distracters. Importantly, both distracters and items making up the shape were letters that induced different color photisms. Using a blocked design in which participants knew what letter would be making up the embedded shape, they found that when the display was presented for one second, synesthetes correctly categorized the form of the shape in 81% of the trials while controls did so only in 59% of the trials. While controls performed better than chance (there were four possible forms), synesthetes were significantly better. Ramachandran and Hubbard (2001a) concluded that this proved the genuinely perceptual nature of the phenomenon. To add evidence in favor of this idea they carried out another task in which they presented a grapheme at an eccentricity of about 7º from fixation (Ramachandran & Hubbard, 2001b). When the digit was flanked by four other digits (i.e. on both sides, on top and below it) controls participants found it difficult to identify the central digit. Synesthetes on the other hand were significantly better at doing so. They claimed that the colors elicited by target and distracters aided in the identification of the otherwise unrecognizable target.

On the other hand, Smilek et al. (2001) carried out a visual search task where a synesthete had to find a dark grey target digit surrounded by distracter digits. Critically, the background color in which the items were presented was colored congruently or incongruently with the photism elicited by the target digit. They found that the synesthete took longer to find the target digit when it was presented against a congruent background color. This finding was interpreted as showing that digits were experienced with their elicited color and therefore lost in the similar color background. They also performed an identification task in which masked digits were again presented in a congruent or incongruent background color. Again identification of masked digit was better when presented against an incongruently colored background. Although statistically better in the incongruent color background, it is worth mentioning that in the worst condition their synesthete still correctly identified 88% of the letters presented for 32ms and masked for 1000ms.

Subsequent experiments have added data favoring this position. Palmeri, et al. (2002) asked a synesthete to look for a white target digit presented amongst a variable size set of distracters. When both target and distracter elicited different synesthetic colors they found that the slope of the synesthete's search function was significantly flatter than that of the control participants. However, when the distracters were characters not eliciting any color, his slope resembled that of the control participants. Authors concluded that, although perceptual in nature, synesthetic colors were not like true colors in that they did not produce pop-out. Instead they proposed that the search was a serial-like one in which synesthetes found it easier to reject distracters on the basis of their color and thus would not search back in those areas. We will come back to this point in the next section. Recently Laeng, Svartdal and Oelmann, (2004) carried out a study similar to that of Palmeri et al. (2002) in which both target stimulus and distracter elicited a synesthetic color. He replicated previous results as searching was much faster when the eliciting color of the target was different from the eliciting color of the distracters (being both of them presented in achromatic shade). He then went ahead and reanalyzed the data as a function of the eccentricity from fixation with which the target stimulus had appeared in the searching display. Surprisingly, faster reaction times were due to those trials where the target was close to fixation. When it was presented in an area 3º to 6º from fixation, the synesthete was faster detecting it than the control participants. In contrast, for eccentricities larger than this, the responses of the synesthete did not differ from those of non-synesthetes. They therefore concluded that since attention was allocated at fixation point prior to the appearance of the searching display and reaction times differed only for those targets appearing close to fixation, the differences found between their synesthete and controls were not due to the pre-attentive pop-out of the photism but to the allocation of attention to the area where the target was presented.

Similar results have been observed in out lab (Lupiáñez & Callejas, unpublished data). We presented either two or four characters at four possible locations (to the left, right, below or above the fixation point). One of the characters was always a number, whereas the remaining characters were letters. One synaesthete (MA) was asked to search for the number target and press the corresponding key depending on whether it was odd or even. In the condition where the target elicited a photism different from that elicited by the distracters the slope of the search function was reduced to 20 ms per item, as compared to the 52 ms obtained when both the target and the distracters elicited the same photism. However, in a subsequent experiment, in which a new condition was added, where the popping out element was one of the distracters, the effect disappeared.

Binding of grapheme and color requires attention

Opposing the already mentioned authors there are two groups proposing that attention is necessary for the binding of (synesthetic) color to grapheme. Mattingley et al. (2001) reported a study where, by means of masking a prime stimulus to render it unconscious (i.e. a grapheme), they showed no influence of such stimulus on the subsequent naming of a color patch in a group of 15 synesthetes. Importantly, when the prime was consciously perceived (500ms display time) they found a congruency effect between the photism associated with the prime stimulus and the color of the patch (i.e. slower color naming times when the photism elicited by the prime did not match the color of the patch to be named). Based on these results, they concluded that attention and conscious perception of stimuli is necessary for the synesthetic color to appear.

Adding to this they performed another series of experiments (Rich & Mattingley, 2003) where they presented the group of synesthetes with complex displays with a Navon-like structure (i.e. global forms made out of local forms). Global and local forms could be made out of the same stimulus (thus inducing the same photism) or different stimuli (thus inducing two different photisms). In a first experiment they asked participants to name the color in which the display was presented and found that when the color was incongruent with both eliciting stimuli (i.e. global stimulus and local stimulus) participants were much slower than when the color was congruent with both eliciting stimuli (i.e. both global and local stimuli). Those conditions where one dimension was congruent and the other was not (i.e. either the global form was congruent with the displayed color and the local form incongruent or vice versa) yielded intermediate naming times. In order to elucidate whether attention could modulate this pattern of results, they carried out a second experiment in which they instructed participants to focus attention either on the global level or the local level. Now only both-levels congruent or attended level congruent-ignored level incongruent conditions were presented. Under these circumstances they found that the magnitude of the congruency effect (i.e. difference between both-levels congruent and attended level congruent-ignored level incongruent) showed the following pattern. When participants were instructed to attend to the global shape, the congruency effect did not change across experiments. When participants had to attend to the local shapes, although the congruency effect was still statistically significant, it was reliably smaller than the effect produced by the same conditions in experiment one. Authors concluded that, “although actively ignored letters can induce a synesthetic color that interferes with naming of the displayed color […], actively ignoring a letter can reduce its synesthetic effect" (pp.1797).

Sagiv and Robertson (2005) carried out a set of experiments on a pair of synesthetes to test the pre-attentive view point. They designed a visual search task in which rotated letters appeared as non-sense symbols therefore not eliciting any photism. In a different experiment they rotated back the target stimulus so that now it was an "L" shape that did elicit a color. They tested each synesthete's performance when neither distracter nor target gave rise to a synesthetic color and when target but not distracter did elicit a color. Results showed that the searching functions for target present trials were not different when the target induced a synesthetic color than when it did not. This is the same result found by Palmeri et al. (2002) in their second experiment and, although they did not take it to mean that photisms are not perceptual in nature, Sagiv and Robertson concluded that synesthetic colors do not pop out but behave in a way that better resembles a type of guided search (Sagiv, Heer and Robertson, 2006). Interestingly, these two synesthetes were also tested by Hubbard (Hubbard, Arman, Ramachandran & Boynton, 2005) and they found that their performance on the embedded figures test was better than that of control participants. They also run the crowding task and now only one of the synesthetes was better than the matched control group. As Hubbard et al. (2005) suggest, this might be showing that synesthesia is a heterogeneous quality.

Even more interesting is to find that, although Sagiv and Robertson (2005) did not find an interaction in the reaction times for detection of target present trials as a function of set size and whether the target was or not a synesthetic inducer, they did find a main effect of target type in one of the two synesthetes. Overall, this synesthete showed faster response times when the target stimulus was an inducer. This synesthete was the one performing better than the matched control group in the crowding task. So far, this is the only time the same synesthete is tested with different paradigms by different researchers and results seem to be adjustable. Whereas Ramachandran and Hubbard's embedded figures task might be too lax of an evidence to prove perceptual effects, Sagiv and Robertson's task might be overlooking some interesting patterns of results.

Several authors have criticized Mattingley and Rich's work on the ground of methodological problems. It is widely accepted that synesthetes are not equal (Dixon, Smilek & Merikle, 2004; Dixon & Smilek, 2005; Hubbard et al., 2005; Ramachandran & Hubbard, 2001b; Smilek, Callejas, Dixon & Merikle, in press) and that different kinds of synesthesia might give rise at different levels of the visual processing. It is also clear that different synesthetes show characteristic patterns of data while performing the exact same task. Mattingley and Rich refuse to take this fact into account and perform all their studies averaging group data from a relatively large sample of synesthetes with the consequent contamination by different patterns of performance and difficulty in the replicability of their findings. Blake, Palmeri, Marois, and Kim (2005) and Smilek, Dixon and Merikle (2005a) also mention some specific flaws of the priming study that have to do with the start up assumption that color can be perceived without awareness and that, if so, it can prime a subsequent response or the possible lack of experimental power to detect a difference that is nominally equal in the unconscious priming condition than the statistically significant difference in the control priming experiment. We also have some comments about their Navon-like stimuli experiment that will be discussed in more detail in a later section.

More evidence has been added to both points of view in the last years (Edquist, Rich, Brinkman & Mattingley, 2006; Kim, Blake & Palmeri, 2006; Mattingley, Rich, Yelland & Bradshaw, 2006; Rich & Mattingley, 2005; Wagar, Dixon, Smilek & Cudahy, 2002) but there is still no glimpse of a consensus. Until methodologically spotless experiments are designed and careful analysis of the individual patterns of results are carried out, a solution to this controversy will not arrive. A good attempt to do so is the study by Sagiv and Robertson (2005) where the same subjects that have been extensively studied by Hubbard et al (2005) have been tested on a visual search task similar to the one used by Palmeri et al (2002) or Laeng et al (2004) and have yielded somewhat conflicting results.

We carried out a set of experiments to study the role of attention in synesthetic perception, by testing how our synesthete MA behaved in situations similar to those already described. We designed a set of visual search tasks similar to those used by Ramachandran and Hubbard (2001a) where we compared the potential benefit of searching for a different shape with the benefit of searching for a different (synesthetic) color. Also we designed another task similar to that utilized by Rich and Mattingley (2003) with some methodological improvements.

EXPERIMENT 1. VISUAL SEARCH WITHOUT SEARCHING CUES

The goal of this first experiment was to explore extra features of MA's perception. In particular, we were interested in learning more about the benefits that perception of the photisms might have in MA's performance when perceiving a difficult stimulus. In order to do so we designed a visual search task in which we combined perceptual similarity with synesthetic similarity to study the relative contribution of each dimension on searching for a camouflaged target.

Taking advantage of the fact that there were several graphemes eliciting the same photism in our synesthete MA, we chose 2 of them that were substantially different in their perceptual shape but elicited the same color (i.e. both "M" and "N" elicited yellow). Also, we chose another grapheme that was perceptually equal (i.e. "W" as a mirror image of "M") but elicited a substantially different color (purple). Instead of asking participants to search for a target stimulus, we constructed a rectangular shape out of it and asked participants to discriminate its orientation (i.e. vertical vs. horizontal). The embedded figures made out of these three letters were quasi randomly distributed across the display and the other two letters were presented as distracters.

A previous pilot experiment had shown that the searching times for an embedded shape conformed by "N"s were considerably faster than those for the shapes made out of "M"s or "W"s in a group of non-synesthetic controls. We therefore predicted that control participants would find a benefit when the shape was made out of the "N" letters because of its perceptual features. However, we predicted that if MA could take advantage of her synesthetic colors, she would be faster finding a shape made out of "W"s since, for her, it was clearly different from the other letters according to its elicited color. We also expected the shape made out of "M"s to produce the slowest reaction times since it had the same perceptual shape than one distracter and the same elicited color than the other distracter. Last, we expected "N" to fall in between, closer to "M" or to "W" depending on which dimension of the stimulus would affect MA's performance in a stronger manner (i.e. unique shape vs. unique synesthetic color).

METHOD

Participants

MA and a group of 10 undergraduate psychology students participated in this experiment. They all had normal or corrected to normal vision and the mean age of the group was 21. All of them were women (including MA).

Stimuli and material

Three letters were chosen as stimuli for this task based on their perceptual features and MA's photism for them. As can be seen in Figure 1, the letters we used were "M", "N" and "W". The first two letters elicited a yellow photism while the last one elicited a purple one. Therefore, photism-wise, "M" and "N" were very similar and "W" was very different. On the other hand, shape-wise, "M" and "W" were the exact same shape after it had been horizontally flipped and "N" was fairly different.

The whole display had a total of 81 letters (9 rows and 9 columns) and at a viewing distance of 53cm subtended 10.78º horizontal and 9.71º degrees vertical. Each individual letter was 0.65-0.86º horizontal and 0.86º vertical. The rectangle was formed by 5 letters on the long side and 3 letters on the short side. Therefore it was about 5.94º x 2.92º. The rectangle's inside was filled with randomly chosen letters other than the one making it. For each display, the letter used to build up the rectangular shape was never also used as distracter (i.e. a display that had a rectangle made out of "Ms" did not have that letter anywhere else other than in the outline of the rectangle).

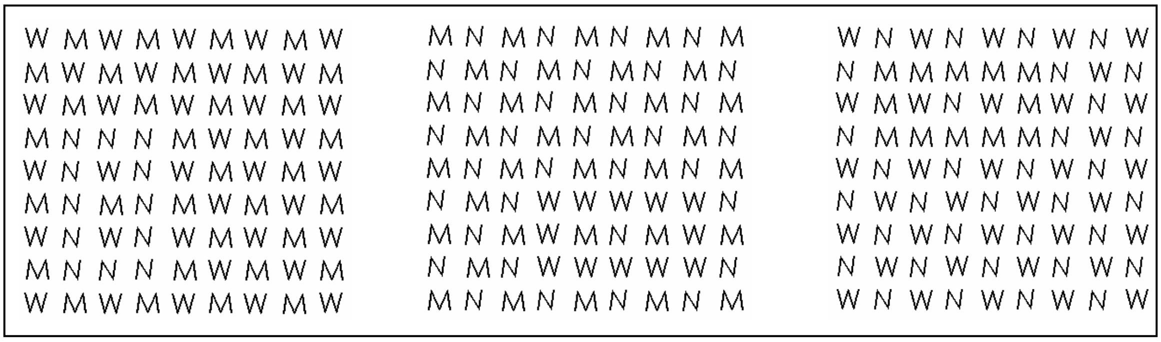


Figure 1. Experiment 1. Three examples of target display. In the left one the target is a vertical rectangle made out of "Ns"; in the middle one the horizontal rectangle is made out of "Ws" and in the right one the horizontal rectangle is made out of "Ms".

Stimulus presentation as well as data collection was carried out on a Pentium computer running E-prime software (Schneider, Eschman & Zuccolotto, 2002). Participants responded by pressing one of two letters in a computer keyboard. A 14' computer screen was used and auditory feedback was given by means of headphones.

Design and Procedure

The task that participants were to perform consisted on a visual search in which the searched target was a rectangular shape made out of 12 letters embedded in a 81-

letter display (9 rows and 9 columns). The rectangle was made out of one of the three letter types used in the display and distracters were the other two letters, randomly distributed across the display. The rectangle could be either horizontally or vertically positioned and could appear in four different locations to prevent participants from expecting where to find it. Participants' task was to find the rectangle and press either the "z" or the "b" key depending on its orientation. MA).

In each trial a fixation point was presented for 800ms and followed by the search display. After a response was given, feedback was emitted if a mistake had been made. Otherwise, the next trial began.

Four blocks of trials were presented with 24 trials each (one per location, position and letter condition). Participants were instructed to respond as fast as possible whether the embedded rectangle was horizontal or vertical and to do so without making mistakes.

RESULTS AND DISCUSSION

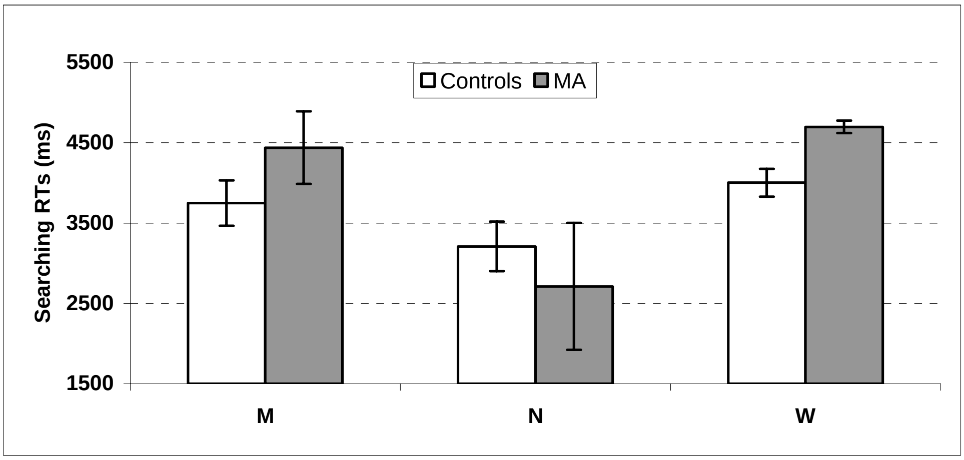
Reaction time analysis

Incorrect responses (7.2%) were excluded from the reaction time analysis. Reaction times were considerably slow for this task and also relatively variable among participants. We therefore used individual standard deviations as criteria to identify and exclude outliers. All response times slower or faster than 2 SD of each participant's mean were excluded from further analysis. Blocks were used as random factor. Control group's scores were averaged across participants for each experimental block and subsequently compared to MA's scores. Mean reaction times and error rates per group and condition can be seen in Table I.

Table I. Experiment 1. RT (and percentage correct) per group and experimental condition.

Letter	M	N	W
MA	4451.92 (11.1%)	2750.03 (3.1%)	4687.28 (3.3%)
CTRLS	3750.43 (8.8%)	3208.91 (4.9%)	4001.65 (4.1%)

A 2 (Group) x 3 (Letter) ANOVA was performed on the averaged data and individual ANOVAs were carried out when necessary. The general analysis informed that there were no differences between groups ($F_{(1, 3)}$=2.85, p=.189). Letter "N" was easier to find than any other letter ($F_{(2, 6)}$=10.64, p=.011) and this was so for control participants ($F_{(2, 6)}$=17.60, p=.003) as well as for MA ($F_{(2, 6)}$=7.22, p=.025). Planned comparisons showed that for MA, searching for a “purple” rectangle among yellow distracters (i.e. “W” condition) was no different than looking for a “yellow” rectangle among yellow and purple distracters (i.e. “M” condition) (F<1). However, looking for a rectangle where the letter forming it was perceptually different than the distracters (i.e. “N” condition) was in fact faster than the other two conditions ($F_{(1, 3)}$=7.017, p=.077 and $F_{(1, 3)}$=14.69, p=.031 respectively). Controls did not show any difference between “M” and “W”. They were both more difficult to find than “N” (both ps<.02).

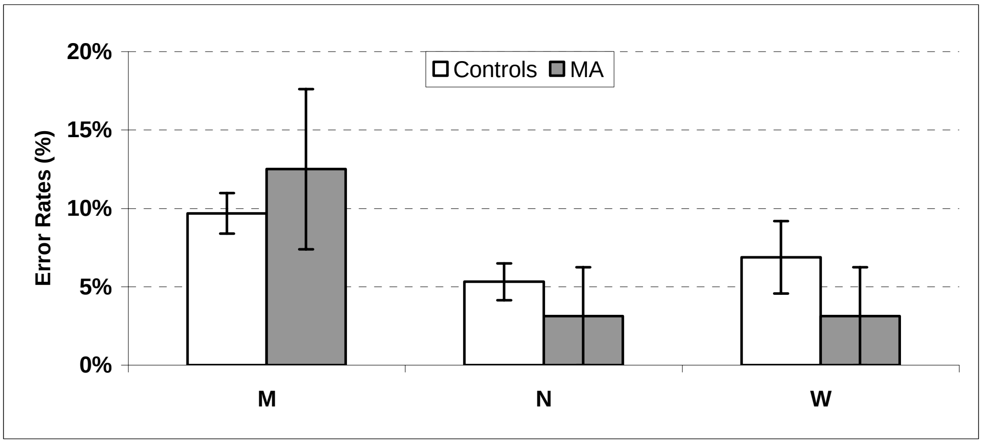


Graph 1. Experiment 1. Reaction times for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

As can be observed in Graph 1, this pattern of results was the same as that found with the control participants. It seems then that MA was not benefiting from the extra dimension of the stimuli (i.e. color) that only she perceived. Her pattern of results showed that she obtained a benefit due to the letter shape, being it of the same type as the one obtained by the control participants. Nevertheless, this particular shape should be more difficult to find for her since it elicited the same color as one of the distracter letters.

Accuracy analysis

The same 2 (Group) x 3 (Letter) ANOVA was carried out for the percentage correct data. None of the main effects or the interaction reached significance. As can be seen in Graph 2, since no time pressure was given to participants, the overall error rates were fairly low for all conditions for MA as well as for the control group.



Graph 2. Experiment 1. Percentages of correct responses for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

From the reaction time data we concluded that colors (photisms) do not appear automatically to MA as she fixates in a display, and therefore she does not benefit from the extra information that they could provide. However, the fact that no influence of letter was found in this experiment does not rule out the possibility that she is in fact able to use the color information for this type of task as long as she knows what she is looking for. That is, if she knows what letter is forming the display, as was the case in Ramachandran and Hubbard's experiment (2001a), she might tune her search to only look for the stimuli eliciting that color. If this was so, we would conclude that colors do not pop-out of the display but they could be able to guide search.

In order to test this hypothesis, we conducted Experiment 2 in which, before the search display was presented, a cue was provided informing about the identity (and therefore color for MA) of the stimuli forming the rectangle for that particular trial.

EXPERIMENT 2. VISUAL SEARCH WITH SEARCHING CUES

In this new experiment, we added a visual cue that indexed the identity of the letter that had to be searched for. We expected that giving this piece of information to participants in general would enhance their performance since their search had a predefined objective. Also, we expected a differential benefit for MA since now she had an additional piece of information that should aid her search. By knowing the identity of the target stimulus she would also know the color she had to "look for".

METHOD

Participants

MA and the same group of 10 students who participated in the previous experiment performed this experiment.

Design and Procedure

The task to be performed was the exact same one as in the previous experiment with the only difference of a cueing letter appearing right before the search display. The fixation point used in Experiment one was replaced in this experiment by the letter, which was also presented on the screen for 800ms. This letter informed of the identity of the stimulus that would be making up the rectangular shape. This time, six blocks of trials were presented.

RESULTS AND DISCUSSION

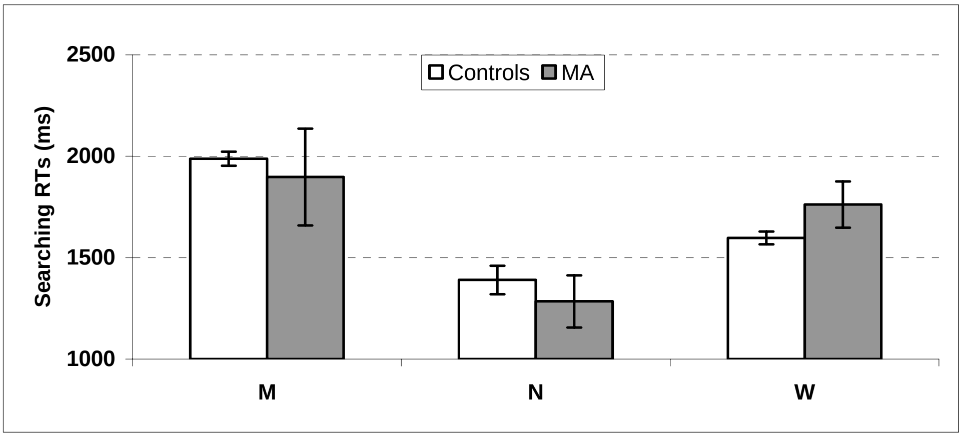
Reaction time analysis

We again used a 2SD cut off to eliminate outliers for each participant. Incorrect responses (6.4%) were also excluded. Again, blocks instead of participants were used as random factor. Mean reaction times and error rates per condition can be seen in Table II.

Table II. Experiment 2. RT (and error rates) per group and experimental condition.

Letter	M	N	W
MA	1897.65 (29.1%)	1284.01 (8.3%)	1762.25 (7.5%)
CTRLS	1987.98 (13.2%)	1389.96 (9.2%)	1597.94 (10.9%)

A 2 (Group) x 3 (Letter) ANOVA was performed on the averaged data and individual ANOVAs were carried out when necessary. No main effect of Group was found ($F<1$). Again, the letter being searched for influenced the reaction times ($F_{(2, 10)}=17.22$, $p=.001$). Searching for an "N" was faster than searching for an "M" ($p<.005$). Nonetheless, "W" was now faster than in the previous experiment and the reaction time associated with it was in between that of the "M" and the "N". We checked whether this pattern of results was due to differential response times for MA and the control group and found no interaction between them ($F_{(2, 10)}=1.49$, $p=.270$). Graph 2 shows that, as control participants, MA was faster when looking for a shape made out of “N” than any other condition. Even more, as shown by planned comparisons, her reaction times for “M” and “W” were both different from those for “N” ($F_{(1, 5)}$=8.01, p=.037 and $F_{(1, 5)}$=12.36, p=.017 respectively). Therefore, the trend for “W” to be faster than “M” was surprisingly due to the control participants and not to MA ($F_{(1, 5)}$=83.69, p=.001).

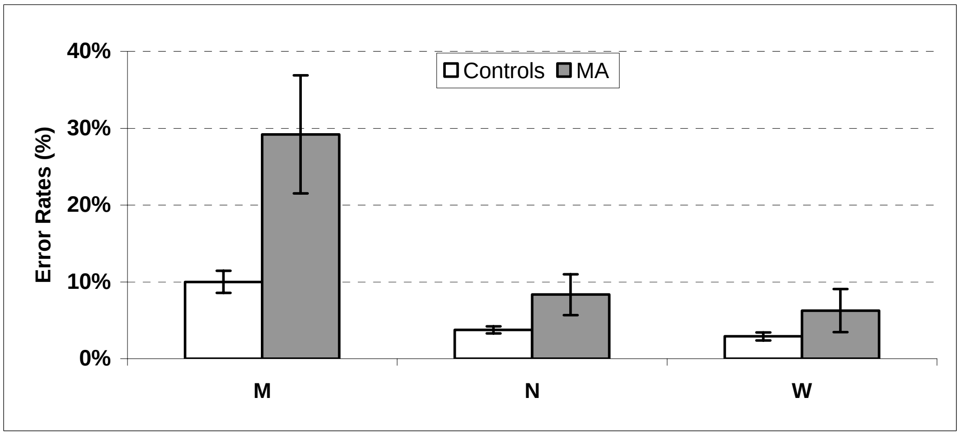


Graph 3. Experiment 2. Reaction times for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

Again, reaction time data does not point to a clear influence of color aiding MA’s search for an embedded rectangular shape. She only finds a benefit when looking for a perceptually different display (i.e. “N”) even though it is supposed to be eliciting the same color as one of the distracters (i.e. yellow). It seems as though shape and not color is aiding her performance.

Accuracy analysis

The same 2 (Group) x 3 (Letter) ANOVA was carried out on the accuracy measures. The groups were now different ($F_{(1, 5)}$=10.96, p=.021 and MA was more error prone than the control group. An interesting pattern of results for the main effect of Letter emerged from the data ($F_{(2, 10)}$=10.90, p=.003). Searching for an “M” display produced far more errors than any other condition. This pattern could only be due to a detriment in MA’s performance since letter “M” was categorized for her as the most difficult to find because it had the same shape as “W” and the same color as “N”. Although the interaction was not reliable ($F_{(2, 10)}$=2.53, p=.129) post hoc tests showed that control participants did not differ in their error rates for the different letters (all ps>.7) whereas MA did (see Graph 4). Her error rate for letter “M” was different than that for “N” (p=.032) and that for “W” (p=.018).



Graph 4. Experiment 2. Error percentages for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

This new experiment showed that MA still does not seem to obtain much benefit from the colors elicited by her synesthesia. In spite of knowing which letter/color to look for, her performance does not change considerably in relation to the previous experiment where the letter forming the target shape was unknown until the display was presented. Especially “W” keeps proving to be difficult to find or at least, the benefit expected from its color does not seem to be larger than the benefit found in “N” due to its shape. The only hint of a differential pattern for MA is that of the accuracy measures where her performance for the letter M was worse than for the other letters. What we found was quite different from what we expected. Instead of being better for “W” than for “M” or “N”, she was worse for “M” than for any other letter. It seems as though she anticipated the difficulty of the task and that influenced her response accuracy; her synesthesia only seems to have an effect on her search by adding more heterogeneity to the distracters in the “M” target condition. Furthermore, she does not seem to obtain much benefit overall from the previous cue.

In order to further study this, another ANOVA was carried out including now Experiment as a between block condition. We then had a mixed 2 (Experiment) x 2 (Group) x 3 (Letter) analysis. We found a main effect of Experiment ($F_{(1, 8)}$=58.38, p=.001) consisting on faster reaction times for Experiment 2. The effect of Letter was also modulated by Experiment ($F_{(2, 16)}$=6.77, p=.007). Presenting a cue aided significantly more to the search of rectangles formed by “M” or “W” than for those formed by “N”. However this benefit was only marginally differential for MA ($F_{(2, 16)}$=3.48, p=.056). This trend was due to her long reaction times for “M” and “W” in Experiment 1 since her reaction times in Experiment 2 were very similar to those of the control group.

The same analysis for the accuracy measures showed that there was no difference between error rates in Experiment 1 and 2. We found that searching for the different letters did not yield the same results for MA and the Control group although this was just a trend ($F_{(2, 16)}$=2.82, p=.089). In particular, MA's performance for letter "M" was clearly worse than that of Controls' for any letter and from her own performance for "N" and "W" (all ps<.03). Even though the second order interaction by experiment was not significant (F<1), since we expected an influence of cue in MA's performance we carried out a separate analysis for her data across experiments. In experiment 1 she was marginally more accurate than in Experiment 2 ($F_{(1, 8)}$=4.66, p=.063) and again searching for a letter "M" was more difficult than any other letter ($F_{(2, 16)}$=6.60, p=.008). The relative effect of letter did not change across experiments ($F_{(2, 16)}$=1.07, p=.365).

This new analysis pours out some remarkable results. Contrary to what would be expected, MA did not benefit from having a searching cue. Even though her reaction times decreased, so tended to do her accuracy. Even more, if the cue had any differential effect on the letters, it was a detrimental one since it only generated an even less accurate performance for letter "M".

Given that the only differences found so far between MA and the control group were those coming from the accuracy data, we carried out another experiment in which we promoted differences in this measure instead of reaction time. In order to do so we showed participants the same display of stimuli for a brief duration of time and compared their accuracy in discriminating the direction of the rectangle.

EXPERIMENTS 3a and 3b. VISUAL SEARCH WITH SEARCHING CUES AND LIMITED EXPOSURE TIME

Experiment 3 tried to look for differences between MA's performance and that of the control group and in order to do so we designed what we thought would be the ideal circumstances to obtain such differential effects.

Since reaction time showed a great deal of variability among participants, we modified the task in order to measure accuracy. We showed the display containing the target rectangle for a limited amount of time and measured correct identification of the target's direction. Two display lengths were used to increase the chances of finding differences between the control group and MA in at least one of them.

METHOD

Participants

MA and a different group of 10 participants performed this experiment. Nine of them were females and their mean age was 20. These participants were different from those performing the previous two experiments.

Design and Procedure

The task to be performed was the exact same one as in the previous experiment with the only difference that the searching display was presented for a limited duration (1000ms or 1500ms). Display duration was manipulated between experiments. Participants first run the 1000ms display duration experiment.

In each experiment (display duration), six blocks of trials were presented and 24 trials were included in each block (one per location, position and letter condition).

Stimulus presentation as well as data collection was carried out on a Pentium computer running E-prime software (Schneider, Eschman and Zuccolotto, 2002). Response times were collected with a computer keyboard. A 14' computer screen was used and auditory feedback was given by means of headphones.

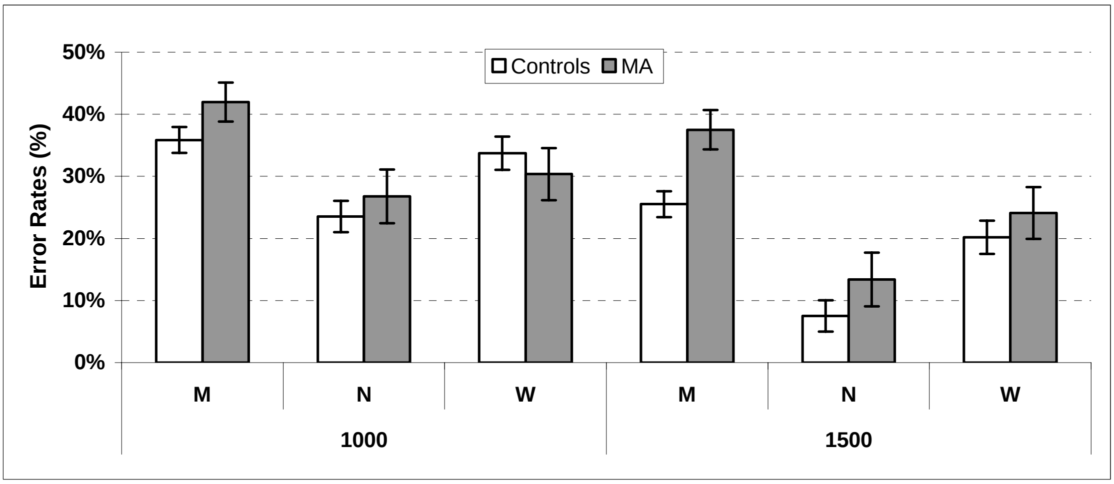
RESULTS AND DISCUSSION

Trials were anticipations had occurred (RT=0ms) were excluded from further analysis (0.75%). Again, blocks and not participants were used as error factor. Mean percentage of correct responses per condition can be seen in Table III.

Table III. Experiments 3a and 3b. Error rates per group and experimental condition.

	Display Duration					
	1000ms			1500ms		
Letter	M	N	W	M	N	W
MA	42.0%	26.8%	30.4%	37.5%	13.4%	24.1%
CTRLS	35.9%	23.5%	33.7%	25.5%	7.5%	20.2%

A 2 (Display duration) x 2 (Group) x 3 (Letter) ANOVA was performed on the data and the following results were obtained. An expected main effect of Display duration was found ($F_{(1, 12)}$=15.46, p=.002). More correct responses were given when the display was presented for longer time on the screen. The main effect of Group was marginally significant ($F_{(1, 12)}$=4.45, p=.054) and surprisingly, the difference was in the opposite direction to that expected. As can be seen in Graph 5, Control participants tended to make fewer mistakes than MA. Last, we found an effect of Letter ($F_{(2, 24)}$=49.64, p=.001). Looking for an "N" was significantly easier than looking for a "W". Similarly, searching for the "W" was easier than the "M" (all ps<.01). Again we checked whether this pattern was only due to MA's data or the Control participants also showed it.



Graph 5. Experiment 3a and 3b. Error rates for MA and the Control group as a function of the time the display was presented and letter that formed the target stimulus. Error bars denote standard errors of the mean.

A separate ANOVA for the Control group showed a main effect of Letter ($F_{(2, 24)}$=40.63, p=.001) that a further analysis demonstrated to be due to the effect of searching for an "N". This condition yielded more correct responses than any other (both ps<.001). The same ANOVA carried out for MA showed that the effect of letter was also significant ($F_{(2, 24)}$=18.30, p=.001). Planned comparisons showed MA's pattern of results mirrored that found for the main effect of Letter. Searching for a shape made out of "Ns" was more precise than searching for shape made out of "Ws" ($F_{(1, 12)}$=5.33, p=.040) and the latter more precise than when the shape was made out of "Ms" ($F_{(1, 12)}$=12.99, p=.004).

Last, the time the display was kept on the screen did not affect the Control group's results ($F_{(2, 24)}$=1.33, p=.284) nor MA's ($F_{(2, 24)}$=1.03, p=.371). However, planned comparisons for MA showed that the difference between "N" and "W" was only present in the long display condition ($F_{(1, 12)}$=6.00, p=.031) and not in the short one (F<1). “M” showed the worst performance (worse than “W”) in both display’s duration ($F_{(1, 12)}$=5.60, p=.036 and $F_{(1, 12)}$=7.46, p=.018 respectively).

It is therefore clear that MA did not get an obvious benefit from the extra information coming from the photism and thus it seems that synesthetic colors are not automatically elicited by the letters and do not automatically guide search in our synesthete. Only when the conditions were altered so as to maximally promote the use of that extra dimension did we find a hint of those colors being used. Only when visualization time was restricted to quite short values did we find that searching for the letters was modulated by the color. The accuracy when looking for “W” was not different from that of letter “N”. It seems then that only under extreme conditions does the color (i.e. purple) help find the grapheme (i.e. “W”). However, the benefit is not as great as to overcome the facilitation due to the grapheme’s shape in the case of “N”. In relation to “M”, we found that it was influenced by the previous knowledge about the identity of the target stimulus. However, this influence goes in an interesting direction. Knowledge of identity does not benefit performance but hinders it. It seems as though knowing that the following trial involves dealing with the “difficult” display does negatively influence performance.

According to Duncan and Humphreys (1989) two factors play a role in visual search producing a continuum of search efficiency. As similarity increases between targets and non-targets the search task becomes more difficult. Likewise, as similarity between non-targets decreases, the task also becomes more difficult. This theory would propose that searching for an “M” would be the most difficult condition since the target shared photism with one of the distracters and perceptual shape with the other distracter. Even more, the distracters did not share photism or perceptual shape. In the case of the target being a rectangle made out of “Ws”, it shared form with “M” but did not share any feature with the other distracter “N”. Adding to this, both distracters shared photism. Last, when the “N” was the target stimulus, both distracters share shape between them and were different in shape from the target. Only the photism of one of the distracters was shared with the target stimulus.

If MA is performing the task in a serial manner and color is becoming apparent only as she searches through the display and identifies each shape, then color will not aid her in finding the target but it will influence her way to deal with the distracters. When searching for an “N” she can group distracters on the basis of their shape; when searching for a “W” she can group distracters on the basis of their color. However, when searching for an “M” distracters cannot be easily grouped since they are heterogeneous in their color and their shape.

Therefore, the predictions from this theory fit well the accuracy data we obtained. Looking for a rectangle made out of “Ns” was consistently found to be the easiest task to do. Looking for a rectangle formed by “Ws” was easier than if the rectangle was made out of “Ms” in some cases and as difficult in other cases. Last, when having to find a rectangle made out of “Ms” MA consistently showed the poorest performance. On the sole basis of perceptual similarity and dissimilarity between target and non-targets, Duncan and Humphreys (1989) would predict that responding to “W” was as difficult as responding to “M”. This was the result found for controls in Experiments 3a and 3b. If synesthetic similarity comes into place, responding to a “W” could become as easy as responding to an “N”, in the case that photism perception was as strong and automatic as shape perception. Therefore, the relative influence of the synesthetic perception that is probably varying as a function of the absence vs. presence of cue and the display duration, could explain the oscillatory findings for letter “W”. Independent of the influence of photism similarity, this theory would always predict “M” being very difficult to find, as compared to “N”, and that is what the data shows for either reaction time or accuracy measures or both.

Following this theory to explain the data we can conclude that, even though photisms do not seem to be experienced prior to the conscious perception of the shape, they do play a role in the visual search task by biasing the similarity between target and distracters and similarity among distracters themselves. Therefore MA does not show any evidence for pre-attentive photism experience.

It is true that the size of our display was similar to that used in previous experiments (Palmeri et al. 2002; Ramachandran & Hubbard, 2001a) but the number of items was increased, thus rendering a more densely populated area and it could be argued that this is the reason for an absence of effect. In order to check this we carried out a control experiment in which we showed MA and a group of controls the display as MA would see it. That is, with letters colored as MA had previously reported that she perceives them.

EXPERIMENT 4. VISUAL SEARCH WITH COLOR CUES

In this last experiment we wanted to make sure that if colors experienced by MA in the previous experiments had had a strength comparable to that of real displayed colors, she would have been able to take advantage of that extra dimension of the stimulus to aid her search even when the density of stimulus on the screen is superior to that used in other studies.

METHOD

Participants

MA and a different group of 10 participants performed this experiment. These participants were different from those performing the previous four experiments.

Design and Procedure

The task to be performed was the exact same one as in Experiment 1 with the only difference that the searching displays were now colored according to MA's reports (see Figure 2 for an example of the colored displays).

Six blocks of trials were presented. All other parameters were kept as in Experiment 1.

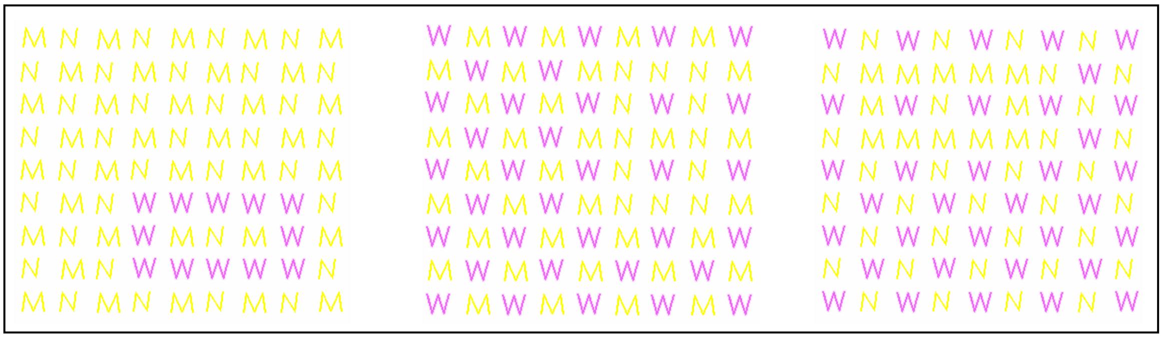


Figure 2. Experiment 4. Three examples of target display. In the left one the target is a horizontal rectangle made out of "Ws"; in the middle one the vertical rectangle is made out of "Ns" and in the right one the horizontal rectangle is made out of "Ms".

RESULTS AND DISCUSSION

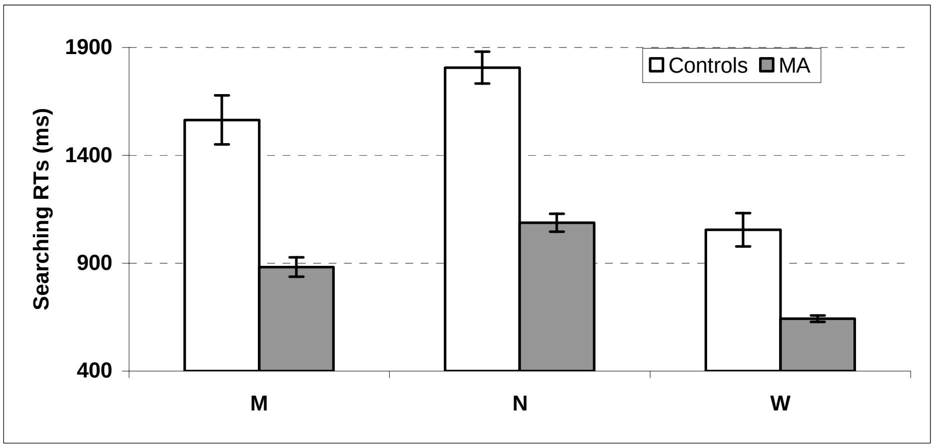
Reaction time analysis

A total of 17% of the trials were eliminated from the reaction time analysis due to incorrect response. Again a 2SD cut off was used to eliminate outliers. The remaining data were submitted to a 2 (Group) x 3 (Letter) ANOVA. Mean reaction times and error rates for each condition and participant can be seen in Table IV.

Table IV. Experiment 4. RT (and percentage of errors) per group and experimental condition.

Letter	M	N	W
MA	882.33 (2.1%)	1087.81 (11.1%)	642.26 (2.1%)
CTRLS	1564.34 (21.0%)	1806.31 (24.9%)	1054.89 (7.8%)

Groups were now different ($F_{(1, 5)}$=86.67, p=.001). MA was faster than control participants. This may have been due to her extensive practice after having performed the previous four experiments. We also found a significant main effect of Letter ($F_{(2, 10)}$=180.57, p=.001). As expected, "W" was faster than "M" or "N" ($F_{(1, 5)}$=114.83, p=.001 and $F_{(1, 5)}$=629.67, p=.001 respectively). Surprisingly, a rectangle made out of "M"s was also faster to be found than when it was made out of "N"s ($F_{(1, 5)}$=40.15, p=.001). This finding was unexpected since both letters were presented in the same color. If anything, we would have expected that due to its unique form, "N" and not "M" would have been easier to find. A significant interaction by group ($F_{(2, 10)}$=18.95, p=.001) showed that control participants found more benefit from having "W" colored in purple than MA did (see Graph 6).



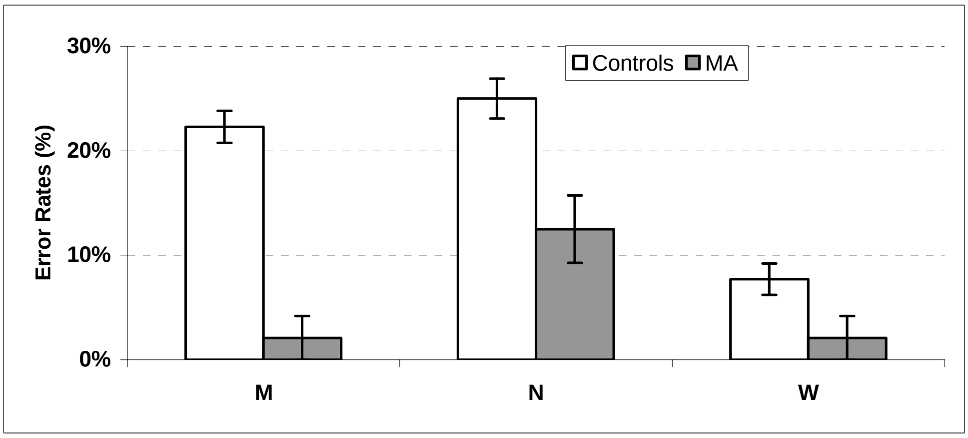
Graph 6. Experiment 4. Reaction times for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

The finding that “M” yielded faster reaction times than “N” was surprising as it was unexpected. It could be that since letter “M” was perceptually bigger than letter “N”, the yellow spot formed by a rectangle made out of “Ms” was more apparent and thus easier to categorize as vertical or horizontal without even processing the identity of the letter forming it. Nevertheless, even though expected, the most interesting result is the relative benefit of letter “W” as opposed to the other letters. Finding these results with MA demonstrates that she is not just bad at searching for items in a display but rather, when presented with achromatic graphemes, color (photism) does not become conscious in time to exert a noticeable effect on her search.

Accuracy analysis

The same ANOVA carried out on the error percentage showed again a different performance for both two groups ($F_{(1, 5)}$=64.22, p=.001). MA was more accurate than the control participants. Again, this could be due to extensive practice with the task. Finding a “W” yielded more accurate responses than any other condition ($F_{(2, 10)}$=18.24, p=.001). This time the difference between “M” and “N” was not reliable (p=.157) and this was due to a differential error rate pattern for both groups ($F_{(2, 10)}$=5.41, p=.026).

As can be seen in Graph 7, MA was as accurate for “M” as she was for “W” while control participants did not show a difference between yellow colored letters. Although counterintuitive, she is definitely obtaining a benefit from answering to letter “M” over letter “N”. Although we do not readily have an explanation for MA’s results, it could well be that after having performed the same visual search task so many times, she had developed some strategies to search for the letters, especially for letter “M” that was always referred to as "the difficult one" and such strategies aided her search when color was present giving rise to a lower error rate for "M" than "N".



Graph 7. Experiment 4. Error rates for MA and the Control group as a function of the letter that formed the target stimulus. Error bars denote standard errors of the mean.

Given that elicited photisms do not seem to automatically guide visual search in MA, our next concern was to study whether, although experienced after the cognition of the inducer, they were still strong enough as to influence behavior when the complexity of the display was raised and most important, whether attention would modulate such influence in any manner.

EXPERIMENT 5. ATTENTION MODULATION OVER PHOTISMS ELICITED BY COMPLEX STIMULI

To study how attention modulates perception of photisms elicited by letters we followed up previous experiments by Rich and Mattingley (2003). There they presented a group of synesthetes with a set of Navon like displays where the color elicited by the stimuli forming the global and the local shape could be either congruent or incongruent with the color in which the display was presented.

As previously mentioned, in the original study they carried out two experiments to test whether ignoring the dimension of a stimulus that elicited a photism incongruent with the display color would be efficient enough as to avoid the photism's influence on performance. They predicted that a photism induced by the letter that was being attended would compete more with the display color than the photism associated to the letter in the dimension of the stimulus that was being ignored. In Experiment 1, where attention was not manipulated, they found that when both local and global letters elicit the same photism and it was congruent with the display color, synesthete participants were faster to name the display color than when it just matched the photism elicited by only one of the two dimensions (either the global or the local). Last, the condition where both dimensions were eliciting a color incongruent with the displayed one was the slowest. That is, a congruently colored stimulus facilitated performance while an incongruently colored one worsened performance. When a dimension of the stimulus was congruent and another dimension incongruent, naming times were in between.

In the second experiment they manipulated, by means of instructions, the dimension of the stimulus that the person was paying attention to. Now, in each case the attended dimension was always congruent and the ignored dimension could either be also congruent or incongruent. They then compared the congruency effect in these circumstances with that found in Experiment 1 for the same conditions where attention was not manipulated. Results from Experiment 2 showed that when participants were requested to attend to the global form and the *ignored* local form was incongruent, they were slower than when both dimensions were congruent. This congruency effect was as large as that found in Experiment 1 for those two conditions. When the instructions asked to attend to the local form and the *ignored* global form was incongruent, again slower naming time was found as compared to the same both-levels-congruent condition. Here, they found that the congruency effect was reliably smaller than that found in Experiment 1 for the very same conditions. That is, when attending local, attention seemed to attenuate the interference coming from a global incongruent color.

Several problems arise from this design. First, they did not make sure their participants were in fact paying attention to the dimension they had been instructed to. Second, because of the way they designed their experiment, they were confounding color congruency with letter consistency. Both level congruent conditions were also letter-consistent (global and local letters were the same) while one level congruent-one level incongruent was also letter-inconsistent (global and local letters were different). Third, in the second experiment only 2 of the original 4 conditions were included. Therefore they did not check the effect of attending to an incongruently colored stimulus and ignoring a congruently colored one, or whether attending to one dimension when both dimensions were incongruent would produce a smaller congruency effect. Fourth, the critical comparison to check the role of attention was made across experiments. Congruency effect when participants were supposedly attending to one specific dimension was compared to the congruency effect found in experiment one for the same conditions. However, there is no evidence whatsoever as to what was being attended in Experiment 1. The logical comparison would have been that of the different original conditions when they were attended vs. ignored. Last, they tested and averaged performance from 17 synesthetes of whom no information is provided regarding the type of synesthesia experienced (i.e. higher vs. lower / projector vs. associator) and this renders their results very difficult to interpret.

The aim of our experiment was to complement this study and also to test how a higher synesthete would behave under such circumstances. Even though the Stroop-NP experiment showed that her colors were automatically elicited and difficult to ignore, the Visual Search experiments showed that they were not strong-vivid enough as to pop out and therefore guide and make easy a difficult visual search task.

METHOD

Participants.

MA and a group of 10 participants carried out the task. They all had normal or corrected to normal vision and the mean age of the group was 22. Eight of them were women (including MA).

Design and Procedure.

The task to be performed was to name the display color of a set of stimuli appearing on the computer screen while ignoring their identity. Stimuli were letter shapes make out of small colored letters.

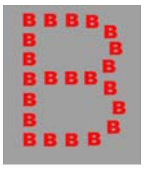
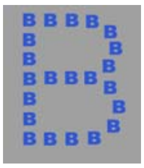
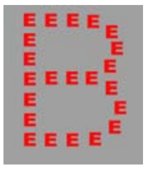
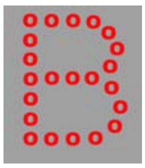
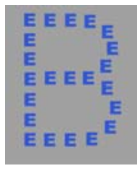
The variables being manipulated were 3: Attention (to the global form or the local form), Letter Consistency (whether the global and local letters were the same or different) and Photism-Color Congruency (whether the color elicited by the stimulus was congruent or incongruent with the display color).

Four blocks of trials were presented. In two of them participants had to pay attention to the global form and in the remaining two they had to attend to the local form. The order of the blocks was counterbalanced across participants. MA run the experiment twice, so that she went through both counterbalancing conditions.

Four different colors were used and two stimuli of each color were presented. The stimuli and their photisms are shown in Table V. With this design we could manipulate Letter Consistency as we kept Photism-Color Congruency constant by presenting two letters eliciting the same photism, one in the global level and another one in the local level. Also, this set of stimuli enabled us to have pure Photism-Color Congruency conditions (i.e. both levels congruent) even when the Letter display was inconsistent. Therefore Photism-Color Congruency had 2 levels for the consistent letter level (i.e. 2 pure levels: a “B” made out of “B”s in red –congruent- or in blue –incongruent-) and 4 levels for the inconsistent letter level (2 pure levels where both letters elicited the same photism: congruent –a red “B” made out of “E”s- and incongruent –a blue “B” made out of “E”s and 2 mixed levels were the color only matched the photism of one dimension of the stimulus: only global letter congruent –a red “B” made out of “O”s- and only global letter incongruent –a yellow “B” made out of “M”s).

Table V. Experiment 5. Experimental design and items used with the corresponding elicited photism. Only the Attend Global condition is shown since the stimuli were the same and only instructions to attend to the global or local form varied between conditions.

L	S	K	Z	B	E	M	O

Attention	Global					
Letter Consistency	Consistent		Inconsistent			
Photism-Color Congruency	Pure Cong: G-cong L- cong	Pure Incong: G-incong L-incong	Pure Cong: G-cong L- cong	Mixed Incong: G-cong L-incong	Mixed Incong: G-incong L- cong	Pure Incong: G-incong L-incong
						

In order to ensure that the Attention manipulation was effective, 11% of trials were catch trials where participants had to detect the presence of a letter and report its identity but only if that letter was presented in the dimension of the stimulus that was being attended (i.e. in a “attend global” condition, they had to detect the presence of a letter “T” only if this was the global form made out by other letters but not if it was the local letter making up a global form). Therefore, in half the catch trials participants had to report the identity of the letter (when it was presented at the level they were attending) and in the other half they had to report the color of the stimulus (when it was presented at the level they were supposed to be ignoring). Letter “T” was chosen because it elicits a black photism for MA, and therefore would not interfere with the rest of the conditions. Attention was manipulated between blocks, and Letter Consistency and Photism-Color Congruency within blocks.

For each level of Letter Consistency, each block had equal number of trials for each pure level of Photism-Color Congruency (24 per level) and a slightly smaller number of mixed-level trials (16 per level). Therefore out of the 144 trials per block 48 were letter-consistent, 80 were letter-inconsistent and 16 were catch trials. All trial types were randomly presented so that participants could not anticipate them.

In each trial a fixation point (a "+" in the middle of the screen) was presented for 750ms. Afterwards, the target stimulus was shown and remained on the screen until participants named the color to the microphone. Once they had given a response the experimenter recorded it on the keyboard for accuracy measurement purposes and the next trial began.

Stimuli and material.

At a viewing distance of about 53cm global letters were from 4.32 to 6.48º wide and from 6.48 to 7.02º tall. Local letters were 0.65º wide and 0.65º tall. Global letters were made by a variable number of local letters (from 12 to 25) depending on their structure (i.e. letter "L" was made of 12 letters while letter "M" was made of 25 letters).

Stimulus presentation as well as data collection was carried out on a Pentium computer running E-prime software (Schneider, Eschman & Zuccolotto, 2002). Verbal naming times were collected with a voice key microphone connected to a serial response box. A 14' computer screen was used.

RESULTS AND DISCUSSION

Catch trials were analyzed to make sure that participants were following instructions. All participants had performances well above chance (lowest individual performance on a category: 81%). Therefore all participants were included in the statistical analysis[1]. Trials were the microphone had been activated due to extraneous

[1] Six out of the 10 participants had lower accuracy scores in the catch trials than MA. A subsequent analysis including only the remaining 4 participants was carried out and none of the results differed from those shown here. Therefore those analyses are not reported.

noise or it had failed to detect a response (2.75%) were excluded from the analysis. A further 1.2% was excluded due to incorrect response. Naming times faster than 200ms or slower than 1200ms were considered outliers and therefore also eliminated from analysis (2.5%).

The mean for MA's scores for each item over the 2 sessions were averaged as so were the scores for the ten participants. Therefore, items and not subjects were used as the error factor in the subsequent ANOVAs. Two statistical analyses were carried out to analyze the data. We first analyzed the pure-level conditions and in order to do so we carried out a repeated measures ANOVA with Group (2) x Attention (2) x Letter Consistency (2) x Photism-Color Congruency (2) as within-item factors. When second or third order interactions were significant, separate ANOVAs were carried out for each group to further study them. Reaction times for each experimental condition can be found in Table VI.

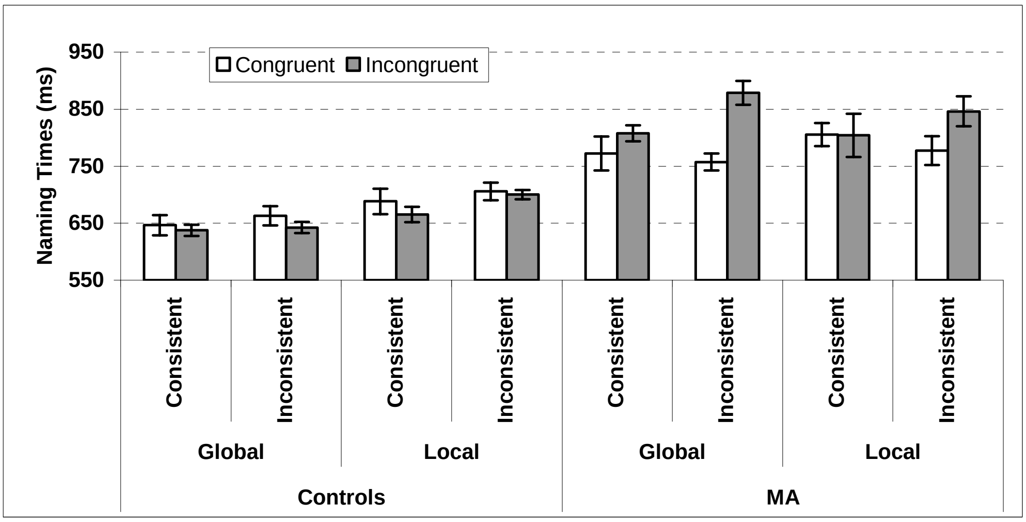
A main effect of Group showed that MA was slower than the control participants ($F_{(1, 7)}$=283.55, p=.001). Also, the effect of Attention was significant in the sense that when participants attended to the global form they were faster than when attending to the local form ($F_{(1, 7)}$=9.12, p=.019). No main effect of Letter Consistency or Photism-Color Congruency was found ($F_{(1, 7)}$=1.5, p=.260 and $F_{(1, 7)}$=1.37, p=.280 respectively).

Table VI. Experiment 5. RT per group and experimental condition.

Attention	Global						Local					
Letter Consistency	Consistent		Inconsistent				Consistent		Inconsistent			
Photism-Color Congruency	Pure Cong G-cong L-cong	Pure Incng G-incng L-incng	Pure Cong G-cong L-cong	Mixed Incng G-cong L-incng	Mixed Incng G-incng L-cong	Pure Incng G-incng L-incng	Pure Cong G-cong L-cong	Pure Incng G-incng L-incng	Pure Cong G-cong L-cong	Mixed Incng G-cong L-incng	Mixed Incng G-incng L-cong	Pure Incng G-incng L-incng
MA	772.33	807.75	757.04	878.06	849.96	878.59	805.37	804.23	777.22	894.40	826.06	846.18
Ctrls	663.51	649.42	691.47	698.46	700.37	657.42	703.46	686.26	719.42	743.78	719.08	703.34

Group x Letter Consistency was not significant either (F<1) so it seemed as though the inconsistency between global and local letter did not affect MA differentially. Nevertheless, Photism-Color Congruency did produce different results for each group in the expected direction ($F_{(1, 7)}$=56.96, p=.001). Responding to congruent trials was faster than responding to incongruent trials, but only for MA, not for the control participants ($F_{(1, 7)}$=8.96, p=.020 vs. F<1). This tells us that MA was processing the photism elicited by the stimulus, in such a way that it interfered with her color naming task.

Photism-Color Congruency was also modulated by Attention ($F_{(1, 7)}$=23.52, p=.002). The congruency effect was much larger when participants had to attend global than local. The second order interaction by group was marginally significant ($F_{(1, 7)}$=4.10, p=.083) and separate ANOVAs for MA and our control group showed that this interaction was due to MA's pattern of responses, which mirrored the general one ($F_{(1, 7)}$=11.66, p=.011). Control participants showed no effect (F<1). While control participants were faster when attending global than local independently of Photism-Color Congruency, MA showed a more complex pattern. The congruency effect was present when attending global (p<.003) but not when attending local (p=.127). This is interesting because the conditions included in this analysis were those where either global and local letter were the same and thus both levels were congruent or incongruent, or global and local letters were different but elicited the same photism, so that were colored either congruently with both letters or incongruently with both letters. Therefore, attending global did not provide with information different from that obtained when attending local. We can then only suggest that when MA is attending local she does not process letter identity to the level of photism activation and therefore obtains no benefit/interference from that information.



Graph 8. Experiment 5. Reaction times for MA and the Control group when responding to pure-level conditions. Error bars denote standard errors of the mean

We also found a significant second order interaction between Group, Letter Consistency and Photism-Color Congruency ($F_{(1, 7)}$=8.26, p=.024). In the separate ANOVA for each group we found no effect for the control participants (F<1) and a significant interaction between Letter Consistency and Photism-Color Congruency for MA ($F_{(1, 7)}$=7.65, p=.028). Graph 8 shows the results found. We predicted a permanent presence of a congruency effect that could be enlarged in those cases where the letter was inconsistent since those are the conditions where color could help or hinder performance. However, what we found was no Photism-Color Congruency effect when letters were consistent (i.e. a “B” made out of “B”s) (F<1). Congruently colored displays were named as fast as incongruently colored displays. When the letter was not consistent, we did find a congruency effect ($F_{(1, 7)}$=27.27, p=.001). Responses to incongruent trials were slower than responses to congruent ones. Again, this pattern of results was unexpected. Photism-Color congruency only affected naming times when the two photism eliciting stimuli were different (i.e. different global and local letter).

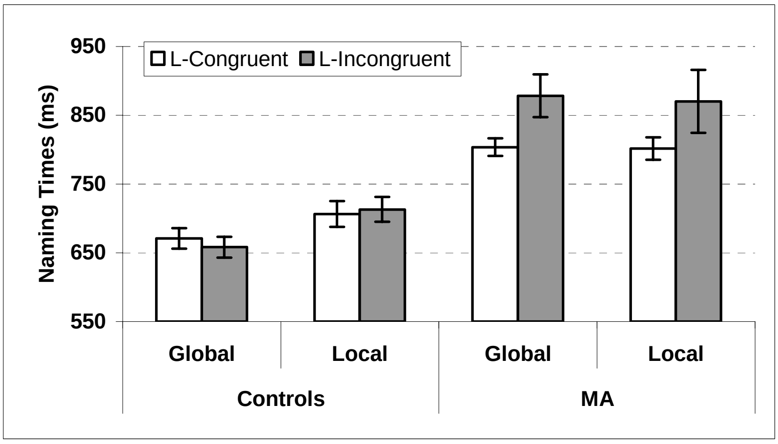
Overall, in this first analysis we found that MA’s Photism-Color Congruency effect was influenced by Attention (only when attending global was the congruency effect found) and by Letter Consistency (only when letters were inconsistent was the congruency effect found). This data might suggest that attending local was more difficult than attending global (as stated by the Global precedence effect) and therefore more resources were devoted to that task and the experience of synesthesia was somewhat diminished. It could also be that the stimuli used in this task were so complex that only when letter identity processing was promoted (i.e. attending to the global form or having an inconsistent stimulus) did MA process it to the extent as to activate the photism associated with it.

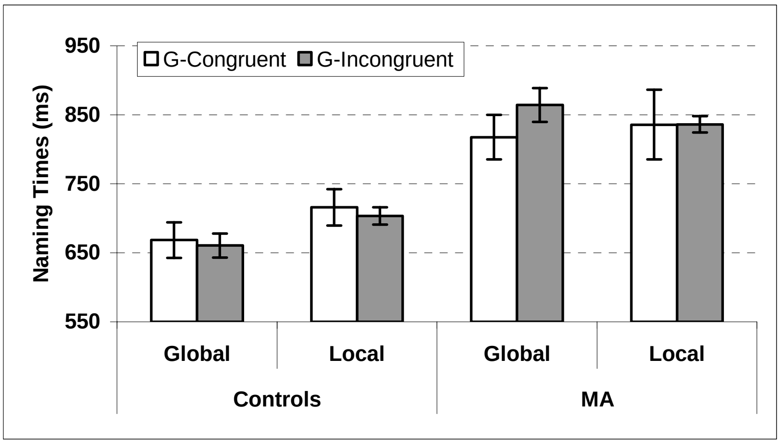
In the second analysis we were interested in the influence of Photism-Color Congruency as a function of the dimension were attention had been allocated. We therefore analyzed those trials were the Photism-Color Congruency was present only at the global level or only at the local level and compared them with those trials were both levels were congruent or both levels were incongruent. As mentioned before, in order to have these Photism-Color Congruency levels, only inconsistent letter conditions could be used for the analysis. The ANOVA had the following factors: Group (MA and Ctrl) x Attention (Local and Global) x Global Photism-Color Congruency (global level congruent and global level incongruent) x Local Photism-Color Congruency (local level congruent and local level incongruent).

Again we found that MA was overall slower to respond than control participants ($F_{(1, 7)}$=178.34, p=.001). Attending global produced faster RTs than attending local ($F_{(1, 7)}$=5.90, p=.046) and this was so for the control group but not for MA (significant Group x Attention interaction, $F_{(1, 7)}$=14.08, p=.007). No main effect of Global Photism-Color Congruency or Local Photism-Color Congruency was found. We expected that these variables would be influenced by Group but it was so only for the Group x Local Photism-Color Congruency interaction ($F_{(1, 7)}$=8.65, p=.022) but not for the Group x Global Photism-Color Congruency ($F_{(1, 7)}$=2.49, p=.158).

A separate ANOVA for each group showed that control participants had no effect of either variable (both Fs<1) while MA had an effect of Local Photism-Color Congruency ($F_{(1, 7)}$=5.98, p=.044) but no effect for the Global Photism-Color Congruency (F<1). Here her pattern of results was not different from that of the control participants: congruent and incongruent trials had similar reaction times. For the Local Photism-Color Congruency she was faster on locally congruent trials than on locally incongruent ones.

We also expected that if attention played a role in synethesia it would modulate the Photism-Color Congruency effect for MA but not for the control participants so that attending global would attenuate the local incongruence and attending local would diminish the global incongruence. None of these two second order interactions were significant (F(1, 7)=1.66, p=.239 for Global Photism-Color Congruency and F(1, 7)=1.07, p=.335 Local Photism-Color Congruency). A subsequent ANOVA for each group showed that for control participants the Local Photism-Color Congruency was not affected by the dimension to which attention was being paid (F(1, 7)=2.91, p=.132, see Graph 9a left side). Likewise, for Global Photism-color Congruency controls did not differ in their naming times as a function of attention (F<1, Graph 9b left side). For MA, the local congruency effect was the same when she was attending local or global form (F<1). As clearly shown in the Graph 9a, attention did not modulate the congruency effect coming from the local dimension. Regarding the congruency in the global dimension, although a congruency effect was seen when attention was paid to the global form and not when attention was paid to the local form (see Graph 9b right side), the Attention x Global Photism-Color Congruency interaction did not reach significance (F(1, 7)=2.47, p=.159)

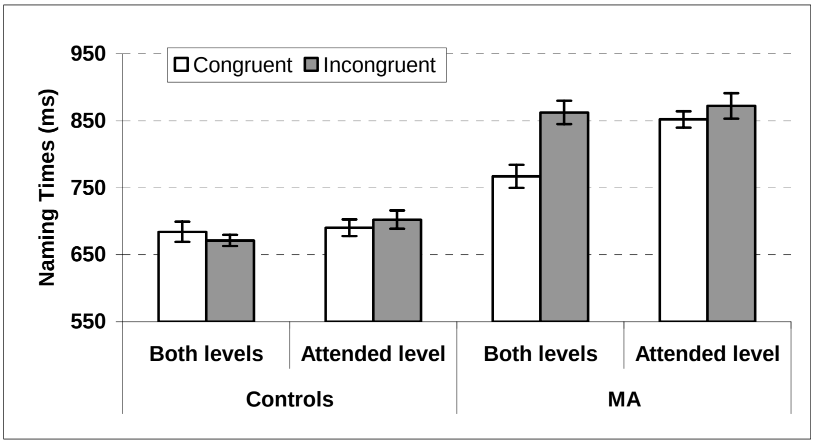




Graph 9a and 9b. Experiment 5. Reaction times for MA and the Control group when responding to inconsistent-letter conditions. a) Conditions where the photism of the local letter was incongruent with the displayed color (collapsed for global letter congruency). b) Conditions where the photism of the global letter was incongruent with the displayed color (collapsed for local letter congruency). Error bars represent standard errors of the mean.

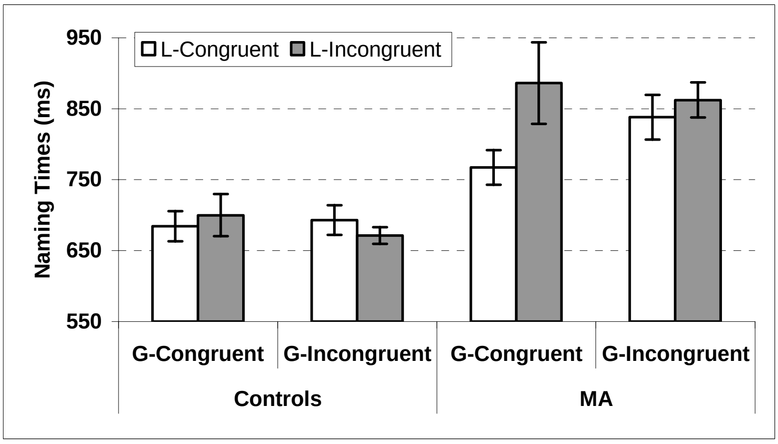
Since the variability of the data was too large to find statistically significant effects, we collapsed Photism-Color Congruency levels as a function of whether attention was being paid to the congruent or the incongruent level. Therefore, attending local levels where the Local Photism-Color Congruency was congruent were collapsed with those trials were the participant had to attend global and the Global Photism-Color Congruency was congruent. The same process was carried out for those conditions where attention was paid to the incongruent level. Last, these 2 resulting conditions were compared to those where either attended and ignored level were congruent or both attended and ignored levels were incongruent. We therefore compared MA and the Control Group for the 4 levels of Attended-Photism-Color Congruency (attended-congruent, attended-incongruent, both levels-congruent and both levels-incongruent).

This new 2 (Group) x 4 (Attended-Photism-Color Congruency) ANOVA showed that the interaction between Group and Congruency was statistically significant ($F_{(1, 7)}$=12.24, p=.001). Control participants were not different independently of the Attention-Congruency condition (all ps>.3). However, MA showed a very different pattern of results. As expected, both levels-congruent trials were faster than any other type of trial (all ps<.001). Nonetheless, as can be seen in Graph 10, an interesting result was found for the remaining 3 conditions. MA was no different when the attended level was incongruent than when both levels were incongruent (p>.9). Even more, those 2 conditions were not different from trials where only the ignored level was incongruent (all ps>.8).



Graph 10. Experiment 5. Reaction times for MA and the Control group as a function of the congruency of the attended level. Error bars denote standard errors of the mean.

This very interesting pattern of results can be interpreted in the light of another significant interaction found in the previous analysis (see Graph 11). An unexpected interaction between Global Photism-Color Congruency and Local Photism-Color Congruency was found (($F_{(1, 7)}$=25.88, p=.001). The congruency effect for each variable was only found on the congruent level of the other variable (i.e. Local Photism-Color Congruency effect was only found when the Global color was congruent and vice versa). Although only marginally significant ($F_{(1, 7)}$=4.14, p=.082), this pattern of results tended to be found in MA and not in control group.



Graph 11. Experiment 5. Reaction times for MA and the Control group as a function of Global and Local Photism-Color Congruency. Error bars denote standard errors of the mean.

A separate analysis confirmed that MA's results followed this pattern ($F_{(1, 7)}$=16.69, p=.005) while control participants did not. This interaction could explain the fact that attending to the congruently colored dimension of a stimulus would not produce faster reaction times than attending to the incongruently colored dimension. It seems as though when one dimension is already incongruent, the fit of the other dimension to the internal expectations is not computed. Stimuli are either right or wrong but not half way through. That is, MA finds no benefit from attending to the congruent level and ignoring the incongruent level.

Almost no errors were made in this experiment, with, many experimental conditions having a 0% error rate. Therefore no statistical analysis of accuracy was carried out.

GENERAL DISCUSSION

The first series of experiments were aimed at studying whether MA's photisms are elicited pre or post attentively. Results from the first four experiments consistently show that MA does not seem to find any benefit from her internally elicited colors when searching for an embedded figure. That is, letter induced photisms do not seem to pop out the same way as real color do in standard perception when searching for an embedded figure. This conclusion is backed up by Experiment 4 where *real* colors were presented and MA showed a fairly different pattern of data. Similar results have been found by other groups when comparing synesthetes' performance in achromatic visual search tasks with controls' performance when shown chromatic stimuli (Hubbard et al., 2005).

Importantly although the photism elicited by a figure when it is made out of "Ws" does not pop out, the photisms induced by the letters do have an influence on MA's search. When searching for a figure made out of "Ms" MA was overall slower and made more errors than controls and her when searching for a figure made out of "Ws". Note that in this condition the target letter shares color with one of the distracters ("N") and shape with the other distracter ("W"). Even more, distracters are dissimilar in this condition, as they induce different photisms. This increased target-distracter similarity and distracter heterogeneity does explain why this condition is the worst for MA (Duncan & Humphreys, 1989). Thus, although photisms are not automatically elicited, at least at low level perceptual levels (they do not pop out), they are automatically elicited in the sense that they seem to be activated in spite of being detrimental to performance. That is, from the visual search experiments we can conclude that photisms do not seem to be easily inhibited, which is in clear agreement with the results from the Stroop-NP experiments (Experiments 2a and 2b in Chapter 1).

Experiment 5 on the other hand, was aimed at studying the influence that selective attention can exert over photisms and their effect on performance. Results from the second analysis show that the congruency effect produced by the perception of a stimulus not colored according to MA's schema is quite strong. Even more, it seems to be independent of the dimension of the stimulus to which attention is being paid. As long as one dimension of the stimulus (either the local or the global form) is incongruently colored MA performs as bad as when both dimensions are wrongly colored. Even more, attending to the incongruently colored dimension and ignoring the congruently colored dimension yields the same results as attending to the congruently colored one and ignoring the incongruently colored one. These results are similar to those found in the Stroop-NP experiment (Lupiáñez & Callejas, 2006) reported in Chapter 1 where the interference produced by photisms on the color naming task was much larger than that produced by the wavelength of the video display on the photism naming task. We then suggested that the emotional response associated to the perception of an incongruently colored stimulus could be a possible explanation of the results found. Here again, MA behaved atypically while performing this task. She reported experiencing a high level of anxiety and discomfort. The emotional state derived from giving answers contrary to what would be natural for her (that is, inhibiting naming the photism in favor of the video color) affects her in a way that prevents normal focusing of attention from working properly. Callejas, Acosta and Lupiáñez (submitted, Chapter 3) have shown that in fact affective reactions can be evoked by the incongruence between external color and internal photism and they can influence behavior.

It could be argued that the attentional manipulation might have not been effective and that is why MA did not show a differential pattern between those trials were she was attending to the congruent dimension and those where she was attending to the incongruent one. An analysis of catch trials showed that MA, as well as control participants, performed the secondary task with a level of accuracy that indexes that instructions were obeyed. Therefore we do have grounds to state that while attention was being paid to one dimension, the incongruence at the ignored dimension was affecting naming times.

Our results from this last experiment are in disagreement with those found by Rich and Mattingley (2003) where they found a modulation of the congruency effect when participants were asked to attend local and the global dimension was incongruently colored. Any of the methodological issues outlined in the introduction could account for these inconsistencies. We lean towards two of them being the most influential ones. On the one hand, they did not have a way to check whether participants were actually following instructions and paying attention to the requested dimension. Note that they limited their analysis to compare a condition where attention was not manipulated, and therefore they did not know how attention was working, with a condition from a separate experiment where they assumed that attention was being paid to the requested dimension. On the other hand, synesthete data was coming from an average of fourteen subjects and it would be extremely improbable that all fourteen showed the pattern reported in their paper.

Taken together, these findings highlight the importance of taking into account individual differences when arriving to conclusions and also the need to study other factors that could be influencing the synesthetes' performance. Ramachandran and Hubbard (2001b) and Smilek and Dixon (2002) pointed out to the difference between higher and lower synesthetes or associator vs. projector synesthetes and later work has shown empirically that this labels do actually represent groups of people that behave differently when confronted with the same task (Dixon et al., 2004). Hubbard et al. (2005) suggests, based on his behavioral and neuroimaging correlations, that there might be even more subcategories of synesthetes. It might be interesting and a good predictor of synesthetes' performance to know the extent to which perceiving a stimulus in the wrong color affects them emotionally. We now turn to study this topic in our synesthetes.

SECTION 2:

SYNESTHESIA AND EMOTION

CHAPTER 3

GREEN LOVE IS UGLY: EMOTIONS ELICITED BY SYNESTHETIC GRAPHEME-COLOR PERCEPTIONS[1]

[1] This chapter has been submitted as a Research Article to Journal of Cognitive Neuroscience being its authors Alicia Callejas, Alberto Acosta and Juan Lupiáñez.

ABSTRACT

Synesthetes experiencing grapheme-color synesthesia often report feeling uneasy when dealing with incongruently colored graphemes, although this issue has not been thoroughly investigated. We experimentally studied these affective reactions related to synesthetic perceptions by means of an evaluation task. We found that the perception of a wrongly colored word affects the judgments of emotional valence. Furthermore, this effect competed with the word's emotional valence in a categorization task: responses were slower (and less accurate) for the inconsistent conditions (i.e. when positive-valence words were presented in a color different from the synesthete's photism -producing a negative affect- or when negative-valence words were presented in the photism's color-producing a positive affect-) as compared to the consistent conditions, thus supporting the automatic nature of these synestheticaly elicited affective reactions. Therefore, the congruency effect that has been taken as an index of the true experience of synesthesia (i.e. faster reaction times to congruently colored words than incongruently colored words) can be reversed when the experimental manipulations turn an incongruently colored word into a more consistent stimulus by aligning the result of the affective reaction produced by the word-color congruence with the valence assessment of such word. This is the first time that an affective reaction elicited by the congruency between the synestheticaly induced color of a word and the color in which the word is actually presented is reported. The underlying neural mechanisms that might be involved in this phenomenon are discussed.

INTRODUCTION

Synesthesia is known as a mixing of the senses in which stimuli from one sensory modality induce experiences proper of a different modality (Beeli, Esslen & Jäncke, 2005; Cytowic, 2002; Dixon, Smilek, Caudahy & Merikle, 2000; Mattingley, Rich, Yelland & Bradshaw, 2001; Robertson, 2001). Thus, taste can be experienced as a shape (Cytowic, 1998), or sounds can are experienced as specific tastes (Beeli, Esslen & Jancke, 2005). The most common form however, involves mixing two features from the same visual modality, i.e., colors (called photisms) subjectively experienced when perceiving non-colored alphanumerical characters (Day, 2005). Different theories have been put forward to account for this unusual phenomenon being one of them the promoter of the idea of a cross-wiring between areas of the brain involved in grapheme form processing and color processing (Ramachandran &

Hubbard, 2001b). Since the path for word processing and color processing seems to be somewhat parallel in terms of neural substrates, depending on where the cross-wiring takes place, different types of grapheme-color synesthesia could be accounted for (Ramachandran & Hubbard, 2001b). These authors suggest that a crosstalk taking place in the fusiform gyrus (where grapheme form is processed as well as color-V8/hV4-), would be the mechanism underlying lower synesthesia -a form of grapheme-color synesthesia that is of a more perceptual nature-. If the crosstalk takes place at higher instances of processing such as the angular gyrus where the next stage in color processing takes place as well as the abstract numerical calculation, then the resulting phenomenon would be what is called higher synesthesia where associations between colors and graphemes seem to be of a more conceptual level (i.e., driven by the ordinal aspect of the graphemes). They have recently provided evidence that hV4 is differentially active in synestehtes but not controls when looking at synesthesia inducing stimuli (i.e. graphemes) (Hubbard, Arman, Ramachandran & Boynton, 2005).

This theory could also account for the fact that a normal individual could experience synesthesia-like phenomena when under the influence of such drugs as LSD if we assume that the cross-activation is due to existing connections that are only active in synesthetes and could become active in normal individuals when taking these substances although these authors favor the idea that these connections are only found in synesthetes and that synesthesia like phenomena experienced when consuming drugs is qualitatively different (Hubbard & Ramachandran, 2005).

A commonly known but poorly studied feature of grapheme-color synesthesia is the experience of emotions associated to the synesthetic event. There is a sense of certitude that somehow conveys the feeling that one's experiences are the right ones (Cytowic, 1993). More specifically, synesthetes experience a positive feeling when they see a consistent stimulus (i.e. a letter colored according to his/her photism for it in grapheme-color synesthesia) and a feeling of discomfort associated to the experience of a mismatch between the physical-external stimuli and the subjective-internal synesthetic perception (i.e. a letter not colored according to his/her photism for it). It has been common in the synesthesia literature to find informal reports about negative emotional reactions associated to the experience of stimuli presented in a color different from their photism. If a synesthete who sees the word "tree" in blue is presented with such word colored in pink, he/she will say "This is wrong!" and this reaction can vary in intensity from a discomfort statement to a fairly strong aversive emotional response.

Even though this affective reaction is easily found among synesthetes, to our knowledge no empirical study has been carried out to test whether it is in fact a measurable and reliable phenomenon that influences synesthetes' behavior. Studies have been undertaken to elucidate the possibility that emotions are the inducer of synesthetic experiences (Ward, 2004) so that only words that have an emotional connotation elicit a synesthetic response. Nevertheless, no study has been carried out on the emotions elicited as side effect of the perception of an incongruently colored stimulus in grapheme-color synesthesia.

As Ramachandran and Hubbard suggest (2001b), the fact that synesthetic perceptions could in turn produce emotional reactions is highly interesting from a neuroscientific viewpoint and also as another piece of evidence in favor of their cross-wiring theory since it is known that information processed in the temporal lobe gets relayed to the amygdala and other parts of the limbic system (Amaral, Prince, Pitanen & Carmichael, 1992; LeDoux, 1992).

Therefore, we wanted to study the nature of these affective reactions. Following the logic established in previous literature to differentiate developmental synesthesia from other experiences such as mere associations or metaphors (Cytowic, 2002; Dixon et al., 2000; Ramachandran & Hubbard, 2001b), our first aim was to determine whether these reactions are just affective memory associations or they are automatically elicited by the perception of an incongruently colored grapheme as photisms themselves are.

In order to do so, we investigated synesthetic perception of emotional words in MA, a Psychology undergraduate student that experiences grapheme-color synesthesia (Lupiáñez & Callejas, 2006). She reports experiencing negative emotions associated to the perception of letters, numbers and words when presented in a color different from her photism for them. She describes her feelings by saying "It is wrong, it's like coming into a room and finding all the chairs upside-down and everything out of place. I can't stand it. It is just wrong". When performing a Stroop experiment to evaluate the automaticity of her synesthesia (i.e., naming the colors of letters and numbers that elicited either the same or different colors as her photisms for them) her discomfort could be overtly perceived (rapid increase of hand perspiration, difficulty to sit still, constant posture readjustments, etc). In this paper we report four experiments where we studied the behavioral influences of these affective reactions.

EXPERIMENTS 1a AND 1b. VALENCE JUDGMENT TASK

Our first aim was to try to reproduce the reported disliking with an indirect behavioral task. Since MA perceives words as clearly and uniformly colored (as opposed to perceiving one color for each letter), we presented her with a set of words and asked her to rate their valence according to their semantic meaning. In order to test the influence of the synesthetic colors, we manipulated the color in which the words were presented so that it would either match (congruent condition) or mismatch (incongruent condition) that of the synesthetic experience. This was compared to an absence of color condition where all the words were presented in black. Informal reports by synesthetes points to black being considered as a neutral color maybe due to the enormous amounts of practice acquired in reading texts in black ink.

METHOD

Participants

Our synesthete MA and a group of 11 control participants took part in this experiment. Participants matched MA for age (22) and gender and they were all students at the Psychology Department at the University of Granada. MA ran the experiment in two different occasions while control participants ran it only once.

Experiment 1a. Evaluation task

Design

Two variables were manipulated in this experiment: word valence and color congruency. To manipulate word valence a set of 72 words were used for the experiment. There was an equal number of neutral words, positive words, anger-related negative words and anxiety-related negative words, being the four groups of words matched in length and subjective familiarity. The words were chosen from a database of words used in previous experiments in our laboratory so that the mean rating for positive words was +2, for neutral words 0 and for negative words (anger related as well as anxiety related) was -2, in a scale going from -3 to +3. Words were presented both in congruent and incongruent color. Congruent colors were those that MA had previously chosen for each word as part of a study to check consistency over time. Incongruent colors were the color-wheel opposites of each chosen color.

Procedure

Randomly ordered words appeared at the centre of the screen one at a time and participants' task was to evaluate the valence of each word without time pressure in a 7-point Likert scale by means of a keyboard and being +3 very positive, 0 neutral and -3 very negative. A white fixation point was presented against a gray background for 500 ms. It consisted on a cross in the middle of the screen and it was accompanied with a reproduction of the responding scale (i.e. the possible rating values from -3 to +3) that was also white and appeared at the bottom of the screen. Following this, the target word was presented replacing the cross and remained on the screen until response. The responding scale was kept in the screen for the full duration of each trial. Stimuli were presented on a 14' monitor connected to a Pentium computer. Presentation of stimuli as well as data recording was carried out using MEL software (Schneider, 1988). A total of 432 trials were run in three blocks of 144 trials each (72 congruent and 72 incongruent).

Experiment 1b. Control task

Design and Procedure

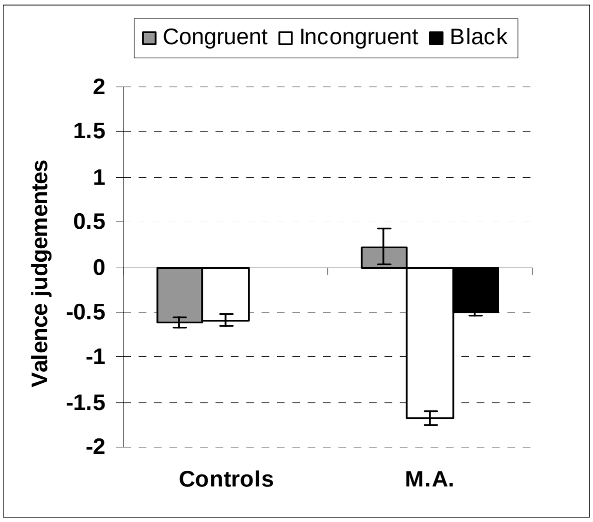
In the baseline black version of the task, the same number of trials was used but this time all the words were presented in black color against a grey background. The procedure used for this experiment was the same as in the previous study. Only MA ran this experiment. Since there was double the amount of trials per experimental condition, the experiment was run only once.

RESULTS AND DISCUSSION

In order to be able to analyze together the data from MA and the control group for the evaluation task, we used items (words), instead of participants, as the random factor in all the analyses. Since MA run the Evaluation task twice in order to have a more consistent estimate, her data from both sessions was averaged after we had checked that the pattern of results was the same for both measurements. The data from the control group was also averaged across participants to arrive at a single score for each item presented.

A mixed 2 x 4 ANOVA was carried out with Group (MA. vs. Control participants) and Congruency (congruent vs. incongruent) as within item factors and Valence (positive, neutral, anxiety related negative and anger related negative words) as between item factor. First, we found that our groups were not different in the overall mean rating of words ($F_{(1, 68)}$=1.29, p=.261). As expected, the effect of word valence was significant ($F_{(3, 68)}$=109.42, p=.001) and the common pattern of ratings for positive, negative and neutral words was found.

However, the most important result was that, as predicted, color congruency modulated emotional rating in MA but not in the control group ($F_{(1, 68)}$=90.27, p=.001). The control group rated words similarly independent of their color congruency (mean rating for congruent=-0.61 vs. mean rating for incongruent=-0.59; F<1)[1]. However, as can be seen in Graph 1, MA's emotional ratings were highly influenced by the congruency between the color and the photism (congruent=0.22 vs. incongruent=-1.68, F(1, 68)= 90.27, p=.001). Furthermore, they were significantly more positive than the Control Group's for the congruent color condition (F(1, 68)= 17.95, p=.001), and more negative for the incongruent color condition (F(1, 68)= 184.70, p=.001).



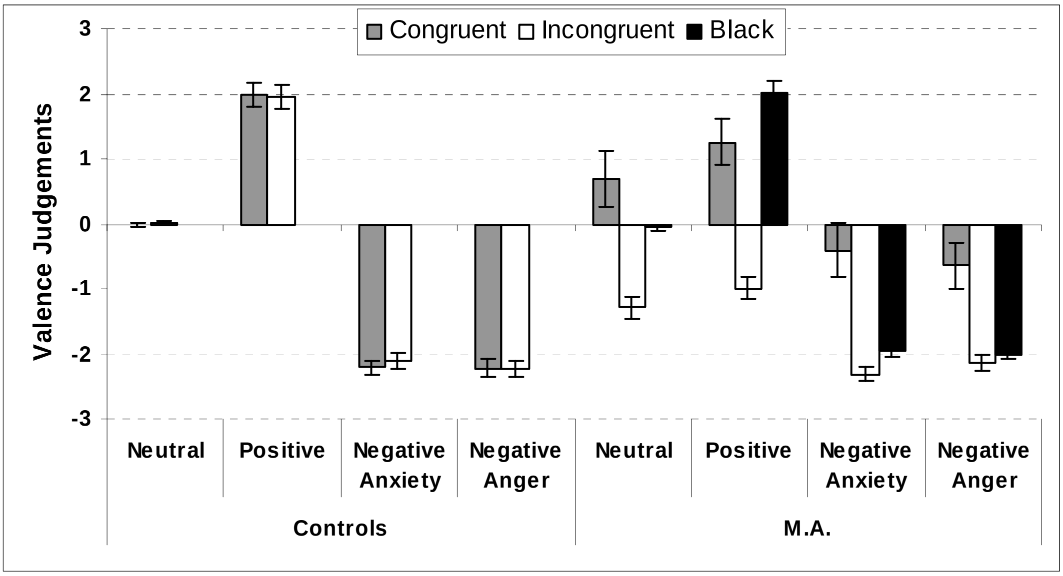
Graph 1. Experiment 1a and 1b. Congruency effect as a function of group. The black bar shows the results of Experiment 1b where all words were presented in black. Error bars denote standard error of the mean.

Interestingly, however, as can be seen in Graph 2, this congruency effect was independent of valence (F<1) Thus, MA seemed to use two sources of information in

[1]Considering the criteria used to select the words was that the average rating would be 2 for positive words, 0 for neutral and -2 for negative words, the expected mean rating would be -0.5 since there was double the amount of negative words than neutral or positive words

order to determine word valence: word meaning and congruency between the presented color and the experienced photism. Needless to say, the same was clearly not true for the control participants.

This congruency effect, which was only observed in MA's ratings, led to other effects. Incongruent color produced a reduced rating for positive words and a more accurate rating for negative words whereas congruent color resulted in an increased rating for negative words and a more accurate rating for positive words. This led to an overall less extreme rating in MA than the control group ($F_{(3, 68)}$=31.66, p=.001) (see Graph 2). It is important to note though, that the main effect of word valence was still significant both for the control group as well as for MA ($F_{(3, 68)}$= 254.86, p=.001 and $F_{(3, 68)}$= 13.31, p=.001 respectively). Therefore, we can conclude that MA, as well as the control participants, were following the instructions that emphasized ignoring the color and concentrating only on the word meaning.



Graph 2. Experiment 1a and 1b. Valence ratings. Mean valence ratings for control group, and MA Error bars represent the standard error of the mean.

Even though the main effect of valence showed that MA's judgments were fitted, in a control experiment we checked that her valence ratings would not differ from those of the control participants when color-photism congruency was controlled. Here we asked her to rate the same set of words but now all of them were presented in black ink. Previous experiments carried out in our lab had shown that in a blocked presentation of black graphemes or words, black was interpreted by MA as a neutral color (i.e. did not produce an affective reaction) whereas the same black stimuli, when mixed within a block of trials with colored words, were interpreted as an incongruent color and thus produced the same pattern of results than incongruent color words.

As expected, now that only one source of information was present (i.e. word meaning), MA's valence ratings did not differ from those of the control participants ($F_{(2, 136)}$= 2.72, p=.069). MA rated black stimuli according to their semantic valence, in a comparable way as control participants rated both congruently and incongruently colored words. As shown in Graph 1, now her mean rating for black stimuli was statistically different from her own rating under color-photism congruency conditions ($F_{(2, 136)}$= 65.10, p=.001). Planned comparisons showed that MA's rating for black stimuli was lower than for congruently colored stimuli ($F_{(1, 68)}$= 14.19, p=.005) and higher than for incongruently colored stimuli ($F_{(1, 68)}$= 220.24, p=.001).

The pattern of results observed in these experiments suggests that, in contrast to control participants, MA seems to use two sources of information to judge emotionality of the words: semantics and synesthetic congruency. The absence of interaction between these two emotionality sources (lack of word valence x color congruency interaction) suggests an independent activation of them. However, if the photism automatically activated an affective reaction, then we would expect it to compete with the word meaning in those conditions where both valences are inconsistent (i.e. congruently colored negative words or incongruently colored positive words). This would in turn raise a competition that would produce an interference effect. To test this hypothesis, we designed a second experiment.

EXPERIMENTS 2a AND 2b. CATEGORIZATION TASK

In these new experiments we tried to reproduce the conditions that would lead to a competition between word meaning and color congruency if the affective reactions associated to inconsistent stimuli are automatically evoked when processing a word. We designed a task that was a modification of the Stroop paradigm (Stroop, 1935). We asked our participants to perform a speeded RT valence-categorization task to test our prediction that if the postulated affective reaction is automatic, under time pressure conditions we should find an interaction between congruency and semantic valence. In a regular Stroop task, the irrelevant dimension of the stimulus is the word meaning whereas the relevant dimension is the color in which the word is presented. Here, the irrelevant dimension was the color in which the word was presented and ultimately the congruency between that color and the photism for that word, which would lead to a positive or negative affective reaction. The relevant dimension was the semantic (emotional) meaning of the word.

In the Stroop literature, the usual finding is to observe a high level of interference when participants are to name the ink color (less practiced task) while avoiding to name the word (a highly practiced task). Therefore we should only expect to find an interference of congruency on MA's valence categorization if processing the emotion elicited by color-photism consistency was as automatic as processing of the semantic meaning of the word.

METHOD

Participants

Again, MA and a different set of 11 non-synesthete undergraduate students run this experiment. They were again matched for age and gender to our synesthete participant.

Experiment 2a. Categorization task.

Design and Procedure

Only the 18 positive and 18 anger-related negative words were used in this experiment. Again all words were presented both in congruent and incongruent color. Twelve blocks of 36 trials were run.

Participants had to categorize the words as being either positive or negative according to their meaning. A speeded response was required by pressing as fast as possible one of two buttons depending on the valence of the word (i.e. positive or negative).

Again, a white fixation point was presented against a gray background and followed by the target word. The word was presented until response was given. Both speed and accuracy were emphasized. Furthermore, a feedback (a tone) was delivered for incorrect responses in order to ensure that the categorization was done according to the meaning of the word, and not depending on the color in which it was displayed. Again, MA run the experiment twice while control participants did it only once.

Thus, the design of this experiment was a 2 (Group; MA vs. Control Group) x 2 (Color-Photism Congruency; congruent vs. incongruent) x 2 (Valence; positive vs. negative). The first two variables were manipulated within items, whereas the last one was manipulated between items.

Experiment 2b. Control task.

Design and Procedure

For the baseline black version of the task, everything was the same as in Experiment 2a except that now all the words were presented always in black color against a grey background. Again only MA ran this experiment, and only once.

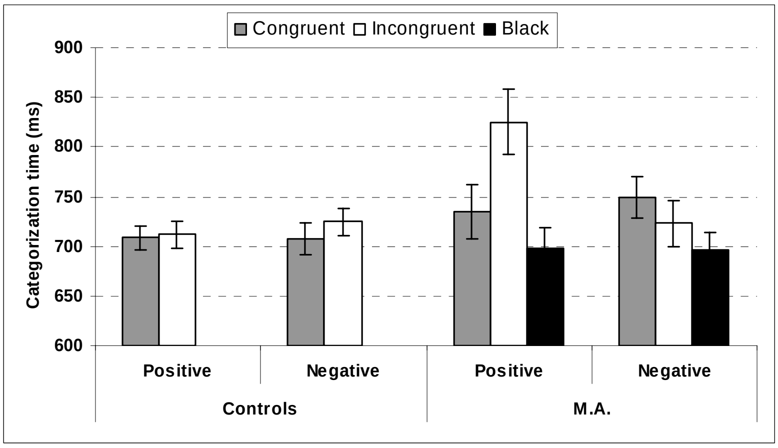
RESULTS AND DISCUSSION

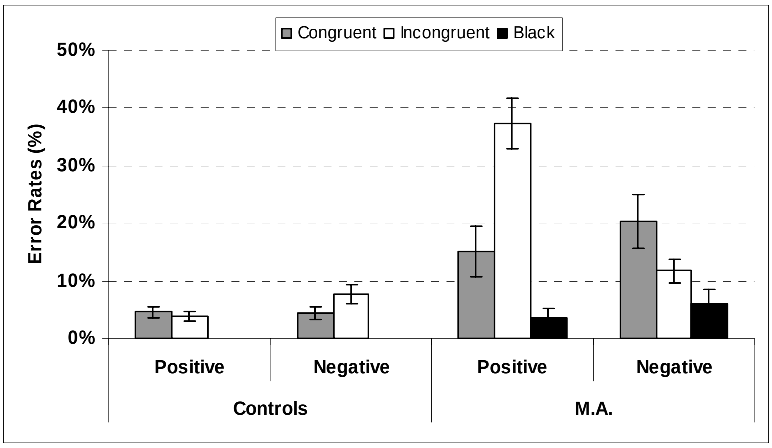
Reaction Time Analysis

Before analyzing the data and once we had checked that MA's pattern was the same in both sessions, we averaged her reaction times across sessions as well as those of the control group across participants. A mixed Group x Valence x Congruency ANOVA was performed on the data using items as the random factor, being the first two variables manipulated within items and the last one between items. Trials with an incorrect response and those with a RT above 2000ms were excluded from the analysis (7.61% and 0.74% respectively). The following results were obtained. A main effect of Group ($F_{(1, 34)}$=11.70, p=.002) informed that MA was around 50ms slower than our control group. This could be due to the fact that, under time pressure conditions, this categorization task was more difficult for her than it was for the control group since she had to ignore, not only the color of the words as control participants had to, but also the correspondence between this color and the photism that has been previously found to be automatically activated by the grapheme (Dixon et al., 2002; Elias, Saucier, Hardie & Sarty, 2003; Mattingley et al., 2001). The participants' subjective reports also supported this idea.

Importantly, the predicted second order interaction between Group, Valence and Congruency was indeed significant ($F_{(1, 34)}$=6.49, p=.016) showing that for control participants, Congruency did not affect Valence ($F_{(1, 34)}$=1.03, p=.317). However, it did so for MA ($F_{(1, 34)}$=5.51, p=.025). As can be observed in Graph 3a, planned comparisons showed that the time taken to categorize positive words was much larger when they were incongruently colored than when they were congruently colored ($F_{(1, 34)}$=6.59, p=.015). Although the pattern of results for negative words was the opposite one, the difference between congruent and incongruent conditions was not reliable (F<1).

We also analyzed the data from the control experiment with black stimuli and found that MA's performance was similar to that of control participants (F<1), whereas it interacted with her own data under color conditions ($F_{(2, 68)}$=3.70, p=.030).





Graph 3. Experiment 2a and 2b. A). Mean reaction time data. B). Mean error rate data. Error bars represent the standard error of the mean.

In order to further analyze the data, we coded a new variable called Correspondence. The crossing of these two variables (i.e., semantic Valence and Color-Photism Congruency), provided us with this third variable. Corresponding trials were those where the evaluation of both variables went in the same direction (i.e. positive-congruently colored words and negative-incongruently colored words). Non-corresponding trials were those where the evaluation of both variables yielded opposite results (i.e. positive-incongruently colored words and negative-congruently colored words).

We performed a new ANOVA with Correspondence and Group as independent variables and found that there was indeed a significant interaction between both variables ($F_{(1, 35)}$=6.55, p=.015). For the control group, the difference between consistent and inconsistent words was not significant ($F_{(1, 35)}$=1, p=.324) whereas for MA we found that inconsistent words were more difficult to categorize, as shown by much longer reaction times (mean RT=787ms), than consistent words (mean RT=729ms), $F_{(1, 35)}$=5.41, p=.026. Therefore, it seems as though color Congruency does have an effect in valence categorization and more specifically, the Correspondence between color Congruency and semantic Valence seems to explain the different pattern of results found in MA and the control participants. Therefore, an incongruently colored word could be easier to categorize if the connotative meaning points in the same direction as the implicit evaluation carried out over the color features of the word. Converging evidence for this idea comes from the analysis of errors.

Accuracy Analysis

The same ANOVA was carried out for the percentage of errors. There was again a main effect of group ($F_{(1, 34)}$=49.72, p=.001). MA was more error prone than our group of control students. Together with the RT data this suggests that in fact the task was more difficult for her than it was for the other participants, as she had to solve the incongruence introduced by the coloring of the words.

Although we found that there was no main effect of Valence ($F_{(1, 34)}$=2.33, p=.136) there was an interaction by group ($F_{(1, 34)}$=6.78, p=.014) in the sense that MA had more trouble categorizing positive words than negative words.

There was a main effect of Congruency ($F_{(1, 34)}$=6.78, p=.014). Congruently colored words were more correctly categorized than incongruently colored words and this was so for MA as well as controls. Nevertheless, the most interesting result was the significant interaction between Valence and Congruency ($F_{(1, 34)}$=19.00, p=.001). Incongruently colored positive words seemed to be more error-prone than any other type of word. Adding to this, and more importantly, the predicted second order Group x Valence x Congruency interaction was also significant ($F_{(1, 34)}$=32.15, p=.001). We then proceeded to separately analyze each group and found that the described pattern of results was only found in MA ($F_{(1, 34)}$=26.08, p=.001). Again, more categorization errors were made for positive words when they were incongruently colored ($F_{(1, 34)}$=27.03, p=.001) and the opposite pattern was found for negative words. Fewer categorization errors were made for incongruently colored negative words than for congruently colored ones ($F_{(1, 34)}$=4.01, p=.052).

Even though there was also a significant interaction between Congruency and Valence for the control participants ($F_{(1, 34)}$=12.40, p=.001), it was just due to the fact that negative words yielded more errors when incongruently colored than when congruently colored (p<.001). As can be seen in Graph 3b, it is worth noting that this pattern of results is the exact opposite to that found in MA where negative words were more difficult to categorize when congruently colored. Moreover, the magnitude of the difference in the control group was much smaller. Although no clear explanation is available for this significant interaction, it could be due to general color associations in non synesthetes.

Regarding the control experiment in which only black colored words were presented to MA (Experiment 2b) we found that her performance was statistically different from that obtained when she responded to congruently and incongruently colored words ($F_{(2, 68)}$= 21.23, p<.001) and not different from the control group (F<1), so again we see how the additional information coming from the color Congruency can account for the differences seen between MA and the control participants.

Finally we re-coded the variables and analyzed the percentage of errors as a function of Correspondence and Group. Once again, there was an interaction between Correspondence and Group ($F_{(1, 35)}$= 30.02, p=.001). A deeper analysis showed a large correspondence effect for MA in the same direction as that found for RT: non-corresponding words were more difficult to categorize (mean error=29%) than corresponding ones (mean error=13%) ($F_{(1, 35)}$= 23.27, p=.001). For control participants we also found an effect, although again it was in the opposite direction and of a much smaller magnitude (i.e. more errors for corresponding words than non-corresponding words ($F_{(1, 35)}$= 11.03, p=.002) (see Graph 3b).

The results from these new experiments point in the direction of an automatic activation of the synesthetic valence of words. As can be seen in Graph 3a and 3b, MA's reaction time and error percentage raise considerably in the non-corresponding conditions, especially in the positive-incongruent one. Given that feedback was provided after each trial, this pattern of data suggests that MA was making a considerable control effort to respond correctly, but the synesthetic valence (particularly the incongruence) exerted an influence to the extent that the correct response could not be controlled at the proper levels. In a standard Stroop experiment, word meaning is taken as the automatic dimension and color naming as the intentional one. The subject has to name the color and inhibit the response associated to the potent activation that comes from the automatic processing of the denotative meaning of the word. Here, the intentional response is the connotative meaning of the word, a dimension that uncountable experiments have demonstrated to be automatically processed (Catena, Fuentes & Tudela, 2002). Moreover, the criterion to select the words was based on previous experiments to ensure they were clearly positive or negative. Still, the affect produced by the incongruence of the color in which the word is presented overcomes that activation of the word meaning and influences the final response. Previous studies carried out in our lab have shown that this interference from the affective component of a word in a categorization task is unusual even when the subjects are trait-anxious patients.

GENERAL DISCUSSION

In these series of experiments we have shown for the first time to our knowledge, that a) emotion is part of the set of subjective experiences known as synesthesia and b) its effects on behavior may be as clear and robust as those produced by the concurrent (i.e. the photism) itself.

In Experiment 1 we showed that color Congruency does influence emotionality ratings in parallel with word Valence. MA's ratings were accurate in the sense that she rated words according to their meaning as control participants did. But she was also influenced by the color in which the word was presented since congruently colored words were rated more positive than incongruently colored words. If color Congruency does have an effect on word Valence and it is of an automatic nature, we would predict that it would affect performance under conditions where a fast response is requested and no time is available for control mechanisms to completely inhibit the information coming from this irrelevant dimension of the stimulus.

Experiment 2 was designed to test this hypothesis and we found that in fact, when time pressure was introduced, Color-Photism Congruency affected performance in a very interesting way. By presenting words with semantic valence colored either congruently or incongruently with the synesthete's set of photisms, we have shown the presence of a bias causing participants to respond faster when there is a consistency between the 2 dimensions of the presented stimulus (i.e. Valence and Congruence). That is, synesthetes might be faster responding to an incongruently colored word than to a congruently colored one depending on the semantic meaning of it.

Previous studies have shown that the perception of the photism associated to a particular word is highly automatic (Dixon et al., 2000; Lupiáñez & Callejas, 2006). Affective priming studies have also shown participants' ability to automatically extract connotative meaning of words even when they do not have to be consciously evaluated (Fazio, Sanbonmatsu, Powell & Kardes, 1986). Putting this together, only if the affective reaction associated to the match-mismatch between a word's photism and the presented color happens automatically would one expect the affective reaction to interact with the automatic evaluation of the words' connotation. And only if that affective reaction was strong enough, would it influence such an automatic processing of words. Moreover, only if this affective reaction is sufficiently strong, would the control mechanisms fail to suppress it in order to give an accurate categorization of the words based on their connotative meaning. It seems then that assessing the fit between the environment and the subjective experiences known as synesthesia, as well as the affective reaction associated with such evaluation, is a strong and highly automatic side effect of at least grapheme-color synesthesia[1]. Also, in a study carried out in our lab in which the task at hand was an abstract/concrete categorization of these same words, that is, a task that is orthogonal to the affective processing of the words meaning, we found the same pattern of results where incongruently negative words and congruently colored positive words are categorized faster than congruent-negative and incongruent-positive ones. It seems then as if synaesthetes automatically evaluate whether the external physical words fit their internal coloring schema. This evaluation seems to happen even when it is not relevant to the task at hand.

From this perspective, the next step in the study of emotions as a side effect of synesthesia would be to discern the mechanisms underlying such processes and whether they are shared by non-synesthetes. Previous studies have pointed to the restrosplenial cortex as a structure that could be interesting to study (Ward, 2004). This structure has been related to the processing of familiar people as opposed to unfamiliar people and also to the processing of emotional words as compared to neutral words

[1] Although not reported here, several other synesthetes have been tested and show the same pattern of response times for the categorization task.

(Maddock, 1999 for a review). Also, this area appears to be active in different studies of brain activation and synesthesia (Nunn et al., 1999, Weiss et al., 2001). Although this area has also been related to memory, a recent study showed that, controlled for memory variables, this area was found active when categorizing words according to their valence (Maddock, Garrett & Buonocore, 2003). Knowing when these evaluative processes take place could be taken as an index of the processing stage where subjective colors (photisms) are bound to the percept and consciously experienced.

As previously mentioned, information that arrives to V1 by means of the retina is then relayed to V2, V4 and temporal areas and it is then that it travels to the amygdala (Amaral et al., 1992). Posterior cingulate cortex-retrosplenial cortex does not have direct connections to the amygdala but it does connect to other frontal regions also related to emotional evaluation such as the anterior cingulate cortex. It also receives input from the orbital and dorsolateral prefrontal cortex, parahippocampal cortex, superior tempral sulcus, precuneus, claustrum and anterior and lateral thalamic nuclei (Goldman-Rakic, Selemon & Schwartz, 1984; Van Hoesen, Morecraft & Vogt, 1993). The question then would be whether higher synesthetes, whose proposed locus for cross-activation is higher up in the visual processing, next to the angular gyrus, would show the same pattern of responses as lower synesthetes whose proposed locus of cross-activation would be localized around hV4 (Ramachandran & Hubbard, 2001b).

A recent study points to the possibility that some linguistic features of words, such as their emotional valence, might be processed very early in time (Ortigue et al., 2004). These authors found ERP differences at around 150ms for emotional words compared to neutral words when the task at hand was discriminating words from non-words. Other electrophysiological studies suggest that the information about the meaning of the word can be accessed almost as the same time as information about its form (Pulvermüller, 2001). It could be the case that emotional words also had a special representation and could be accessed faster than equal frequency neutral words. If so, we could then predict that the effect of incongruently colored words would be present only in those cases where photisms were bound to graphemes prior to graphemes' emotional assessment (i.e. only for projector-lower synesthetes; Dixon, Smilek & Merikle, 2004; Ramachandran & Hubbard, 2001b). If the information is sent before the photism is added to the phenomenological experience or if no photism information is sent (i.e. as in the case of non-synesthetes) the outcome of the evaluation would be the usual one. However, if words' meaning is not accessed so early in the processing, it might be the case that by the time word's information is relayed to the emotional centers for its evaluation, it has already been dressed with its corresponding photism by all synesthetes independent of the stage at which the cross-activation is occurring. If the object of evaluation includes the information about the photism, then the evaluative process will have to deal with the semantics of the word itself, the inconsistencies between the 2 pieces of color information and the relationship between these two features of the stimulus being assessed. We believe that MA, as well as the other synesthetes tested, is a higher-associator synesthete. However, informal observations point to the possibility that lower-projector synesthetes also show emotional reactions associated to the perception of incongruently colored stimuli. More investigation needs to be carried out on the dynamics of this affective reaction to clarify the specific characteristics of the synesthetes showing it and the temporal course of the stimulus processing when congruent and incongruently colored.

CHAPTER 4

ARE ALL SYNESTHETES CREATED EQUAL? GENERALIZATIONS OF SYNESTHETICALLY INDUCED AFFECTIVE REACTIONS

ABSTRACT

We have previously found that the perception of an incongruently colored stimulus such as a word gives rise to an affective reaction that in turn influences emotional rating performance in our synesthete MA. Here we try to replicate those findings in a sample of three other synesthetes to check whether the results previously found were due to idiosyncrasies of our synesthete. A categorization task where emotional words were presented in either the congruent color or an incongruent one was administered to our three synesthetes. Results show that the previously found pattern was replicated in tow of the three synesthetes. A subsequent set of experiments were performed to check whether the synesthesia in the synesthetes not showing the effect was too weak as to affect performance. Results informed that strength of synesthesia for word and some personality traits could be driving the absence of congruency effect.

INTRODUCTION

It now seems to be an accepted statement that not all synesthetes are equal and not all of them experience their synesthesia in the same manner (Dixon, Smilek & Merikle, 2004; Dixon & Smilek, 2005; Hubbard, Arman, Ramachandran & Boynton, 2005; Hubbard & Ramachandran, 2005; Ramachandran and Hubbard, 2001b; Smilek & Dixon, 2002). However, there are still some researchers that do not acknowledge this difference or argument that our knowledge about synesthesia is still far away from a time when clear factors affecting one synesthetes and not other can be identified and tested (Edquist, Rich, Brinkman & Mattingley, 2006; Mattingley, Payne & Rich, 2006).

Dixon et al. (2004) tested a group of synesthetes on a Stroop color naming task and a Stroop photism naming task and found that the pattern of results for what they call “projectors” was reliably different from the pattern found for the “associators”. Most important, the groups had been defined a priori based on the subjective reports of the synesthetes tested about the peculiarities of their synesthetic experiences. Also, Hubbard et al. (2005) found that the extent to which hV4 was activated in synesthetes correlated with their performance in behavioral tasks used to evaluate synesthesia. They also found that 2 distinct groups could be differentiated based upon both, the behavioral performance and the brain activation level.

Nevertheless, the specific determinants of the different types of synesthesia are yet to be enunciated. Although some synesthetes readily volunteer that they experience colors “out there in space” or “in their mind’s eye”, there are still some other synesthetes that do not fit into these categories and explain their synesthesia as “neither of the previous two”. Whether this means that the higher/associator-lower/projector classification is not complete or that it is focusing on the wrong features of the experienced phenomena is yet to be discovered. What seems to be clear is that independently of the features that describe each subgroup of grapheme-color synesthesia, synesthetes are a heterogeneous group and that fact has to be taken into account in order to make scientific progress.

A quite common but virtually unstudied feature of grapheme-color synesthesia is the emotionality attached to the synesthesia experience itself. When a stimulus’ color matches the photism that a synesthete experiences for it, a positive sensation is felt. On the other hand, if the color does not match the internal experience a discomforting sensation is felt. This side-effect of grapheme color synesthesia was first empirically reported by Callejas, Acosta & Lupiáñez (submitted, Chapter 3). A congruency effect was found so that congruently colored words (i.e. same color as the synesthete’s reported photism for the word) were categorized faster than incongruently colored words. However, this was only found for positive words and an absence of congruency effect or a reversal was found when the stimulus eliciting a color was a negative valence word. The authors proposed that synaesthetes automatically evaluate whether the external physical words fit their internal coloring schema and this would happen even when it is not relevant to the task at hand. Therefore external coloring of the words being either congruent or incongruent with their internal coloring schema led to positive or negative affective reactions, which interfered with the evaluation of the emotional meaning of the words.

The study presented here had two goals. On the one hand we wanted to test whether the affective reactions found in our synesthete MA when viewing stimuli colored incongruently with her photisms (Callejas et al., submitted, Chapter 3) are common to other synesthetes. On the other hand we wanted to check whether differences would be found amongst synesthetes in this respect.

The fact that a wide number of synesthetes that communicated with us as well as with other labs have reported feeling discomfort when watching a stimulus wrongly colored gave us a relative certitude that the results previously found would be replicated with other synesthetes. However, it could also be the case that some idiosyncratic features of MA's perception or personality were making that discomfort to be reflected in her behavioral performance. Therefore we conducted the present set of experiments to test these synesthetically elicited affective reactions in other synesthetes different from MA.

EXPERIMENT 1a AND 1b. EFFECT OF PHOTISM-COLOR CONGRUENCY IN A CATEGORIZATION TASK.

We first tried to replicate the findings of Callejas et al.'s Experiment 2a and 2b on a set of 3 different synesthetes. In the original study, a set of positive and negative emotionally charged words were presented in congruent and incongruent color (Experiment 2a) or in black color (Experiment 2b) and the participants had to categorize them as positive or negative according to their semantic connotation, while ignoring the color itself. What they found was that Photism-Color Congruency interacted with word Valence so that corresponding conditions (positive-congruently colored and negative-incongruently colored) were faster and more accurately responded to than non-corresponding conditions (positive-incongruently colored and negative-congruently colored). When words where presented in black, however, the pattern of results mirrored that of control participants. We run these same experiments in three other synesthetes that also experienced colors for words and we compared their subjective reports with the objective performance.

METHOD

Participants

Three synesthetes and three groups of control participants performed these two experiments.

EL is a grapheme-color synesthete that was 16 years of age at the time of testing. She consistently perceives colors for letters, numbers and words as a whole. She also experiences other types of synesthesia. She experiences colors in her mind's eye. Prior to testing she reported not caring much whether the words were *correctly* or incorrectly colored.

PR is a grapheme-color synesthete that was 52 at the time of testing. As the previous synesthetes, she also experiences color in her mind's eye for letters, numbers and words as a whole. She reported disliking incongruently colored words.

Both EL and PR are Canadian and native English speakers. They were contacted by means of the Waterloo Synesthesia Research Centre's database and tested at the University of Waterloo, Canada.

PSV is a native Spanish synesthete. She is 29 and among other types of synesthesia, she experiences colors for numbers, some letters and words, in her mind's eye. She is a Fine Arts graduate student and as such, she has a very fine grained ability to discriminate and classify colors. She reports a strong displeasure when seeing something "incorrectly" colored. She explains it as something similar to the sensation felt when watching something disgusting that automatically drives oneself to fixate at a different object or location.

The control participants for each group were native speakers of the same language as the synesthete they were paired with. Six English speaking participants run EL's and PR's experiments. Nine Spanish speaking controls run PSV's experiments.

Stimuli and material

A set of 18 positive words and 18 negative words were selected for EL and PR from the ANEW (Bradley & Lang, 1999) taking into account Word Frequency, mean Valence and strength of the photism experienced for them. Both Frequency and Valence values were drawn from the ANEW. Word mean frequency was 44 (SD 50). Frequency was not significantly different between EL and PR, neither between positive and negative words (both Fs<1). Word mean valence for positive words was 8.2 for EL as well as PR. For negative words it was 1.8 again for both of them (ANEW min: 1.25; max: 8.82). Therefore words were clearly positive or clearly negative. Last, the subjective strength of photism perception measured in a 7 point scale (1: very faint; 7: very vivid) was, for EL: 7 for positive words and 6.3 for negative words, and for PR: 6.5 for positive words and 5 for negative words.

For PSV out of the 72 words used in the Callejas et al. study, a set of 26 were selected so that neither of them elicited a black or a grey photism. A total of 13 positive words and 13 negative words were selected. Words were equated in subjective familiarity (4.6 in both cases), with a mean emotional rating of -3.8 for negative words and 3.5 for positive words as measured by previous studies in control participants in a 10 point Likert scale (from -5 to +5). PSV also rated the vividness of her photisms in a 7 point scale. For positive words it was 5 and for negative words it was 6.4.

Words were presented on a neutral grey background screen to ensure good visibility of all different colors.

Programming of the experiments, stimulus presentation and data collection were carried out on a 14'' screen controlled by a Pentium computer running e-prime (Schneider, Eschman & Zuccolotto, 2002)

Design and Procedure

Four variables were present in Experiment 1a. Valence had two levels (positive and negative words) and Congruence had two levels (congruent and incongruent color). A variable Group was coded with two levels: synesthete and control. Last, since three different synesthetes were tested along with their corresponding control group, a new variable termed Case was coded with three levels: EL, PR and PSV or EL's, PR's and PSV's control group.

Congruent color was the color chosen by each synesthete for each word. Incongruent color was the color-wheel opposite to the congruent one. For each synesthete and its corresponding control group a total of 8 trials per word and coloring condition were presented. Therefore EL and PR run 576 trials each (4 blocks of 144 trials each) and PSV run 416 (8 blocks of 56 trials each). Before the experimental trials a set of practice trials were given to familiarize synesthetes and controls with the task. Participants were encouraged to rest between blocks.

In Experiment 1b all words were presented in black ink and therefore only Valence was manipulated. Only synesthetes run this experiment. Again 8 trials per word were presented (4 blocks of 72 trials each for EL and PR and 4 blocks of 52 trials for PSV).

Each trial began with a fixation point, which was presented for 1000ms and followed by the target word, which replaced the fixation point. Participants had to hit one of two keys (i.e. "z" and "m") depending on whether the word was positive or negative. Auditory feedback was given when an incorrect response was emitted. All synesthete participants run Experiment 1a first and Experiment 1b after a short break.

RESULTS AND DISCUSSION

Trials with incorrect responses were eliminated from all the RT analyses. In Experiment 1a these accounted for 5.3% and 4.2% (EL and her control group respectively); 1.7% and 1.7% (PR and her control group respectively) and 1.7% and 6.6% (PSV and her control group respectively). For Experiment 1b 1.7% was excluded for EL, 2% for PR and 0.5% for PSV. Since participants' reaction times were somewhat variable, a 2 standard deviation cut off criteria was set to eliminate extreme values. Items (words) and not participants were used as random factor in the statistical analysis. Therefore, for each word and group, reaction times and error percentage were averaged -across participants and trials- for each control group and -across trials only- for each synesthete for each experimental condition (word valence and congruence type). Since the words used for each synesthete and control group were different, Case along with Valence was analyzed as a between items variable. Group and Congruence were considered within item variables.

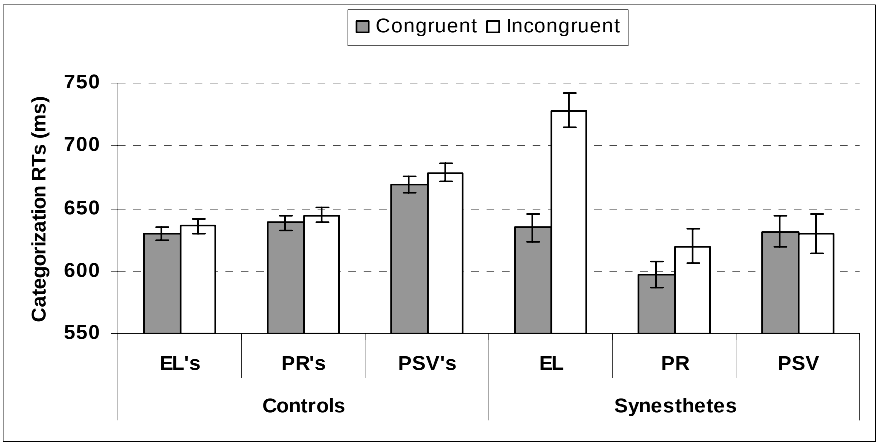
Experiment 1a. Reaction time analysis

A mixed ANOVA was carried out with Group (synesthete and control), Case (EL, PR and PSV or EL's, PR's and PSV's control group), Valence (positive and negative words) and Congruence (congruently and incongruently colored words). Mean reaction time and percentage correct per condition and group can be found in Table I.

Table I. Experiments 1a and 1b. Mean categorization RT per group, subject and condition. Error percentages are shown in parenthesis.

		Group							
		Synesthetes				Controls			
Valence	Congruence	EL	PR	PSV	Total	EL's	PR's	PSV's	Total
Positive	Congruent	607.2 (3.5%)	573.2 (2.1%)	640.5 (2.9%)	607.0 (2.8%)	637.67 (3.5%)	646.5 (2.4%)	658.3 (7.9%)	647.5 (5.2%)
	Incongruent	607.2 (9.0%)	623.4 (2.1%)	645.0 (1.0%)	625.2 (4.0%)	641.1 (3.1%)	646.9 (2.8%)	662.1 (6.6%)	650.1 (4.7%)
	Black	558.6 (2.8%)	626.4 (0.7%)	622.1 (0.0%)	602.4 (1.2%)				
Negative	Congruent	661.44 (5.6%)	620.90 (1.4%)	622.77 (2.9%)	635.0 (3.3%)	621.4 (3.1%)	630.5 (1.4%)	680.3 (6.4%)	644.1 (3.7%)
	Incongruent	735.2 (3.5%)	616.2 (1.4%	615.1 (0.0%)	655.5 (1.6%)	630.4 (4.9%)	642.1 (3.1%)	695.0 (5.7%)	655.9 (4.6%)
	Black	565.6 (2.8%)	623.8 (1.4%)	607.7 (1.0%)	599.0 (1.7%)				

Positive words on average were categorized as fast as Negative words (F<1). Synesthetes as a group where not faster than controls ($F_{(1, 92)}$=2.09, p=.152). However, a significant Group x Case interaction showed that this was due to EL ($F_{(2, 92)}$=22.89, p=.001) being slower than the other synesthetes (both ps<.05) and slower than her control group (p=.015) while the other two synesthetes were as fast as their respective control groups. Last, as expected, there was a congruency effect ($F_{(1,\ 92)}$=20.36, p=.001) modulated by Group ($F_{(1,\ 92)}$=10.13, p=.002). As shown in Graph 1, the congruency effect was found for the synesthetes ($F_{(1,\ 92)}$=17.84, p=.001) but not for the controls ($F_{(1,\ 92)}$=3.12, p=.080), although they showed a trend in the same direction. Congruently colored words were responded to faster than incongruently colored words.

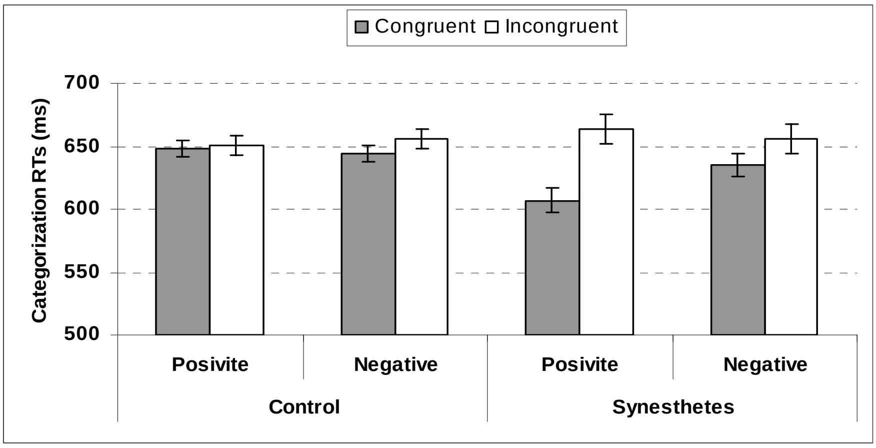


Graph 1. Experiment 1a. Reaction times for each Group and Case as a function of Congruence.

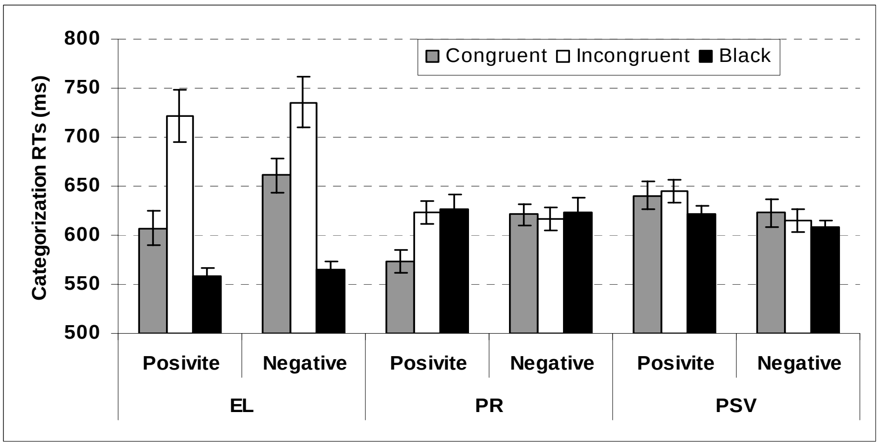
The second order interaction by Case was also reliable ($F_{(2,\ 92)}$=9.08, p=.001). A separate ANOVA for each Group showed that the three cases of control participants performed in a similar manner (F<1). Synesthetes on the other hand showed different susceptibility to the Congruence effect ($F_{(2,\ 92)}$=10.14, p=.001). While planned comparisons informed that EL showed faster reaction times for congruently colored words ($F_{(1,\ 92)}$=40.26, p=.001), PR showed a Congruence effect although it was not statistically reliable ($F_{(1,\ 92)}$=2.34, p=.129) and PSV did not even show nominal differences (F<1). Last, the second order interaction between Congruence, Valence and Group was also significant ($F_{(1,\ 92)}$=5.30, p=.023, see Graph 2).

A separate ANOVA for each group showed that, as expected, Controls did not have a significant interaction between Congruence and Valence (F(1, 92)=1.30, p=.257) whereas Synesthetes did ($F_{(1,\ 92)}$=3.91, p=.051). As shown by planned comparisons there was a congruency effect for positive words ($F_{(1,\ 92)}$=19.22, p=.001) and no effect for negative ones ($F_{(1,\ 92)}$=2.53, p=.115). Last, the Congruence x Valence interaction was not different for the three groups of controls (F<1) nor was it for the three synesthetes (F<1). However, a separate analysis for each synesthete (see Graph 3) showed that the interaction between Congruence and Valence was only present in

PR ($F_{(1, 34)}$=10.46, p=.003) but not in EL or PSV (both Fs<1). PR showed a congruency effect for positive words ($F_{(1, 34)}$=17.46, p=.001) and a nominally inversed congruency effect for negative words (although not statistically reliable, F<1). Planned comparisons showed that, although the interaction was not reliable for EL, the magnitude of the Congruence effect was larger for positive words than for negative words ($F_{(1, 34)}$=13.65, p=.001 and $F_{(1, 34)}$=5.66, p=.023 respectively)



Graph 2. Experiment 1a and 1b. Reaction times for each Group as a function of Valence and Congruence.



Graph 3. Experiment 1a and 1b. Reaction times for each synesthete as a function of Valence and Congruence.

Results from a previous rating experiment (similar to Experiment 1a in Callejas et al., submitted, Chapter 3) are consistent with this categorization data. Participants were asked to rate how positive or negative the same set of words was on a 7 point Likert scale. Contrary to MA's experiment, here a speeded response was required. A Congruence effect was found for EL and PR and this effect interacted with word Valence. Congruently colored words were given more accurate ratings than incongruently colored ones and this effect was maximal for positive words. PSV showed no difference as a function of Congruence.

Experiment 1b. Reaction time analysis

In order to check whether a blocked presentation of black words was also a neutral condition for these three synesthetes we compared each synesthete's performance on the black version of the task to their own performance under color conditions and also to the performance of their respective control groups. Results on the black version can be seen in Graph 3 and in Table I.

For EL we found that when congruent, incongruent and black were consider as three levels of a Congruence variable, she showed an effect ($F_{(2, 68)}$=42.68, p=.001) consisting on slower times for incongruently colored words than congruently colored ones (p=.001) and slower times in congruently colored words than in black colored words (p=.001). When we compared her performance under black conditions with that of her control group we found a significant effect ($F_{(2, 68)}$=58.88, p=.001); she was faster than controls (both ps<001).

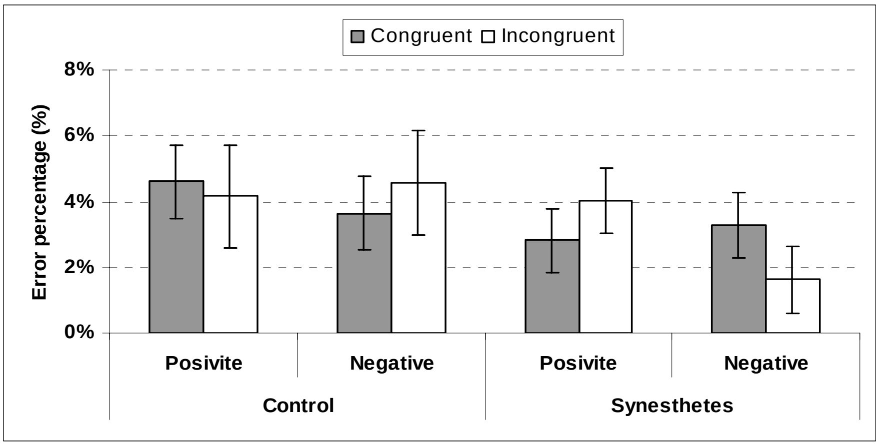
For PR we found again an effect of Congruence ($F_{(2, 68)}$=4.48, p=.015) and post hoc comparisons showed it was due to the fact that congruently colored words tended to be faster than incongruently colored ones (p=.65) and faster than black ones (p=.017). Black words were not different from incongruent ones (p=.855). When black performance was compared to the results of her control group we found no differences ($F_{(2, 68)}$=1.94, p=.152).

Last, for PSV there was no significant difference between congruent, incongruent or black colored words ($F_{(2, 48)}$=2.37, p=.104). Again, since black showed the same RT pattern than congruent and incongruent colored words, it was also statistically different than the performance of her control group ($F_{(2, 48)}$=35.40, p=.001). While controls' performance for congruent and incongruent colors were not different (p=.498), both were slower than PSV's performance for black words (both ps<001).

It is interesting to see how black words do not behave in the same manner for all three synesthetes. While EL seems to be faster for black words than in any other condition, PR shows the same performance for black words as for incongruently colored words. PSV did not show a congruence effect and so the expected absence of difference between black and colored words was found. PR's results could either mean that black is not taken as a neutral shade and it thus resembles the RTs obtained for the incongruent condition or that she does not have an effect of incongruence but a large benefit for congruently colored positive words. Given her overall pattern of results and that of her control group, it seems as though she is just obtaining a benefit for congruently colored positive words as compared to any other condition.

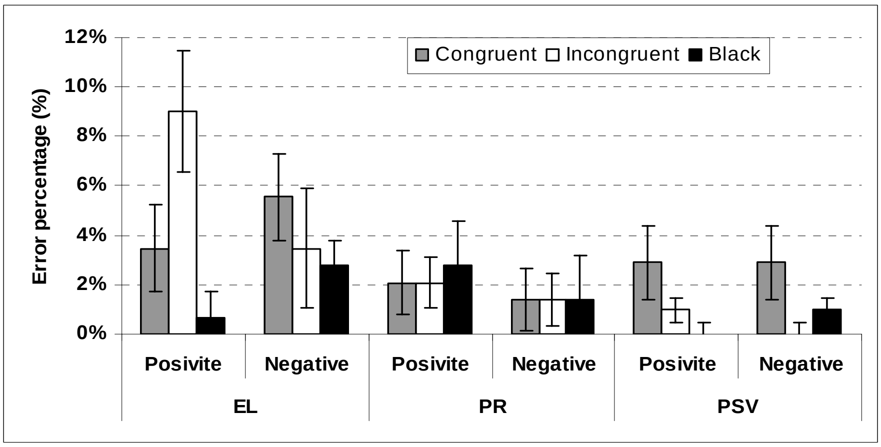
Experiment 1a. Accuracy analysis

The same ANOVA was carried out on the error percentage for each group. Mean error rates per group and experimental condition can be seen in Table I. No main effect of Valence showed that positive words were as easy to categorize as negative words (F<1). Synesthetes as a group were more accurate than control participants ($F_{(1, 92)}$=4.70, p=.033). In fact a significant Group by Case interaction ($F_{(2, 92)}$=9.74, p=.001) showed that PSV's control group was less accurate than her (p=.036). Congruent words were categorized as accurately as incongruent ones (F<1). See Graph 4.



Graph 4. Experiment 1a. Error percentage for each Group as a function of Valence and Congruence.

Only the expected Group x Congruence x Valence second order interaction was significant ($F_{(1, 92)}$=6.06, p=.016,). Separate ANOVAS for the synesthetes group and the controls group showed a marginally significant interaction for the synesthetes F(1, 92)=3.51, p=.064 and no effect for the controls ($F_{(1, 92)}$=1.37, p=.244). Synesthetes were more accurate for incongruently colored negative words and congruently colored positive words (see Graph 4). Last, the third order interaction approaching significance ($F_{(2, 92)}$=2.71, p=.070) showed that the Congruence x Valence x Group interaction tended to be different for each Case.



Graph 5. Experiment 1a. Percentage correct for each synesthete case as a function of Valence and Congruence.

The separate ANOVA for each Group showed a lack of Case x Valence x Congruence interaction for the controls group (F<1) and a trend towards an interaction for the synesthetes group ($F_{(2,\ 92)}$=2.70, p=.073). As shown in Graph 5, PR showed nominally equal error rates for congruently and incongruently colored words. Planned comparisons informed that PSV also showed no congruency effect for either positive or negative words (F<1 and $F_{(1,\ 92)}$=1.93, p=.167 respectively). Last, the pattern found for EL was a replica of that found for the synesthete group as a whole. It was also the same one found in previous experiments with MA (Callejas et al., submitted, Chapter 3). She showed improved performance for corresponding conditions (i.e. congruently colored positive words and incongruently colored negative words) as compared to non-corresponding conditions although only the effect for positive words was significant ($F_{(1,\ 92)}$=9.93, p=.003 for positive words and $F_{(1,\ 92)}$=1.40, p=.240 for negative words).

Experiment 1b. Accuracy analysis

Again synesthetes' performance for black words was compared to their own performance under color conditions and to that of their corresponding control group. Error percentages for the black condition are also depicted in Graph 5.

EL showed again the biggest differences between Congruence conditions ($F_{(2,\ 68)}$=4.68, p=.012). Black words were the most accurate ones and incongruently colored words the more error prone and this difference was reliable (p=.010). Her performance under black coloring conditions was not different from that of her control group ($F_{(2,\ 68)}$=2.05, p=.136). PR showed no difference between Congruence conditions (F<1). Black coloring did not influence response accuracy differently than congruent or incongruent colors. When compared with her control group no differences were found either (F<1). Last, PSV showed no difference as a function of color ($F_{(2, 48)}$=2.11, p=.132). When compared with her control group we found she was different ($F_{(2, 48)}$=27.96, p=.001) because she was more accurate than they were.

Several interesting facts rise from this data. First, the synesthete group data as a whole replicates previous findings (Callejas et al, submitted, Chapter 3). A significant modulation of Congruence by word Valence was found for the synesthetes group and not for controls group in RT data as well as in accuracy data. This result supports the idea that the modulation of Congruence by Valence found in MA was not due to idiosyncrasies but to a real phenomena that can be found in other synesthetes.

However, it is also important to note that not all synesthetes as individuals showed that pattern. A priori we had two reports of disliking wrongly colored words and one report of indifference. PR reported not liking wrongly colored items. PSV was much stronger in her statement. She equated it with something so unpleasant as to drive gaze away from it. Last, EL showed indifference about coloring conditions although it is important to point out that after running the experiments she did report having found wrongly colored words quite unpleasant to work with. Therefore, although all of them informed disliking “wrongly colored words” in different degrees, behavioral data only backs up the statements of EL and PR. While EL showed a modulation of congruency for both RT and accuracy measures, PR only showed it for RT data. Surprisingly, PSV did not even show a congruency effect in the first place. This will be discussed in more detailed in a later section.

The fact that the modulation of Congruence by Valence was found in these two synesthetes has an additional importance since they were native speakers of a different language than MA and therefore the effect cannot be attributed to any specific feature of Spanish language or the words used. It is also interesting to see that the most consistent result is a decrease of the congruency effect for negative words but rarely does the effect reverse (i.e. faster or more accurate reaction times for incongruently colored negative words). This reversal was found in MA but not in these two synesthetes. Since all these synesthetes reported perceiving colors in their mind’s eye, the documented difference between projectors and associators (Dixon et al., 2004) cannot be the factor accounting for these different patterns of results. Other yet unidentified features of the synesthetes, their perceptions or the stimuli used may account for these differences.

What seems clear is that, although the general pattern found for synesthetes as a group does replicate previous results, not going further in the analysis would lead to erroneous conclusions since some synesthetes showed the Valence modulation of Congruence and some others did not even show a Congruence effect. Mattingley & Rich (2004) also reported that the variability of their data for a large group of synesthetes in a synesthetic Stroop task was considerably high and while some synesthetes showed a 200ms effect, others did not show a congruency effect at all. In fact, some participants even showed a reversal Stroop effect whereby when they had to name the color in which a stimulus was presented and such color was different from the photism elicited by the presented stimulus they were faster than when the color matched the elicited photism. They propose that relative strength of the synesthetic color and not a difference between associators and projectors might be the underlying reason for such variability in results. PSV's subjective ratings for the vividness of her synesthetic experience were no different from those of EL. However, these ratings only ensure that each synesthete's experience is maximized but not that it is equated across synesthetes. It could well be that PSV's experiences are in general fainter than those of EL and PR.

Since we had not found a congruency effect for PSV in this valence categorization task, we decided to carry out a standard synesthetic Stroop task and a modified synesthetic Stroop task with her just as we did for MA (Lupiáñez & Callejas, 2006, Chapter 1) to test whether her lack of effect was due to a general lack of interference between photisms and real colors.

EXPERIMENTS 2a AND 2b. TEST OF THE STRENGTH OF PSV's SYNESTHETIC EXPERIENCES: STROOP INTERFERENCE WITH A COLOR NAMING AND A PHOTISM NAMING TASK

We used a standard Stroop (Stroop, 1935) task in which participants had to name the color of a letter or number presented on the screen. The identity of the letter was manipulated so that it would elicit the same color presented or a different one. For the modified Stroop task we showed the very same stimuli but now asked our participant to name the photism elicited by the letter and to ignore the displayed color. If her absence of congruency effect was due to very weak experience of her photisms, we would expect an absence of standard Stroop effect for her because the experience of photisms was not strong enough as to affect her color naming times and we would also expect to find a strong congruency effect in the photism naming version since the real color would interfere to a greater extent. Alternatively, if photisms were vividly experienced, we would expect to find a large Stroop interference effect in the color naming task and a smaller interference effect in the photism naming task.

In this task we also measured negative priming as the influence of a previously ignored color on the current response to test whether PSV was able to inhibit information that would interfere with the task being performed.

METHOD

Participants

PSV and the same set of Psychology Undergraduate Students that served as control group for the valence categorization task performed the experiments. Obviously, control participants only performed the color naming task (Experiment 2a) while PSV performed both color naming and photism naming tasks.

Stimuli and material

A set of eight letters and numbers were selected so that they elicited one of four different colors. Colors chosen were black, white, red and yellow. Each stimulus appeared in either a congruent or incongruent color. Congruent colors were those picked by PSV for each stimulus. Incongruent colors were the other three remaining colors. The target stimulus subtended .76º vertical and .54º-.86º horizontal.

Programming of the experiments, stimulus presentation and data collection were carried out on a 17” screen controlled by a Pentium computer running e-prime (Schneider et al., 2002). This was the only difference with Lupiáñez & Callejas, 2006, Chapter 1) since they programmed the task using MEL (Schneider, 1988). Naming times were collected by means of a voice key and response accuracy was coded with the keyboard.

Design and Procedure

The design of the experiment was the same as in Lupiáñez & Callejas (2006, Chapter 1). Since each letter appeared in each one of the four colors, there were 25% congruent trials and 75% incongruent trials.

In each trial a black fixation point appeared on a dark grey screen for 500ms and was followed by the target stimulus. The target was present until a vocal response was given. After accuracy was manually coded the next trial began.

Five blocks of 48 trials were run for each experiment (a total of 240 trials). There were 60 congruent trials and 180 incongruent trials. As in Lupiañez & Callejas, (2006, Chapter 1), since the order of the trials was pseudo-randomly assigned so that neither the same color nor the same elicited photism would appear in two consecutive trials, the number of control and ignored repetition trials varied for each participant.

PSV run each experiment in three different times in different testing sessions (counterbalanced) while control participants run Experiment 2a only once.

RESULTS AND DISCUSSION

Reaction time analysis. Experiment 2a: Color naming.

Color naming times for each condition and for each item were averaged across participants for the control group and across sessions for PSV. Therefore items and not subjects were used as random factor.

The first trial of each block was eliminated from analysis. Incorrect responses as well as trials were the voice key was triggered by stimulus other than the vocal response were also eliminated (3.8% and 1.4% respectively for PSV and 2.9% and 1.1% respectively for the control group). Responses faster than 200 ms and slower than 1500 were also eliminated (1% for PSV and 2% for controls). Mean naming times and percentage correct for each condition can be seen in Table II.

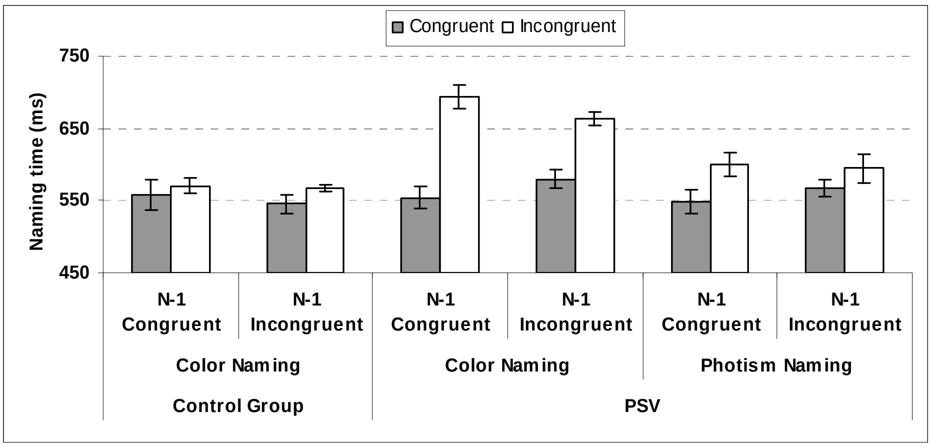
Stroop analysis.

A mixed ANOVA was performed on the mean reaction times with the factors Group (PSV vs. Controls), N-1 Congruence (N-1 congruent vs N-1 incongruent) and N Congruence (N congruent vs. N incongruent). A main effect of group showed that PSV was slower to respond than her control participants ($F_{(1, 7)}$=112.57, p=.001). N-1 Congruence did not affect RTs (F<1) but N-Congruence did ($F_{(1, 7)}$=30.71, p=.001). Congruent trials were responded to faster than incongruent ones. This pattern was due to PSV's performance (significant N-Congruence by Group interaction, $F_{(1, 7)}$=18.50, p=.004). She showed a large congruency effect (113ms, $F_{(1, 7)}$=42.04, p=.001) while control participants did not ($F_{(1, 7)}$=1.39, p=.277). The second order interaction was marginally significant ($F_{(1, 7)}$=4.55, p=.070). Inspection of the data showed that the PSV showed a modulation of N-Congruency by N-1 Congruency while participants did not. This was not surprising given that control participants did not show an N Congruence effect to start with.

Table II. Experiment 2a (color naming) and 2b (photism naming). Mean naming times per condition for each group and experiment. Error rates are shown in parenthesis.

	N-1 Congruent		N-1 Incongruent		
	N-Congruent	N-Incongruent	N-Congruent	N-Incongruent	N-Incongruent
Group	Control	Control	Control	Control	Ignored repetition
PSV	553.78	694.39	579.84	663.66	657.29
Color-naming	(1.4%)	(2.5%)	(1.5%)	(7.8%)	(6.2%)
PSV	548.69	600.24	566.97	594.37	602.72
Photism-naming	(1.8%)	(6.5%)	(0.0%)	(7.0%)	(2.2%)
Control group	556.68	570.10	544.93	566.27	557.18
Color-naming	(3.8%)	(4.4%)	(2.6%)	(5.1%)	(3.8%)

A separate ANOVA for each group confirmed that for controls there was no effect of N-Congruence or interaction with N-1 Congruence (F<1). The same analysis showed for PSV that her N-Congruence effect was modulated by N-1 Congruence ($F_{(1, 7)}$=15.27, p=.001). As can be seen in Graph 6, her congruency effect was larger when the previous trial was congruent than when the previous trial was incongruent (141ms vs. 84ms).

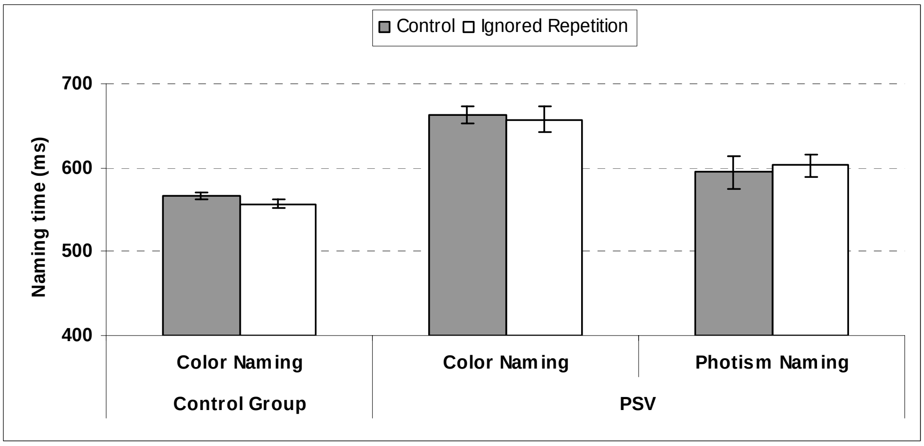


Graph 6. Experiment 2a and 2b. Stroop effect. Reaction times for PSV for the Color Naming and Photism Naming version of the Stroop task and reaction times for her Control group for the Color Naming version.

These results are clear evidence that PSV does show a congruency effect in the standard synesthetic Stroop task and this effect is quite large considering she reports experiencing colors in her mind's eye. Her performance suffers from a clear interference when the color she perceives does not match the internally experienced one. It is also interesting to see that her online control mechanisms, although able to reduce the interference, are not capable to eliminate it.

Negative Priming analysis.

To further test her ability to suppress distracting information we analyzed the NP trials. As we did in our previous work (Lupiáñez and Callejas, 2006, Chapter 1), since ignored repetition trials were always incongruent and also preceded by an incongruent trial, to have a suitable condition to compare the results with, only incongruent trials preceded by incongruent trials were selected for the control condition. A mixed ANOVA with the factors Group (PSV and Controls) and NP (Control vs. Ignored Repetition) was carried out on the reaction time data. Means for these conditions can also be found in Table II and in Graph 7. Again PSV was slower than the control group ($F(1, 7)=63.10$, $p=.001$). No significant NP effect was found ($F(1, 7)=1.3$, $p=.286$) and no modulation by group ($F<1$).



Graph 7. Experiment 2a and 2b. Negative Priming effect. Reaction times for PSV for the Color Naming and Photism Naming tasks and Color Naming for her Control.

Reaction time analysis. Experiment 2b: Photism naming.

Again items were used as random factor. After eliminating the first trial of each block, a further 2.5% was eliminated due to incorrect triggering of the voice key and

1.4% due to errors. A further 1% of trials with extreme values (lower than 200ms and higher than 1500ms) were also eliminated from the analysis.

Stroop analysis.

First a repeated measures ANOVA for PSV was carried out with N-1 Congruence and N-Congruence as factors. A subsequent analysis comparing PSV's performance across experiments was carried out. The first analysis showed a congruency effect of about 40 ms ($F_{(1, 7)}$=15.78, p=.005). This effect was not significantly modulated by the congruency of the previous trial ($F_{(1, 7)}$=2.30, p=.173), although there was a trend in the same direction as in the color naming task. Results are represented in Graph 6 and Table II.

In order to carry out the second analysis a new variable was coded: Experiment (Color naming vs. Photism naming). We then conducted another repeated measures ANOVA with the factors Experiment, N-1 Congruence and N-Congruence. A main effect of Experiment showed that PSV was faster naming the photism than naming the display color ($F_{(1, 7)}$=20.55, p=.003). The N-Congruence effect was also different across experiments ($F_{(1, 7)}$=11.51, p=.012). The congruency effect was much smaller for the photism naming task and this was so because incongruent trials were responded to faster than in the color naming task (p=.026). Last, N-1 Congruence also modulated N-Congruence ($F_{(1, 7)}$=12.11, p=.010), and this modulation did not depend on the task (Experiment). When the previous trial had been incongruent, the current trial showed a smaller congruency effect due to slower RTs for congruent trials and faster RTs for incongruent trials.

Negative Priming Analysis

Again we first analyzed PSV for the photism naming task and we then proceeded to compare her performance on both tasks. The NP ANOVA showed no effect of NP (F<1). The analysis comparing PSV's NP conditions for both experiments had two factors: Experiment and NP condition. Again only the main effect of Experiment was significant ($F_{(1, 7)}$=12.77, p=.009) showing that PSV was faster to name the photism of a stimulus than the actual color in which it was presented. NP as well as its modulation by Experiment were not significant (both Fs<1).

Accuracy analysis.

Performance was kept very high across Groups and Experiments. Some conditions showed perfect performance and thus no variance. Therefore, no statistical analysis was carried out. Percentage correct for each Group and Experimental condition can be seen in Table II.

We wanted to test whether PSV's synesthesia was not vivid enough as to produce a congruency effect and whether that was the reason for her not to show any effect in the emotional task performed in Experiment 1a. Results in the Stroop-NP task show that PSV's performance does get affected by the match-mismatch between the presented color and the experienced photism. Even more, as it happens with MA (Lupiáñez & Callejas, 2006, Chapter 1), the interference produced by an incongruent photism, when having to name the ink color, is reliably larger than the interference produced by an incongruent ink color when having to name the photism. That is, her patterns of results most resemble that of the projectors shown by Dixon et al. (2004).

It is also interesting to see that PSV is slower than her control group when naming the ink color. However, if we compare her overall reaction times across experiments with controls we find that she is not slower than controls when her task is to name photisms (p=.679). She is as fast as controls to name something that is not being perceived through her senses but slower than them when having to name the color that is presented in the screen and visually processed. This also shows that her experience is quite strong. In fact, she informed several times during the different testing sessions that she liked the photism naming task more and that she found it easier to perform than the color naming task. Last, the lack of NP effect shows that PSV does not succeed in inhibiting the distracting information enough as to make it less accessible for the next trial.

Results show that PSV does strongly experience photisms and this experience is sufficiently strong and automatic as to cause an interference with the task to be performed. Since lack of Stroop interference cannot be put forward to explain her lack of congruency effect in Experiment 1a we though of a different reason. In the valence categorization task the dimension of the stimulus she is responding to (emotional meaning of the words) is orthogonal to the Congruence manipulation (matching between the presented color and elicited photisms); this could be a factor to explore. In

Experiment 1a she did not have to respond with a color name but with a valence category. Thus she was able to inhibit the irrelevant information and focus on the required task. In the Stroop task, since the dimension to be ignored shares a response code with the dimension to be attended to, the interference (i.e. congruency effect) occurs.

Alternatively, it could be either that since words are more complex stimuli than letters or numbers, it is easier for PSV to ignore their coloring, or that words elicit weaker photisms that letters or numbers. Any of these reasons could explain why PSV does not show a congruency effect in the emotional categorization task with words, whereas she shows a strong Stroop effect with letters and numbers. Therefore, if color processing was somehow promoted by the task, we might be able to find some modulation of color-photism congruency on the emotionality processing of the words or vice versa. To test this idea we designed a new experiment in which we presented the same words but now asked her to categorize not the valence of the word, but the accuracy of their coloring (according to her internal coloring for the words, i.e., her photisms). The rationale was as follows. Access to word meaning has been shown to be highly automatic (Mari-Beffa, Fuentes, Catena, Houghton, 2000) and therefore regardless of whether the response is associated to the meaning or not, it is going to be processed. However, it might be the case that photisms can be easily ignored when the task is more demanding and they are not pertinent to it. Now, if this is the case, when processing of the photism is promoted we would expect it to interact with the semantic connotation of the word and thus show the typical inversed congruency effect for negative words. In order to test this hypothesis we conducted Experiment 3.

EXPERIMENT 3. CATEGORIZATION OF COLOR ACCURACY

We designed this experiment to test the hypothesis that photisms elicited by words (not only those elicited by letters and numbers) do influence PSV's performance when they are processed, and furthermore, that this influence is modulated by the valence of the stimulus being processed. In this new task the same set of emotional words and some additional neutral filler words were presented in both congruent and incongruent colors (according to the elicited photisms). We asked PSV to discriminate whether the words were correctly colored or not. Therefore now the color was the attended dimension of the stimulus and the connotation (the valence of the emotional words) the ignored one. We also asked MA to run this experiment to compare her performance with that of PSV. Since MA did show a behavioral effect due to her affective reaction when faced with incongruently colored words being color not a relevant dimension of the stimulus, we expected her to also show the same congruency effect here.

METHOD

Participants

PSV and MA run this experiment.

Stimuli and material

The same set of 26 emotional words used for PSV's Experiment 1 was used here. An additional set of 13 filler neutral words were also introduced to divert attention from word valence.

A set of 30 emotional words previously used in MA's experiments were used here. None of them elicited a black or grey color. An additional set of 15 neutral words were also introduced to diver attention from word valence.

Since words were chosen so that they did not elicit either black or grey photism, MA's and PSV's word sets were somewhat different.

Design and Procedure

Experiment 3 was very similar to PSV's Experiment 1 (this chapter) and MA's categorization experiments. The variables being manipulated were the Valence (Positive, Neutral and Negative) of the word and the Congruence between the presented color and induced photism. Therefore a new level of the Valence variable was added. Again, congruent colors were those chosen by each synesthete for each word and incongruent colors were the color-wheel opposites.

PSV run 8 blocks of 78 trials each (39 congruently colored words and 39 incongruently colored words). MA run 4 blocks of 90 trials each (45 congruently colored ones and 45 incongruently colored ones). She run the experiment twice.

At the beginning of each trial a white fixation point appeared on a grey background for 1000ms. It was then followed by the target word that was kept on the screen until subject's response. Synesthetes were to respond by hitting the "z" or the “m” key in the keyboard, depending on whether the word was correctly or incorrectly colored. After response the next trial began.

Auditory feedback was given for wrong responses. The experiment was run in a dimly lit room.

RESULTS AND DISCUSSION

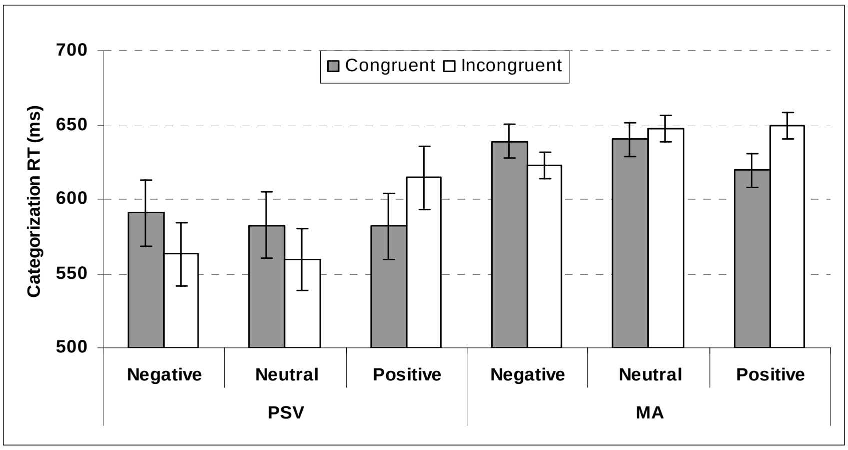
Reaction time analysis.

Data per Synesthete and experimental condition can be seen in Table III. Trials were averaged for each item (i.e. word) and items were used as random factor. For MA, trials were averaged across sessions. Incorrect responses were eliminated from analysis. These accounted for 1% of PSV’s data and 5% of MA’s data. A further 2 standard deviation filter was used to eliminate extreme values. A mixed 2 (Synesthete) x 3 (Valence) x 2 (Congruence) ANOVA was performed. Since words presented to PSV were not the same as those presented to MA, Synesthete was a between item variable as well as Valence, whereas congruency was a within items variable.

Table III. Experiment 3. Mean categorization times per synesthete and condition. Error rates are shown in parenthesis

	Valence					
	Positive		Negative		Neutral	
Subject	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
PSV	582.0 (1.0%)	614.4 (0.0%)	590.8 (0.0%)	563.0 (0.5%)	582.6 (1.0%)	559.5 (1.9%)
MA	619.6 (5.0%)	649.7 (8.3%)	638.9 (6.8%)	623.0 (0.9%)	640.4 (3.3%)	647.6 (2.5%)

Reaction times did not change as a function of Valence (F<1) or Congruence (F<1) but they were different for PSV and MA ($F_{(1, 78)}$=44.96, p=.001). MA was slower than PSV. A modulation of Congruence by Valence was found ($F_{(2, 78)}$=4.40, p=.015). As shown by planned comparisons (see Graph 8), the color of a positive word was categorized faster if it was congruent ($F_{(1, 78)}$=5.67, p=.019) and the color of a negative word was categorized faster if it was incongruent although this was not statistically reliable ($F_{(1, 78)}$=2.77, p=.100). For neutral words no differences were found between congruent and incongruent trials (F<1). This pattern was not different for PSV and MA (F<1).



Graph 8. Experiment 3. Reaction times for PSV and MA as a function of word Valence and Color Congruence.

Accuracy analysis. Experiment 3a

A mixed 2 (Group) x 3 (Valence) x 2 (Congruence) ANOVA was carried out on the error rates and we found that MA was more error prone than PSV ($F_{(1, 78)}$=10.23, p=.002). Other than that, no differences were found for Valence, Congruence or the interaction although the pattern of errors for MA resembled that of the RT analysis.

Experiment 3 shows that PSV's performance does not differ from that of MA when the processing of the color in which the words are presented is enhanced. In this case, she does find it easier to categorize positive words when they are colored right and negative words when they are colored wrong. We therefore interpret PSV's results as showing that when the affective reaction produced by the perception of a colored word goes in the same direction as the valence of the word itself, she finds it easier to respond than in the non-corresponding conditions. Her subjective reports confirming it is unpleasant to look at words when wrongly colored points to the possibility that the affective reaction is always present even though it might not always show up behaviorally.

An alternative explanation, however, to the pattern of results observed for both PSV and MA could be that they are faster when the response-valence mapping is consistent (i.e. Yes-Positive or No-Negative) than in those cases when the required response is "yes" but the word valence is negative or when the response is "no" but the word valence is positive. This effect could be a general one and thus not related to the emotion elicited by the color-photism congruence. In order to test this hypothesis we conducted the following control experiment. Since non-synesthetes could not perform this task, as the coloring of the words does not carry additional meaning for them (i.e. there is no photism to compare with) we designed a modified version in which control participants also had to discriminate whether the same words were correctly colored, although based on an arbitrary criterion.

EXPERIMENT 4. CONTROL EXPERIMENT FOR EXPERIMENT 3

Word color for synesthetes is not determined by word connotation but neither is it by each letter's color. It is usually, at least in our synesthetes, the word as a whole or a competition between some of the letters in the word that are reported to cause the specific color and not other. Therefore, in order to promote the same type of processing for controls, we chose a criterion for them to judge when a word was colored *right* or *wrong* that ensured they would access their semantic meaning while not having to pay attention to the word's connotation. Participants were instructed that abstract words should be colored in *cold colors* (i.e. blue and purple hues) while concrete words should be colored in *warm colors* (i.e. red and orange hues). Their task was to respond whether the words presented were colored right or wrong according to that criterion. Therefore, although apart from the concretness dimension these words also had a connotative meaning, that was irrelevant to the task at hand just as it was in Experiment 3.

METHOD

Participants

A group of 14 control participants run Experiment 4. Control participants were Psychology undergraduate students. Their mean age was 21 and all but one were females.

Stimuli, material, design and procedure

Experiment 4 was as Experiment 3 for PSV except for the colors in which the words were presented and the instructions given to participants.

Five hues ranging from pure blue to violet color were used as cold colors and another five hues ranging from pure red to pure yellow were used as warm colors.

Colors were assigned to words in a random order and some colors were more common than others (each color was used from 4 to 11 times in each block) in order to make sure the variety and frequency of colors was as similar as possible to that of the synesthetes' experiments. Each word maintained its assigned "congruent" and "incongruent" color across blocks. Therefore, in this experiment Congruence referred to the relationship between the word's concreteness and the color in which it was presented given the coloring criteria put forward. Then a congruent trial would be the one where participants had to respond "yes" whereas incongruent trials would be those were participants had to respond "no".

RESULTS AND DISCUSSION

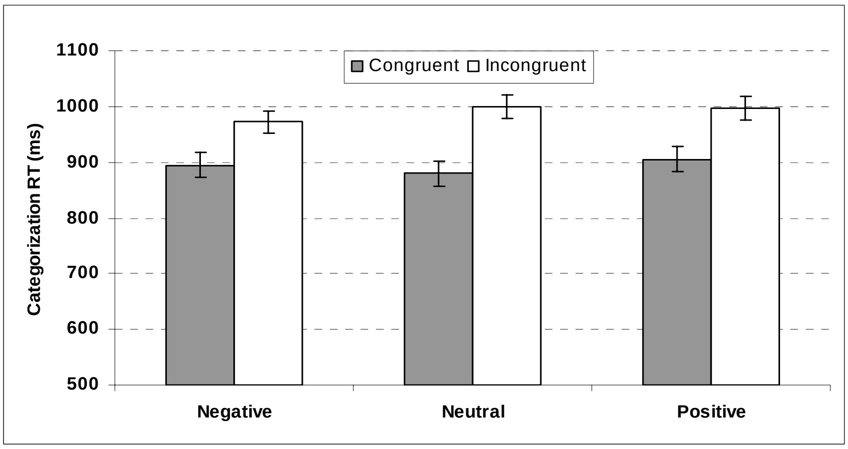
Reaction time analysis.

The same analysis was carried out for control participants. Therefore trials were averaged for each item (i.e. word) and items were used as random factor. Since this task resulted much more difficult for controls than the task synesthetes were performing we only analyzed the last 2 blocks to ensure a good amount of practice and therefore that our results would not be due to the novelty and difficulty of the task. Incorrect responses (12%) were eliminated from analysis. A further 2 standard deviation filter was used to eliminate extreme values. A mixed 3 (Valence) x 2 (Congruence) ANOVA was performed. Mean reaction times can be seen in Table IV and Graph 9.

Table IV. Experiment 4. Mean categorization times per condition. Error rates shown in parenthesis

Valence					
Positive		Negative		Neutral	
Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
905.3 (7.1%)	996.3 (13.2%)	894.5 (8.2%)	971.9 (7.1%)	880.4 (14.8%)	1000.5 (19.0%)

Words' reaction time did not vary as a function of Valence (F<1) but it did as a function of Congruence ($F_{(1, 36)}$=29.58, p=.001). As shown in Graph 9, congruent words were responded to faster than incongruent words. That is, saying "yes" was faster than saying "no", a general finding in most tasks. However this Congruence effect was not modulated by the Valence of the word (F<1), so saying "yes" when the word was positive was not faster than when the word was negative. Similarly, saying "no" when the word was negative was not faster than when it was positive.



Graph 9. Experiment 4. Reaction times for the Control group as a function of word Valence and Color Congruence.

Accuracy analysis.

The mixed 3 (Valence) x 2 (Congruence) ANOVA yielded the following results. Responding to positive and negative words was more accurate than responding to neutral ones ($F_{(2, 36)}$=11.11, p=.001) and responding to congruent words was marginally more accurate than to incongruent ones ($F_{(1, 36)}$=4.07, p=.052). However this two variables did not interact ($F_{(2, 36)}$=2.03, p=.146).

The main aim of this control experiment was to check that the results found in the previous experiment were not due to factors other than the relationship between word's valence and color-photism relationship. The fact that control participants did not show an interaction between Valence and Congruence rules out the possibility that the pattern we found en Experiment 3 was due to responding "no" being easier if the word was negative and responding "yes" easier if the word was positive.

GENERAL DISCUSSION

With this set of experiments we were interested in testing whether the affective reactions elicited by incongruently colored stimuli found in MA were just an idiosyncratic feature of her synesthesia or they generalized to other synesthetes. Three synesthetes were tested for this effect in the first experiment. We presented them with emotional words both in their right color and in a wrong color, according to their photisms for each word. By having synesthetes categorize the words according to their semantic valence we found that, although the three of them reported unpleasantness associated to the presentation of incorrectly colored words, only two of them replicated the previously found pattern of results. EL showed a modulation of Congruence by word Valence in RT measures and error rates. PR showed a modulation in RTs but not in error rates. It is interesting to see that even when the effect is found, it seems to range from a reduction to a complete reversal of congruency.

The factors underlying this various degrees are still not understood but it is important to show that the pattern is found. When there is a correspondence between the connotation of the word and the affective reaction reported by the synesthete (i.e. positive word that is congruently colored and therefore produces a pleasant sensation or alternatively, a negative word incongruently colored and therefore producing an unpleasant sensation) their performance is relatively better than in conditions where the result of the connotation assessment goes in the opposite direction as the result of the *synesthetic* assessment (i.e. for a positive word incongruently colored the connotation assessment signals “positive” and the *synesthetic* assessment signals “negative”. For a negative word congruently colored the connotation assessment signals “negative“ while the *synesthetic* assessment signals “positive”).

Since PSV did not even show a difference between congruently and incongruently colored words we carried out a Stroop experiment to test whether her synesthetic experiences were automatic enough as to influence her performance. A standard synesthetic Stroop showed that she did find it more difficult to name the ink in which a letter or number was presented when the elicited color did not match the ink color. Even more, in a reversed Stroop task in which she had to ignore the ink color of the stimulus to name the in *her-mind’s-eye* experienced photism the interference produced by the color presented in the screen was much smaller. It seems then that she did perform in a similar manner as other synesthetes like MA (Lupiáñez & Callejas, 2006, Chapter1). Even more, based on her pattern of Stroop results it could be concluded that her synesthetic experiences are of a relative strong degree (strong enough to influence visually perceived colors and strong enough to be relatively uninfluenced by them). Adding to this, the absence of a Negative Priming effect on neither of the two tasks suggests that she was not successful in the suppression of the interfering information.

Having found a strong pattern of Stroop interference we went back to the affective side effect of synesthesia and tested whether the absence of a congruency effect in this realm was due to the fact that color was an irrelevant dimension of the stimulus and since the task was more demanding, color processing was taken apart as to not influence PSV´s performance in the valence categorization task. By making her categorize whether the color matched or mismatched the word's elicited photism we ensured that she carried out enough processing on the color as to experience the reported unpleasantness associated with wrongly colored words. Results showed that when color processing was promoted, correspondence between the affective reaction induced by the color-photism relation and the connotation of the word influenced performance and made her respond faster and more accurate to corresponding conditions than to non-corresponding conditions. The fact that MA showed the same pattern of results backs up the deduction that the affective reactions underlying performance in Experiment 1a (where MA also showed an effect, see Callejas et al., submitted, Chapter 3) are the same ones playing a role here. Even more, the fact that control participants did not show an effect in the same direction supports the idea that the modulation found is not due to the fact that responding “no” to negative words and “yes” to positive words is easier than the other conditions.

The question to be answered now is why, given PSV's subjective reports and her clear patterns of interference found in the Stroop tasks, she did not show an effect in Experiment 1a. Even though color was completely irrelevant in this experiment, the task was not as resource demanding as to prevent automatic processing of the color. In fact, she did report realizing some words were not colored right. Therefore she was conscious of the mismatch between color and photism. It could be the case that her synesthesia for words is of a more “higher” level (Ramachandran & Hubbard, 2001b) and connotation assessment was already carried out by the time the photism was experienced and the unpleasantness reaction was felt.

Alternatively other personality factors could be playing a role in PSV's performance. Some factors such as anxious traits could be enhancing the affective reaction so much as to make it influence performance (Acosta, Lupiáñez, Fresse & Megías, under revision). When testing PSV and MA with the Spanish normalized version of the STAI test to measure trait-anxiety, we found that PSV's scores were in the lowest percentiles (score:11, percentile: 11) while MA's were in the highest ranges (score:34, percentile: 80). Although no cause effect can be drawn from this data, it informs of individual differences other than the synesthesia experience per se that could be influencing, not only these affective aspects of synesthesia but many other aspects of their perception and experiences. It could be that having a low anxiety trait helps in coping with the anxiety state elicited by the incongruence situation so that it does not influence performance. This would not be so when having a high anxiety trait. However, the incongruence situation presented in Experiment 3 is much more subtle and it may not be actively dealt with resulting in it being observable in MA as well as in PSV. In fact, both synesthetes reported liking this experiment much more than the previous ones. The fact that their task was to “judge” whether something was colored right or wrong placed them in the position to have control over the situation and not have to disregard their experiences in order to perform an unrelated task (as was the case in Experiment 1). These observations encourage researchers to broaden the scope of the circumstances taken into account when studying synesthesia and specially when trying to discern the underlying factors that cause the differences between synesthetes in their performance on behavioral tasks.

CHAPTER 5

CONTEXT EFFECTS ON SYNESTHETICALLY INDUCED AFFECTIVE REACTIONS

ABSTRACT

Informal reports from synesthetes suggest that the affective reaction experienced when perceiving an incongruently colored stimulus might be permeable to contextual influences. In order to test these reports we carried out a set of four experiments where we manipulated the color in which a set of words were presented (i.e. black or grey) as well as the context in which they were shown (i.e. achromatic vs. chromatic context) and tested how these factors influenced our synesthete's ratings for the valence of those words. Also we tested how the same shade of grey would affect their performance when it was perceived as white. We found that black was clearly susceptible to context effects whereas perception of grey tended to be unpleasant under chromatic and achromatic conditions. Last, grey colored-white perceived words seemed to be less incongruent in color than the very same stimuli when subjectively perceived as grey. Results show that the affective reaction elicited by the incongruence between the presented color and the elicited photism is not driven exclusively by the stimulus but also influenced by other factors.

INTRODUCTION

Synesthesia is a rare phenomenon whereby the conscious perception of a stimulus is accompanied by the subjective experience of another sensation not directly linked to it (Grossenbacher, 2001). Being grapheme-color synesthesia the most common case (Day, 2005), it is also the one most deeply studied to the moment (Grossenbacher, 2001; Ramachandran & Hubbard, 2001b; Rich & Mattingley, 2002 for reviews).

Previous informal reports have pointed to the emotional nature of synesthesia (Cytowic, 1993; Ramachandran & Hubbard, 2001b). Synesthetes experience their photisms as a vivid phenomenon, which is accompanied by a sense of certitude that what they see is real. Synesthetes also report experiencing a feeling of disconfort when a stimulus is presented in a color that does not match the internally experienced photism. Recently, Callejas, Acosta and Lupiáñez (submitted, Chapter 3) showed for the first time that this subjective feeling of disconfort can be objectively measured and reproduced in a laboratory setting. Even more, it has been shown to be automatic and difficult to ignore when it interferes with the task being performed.

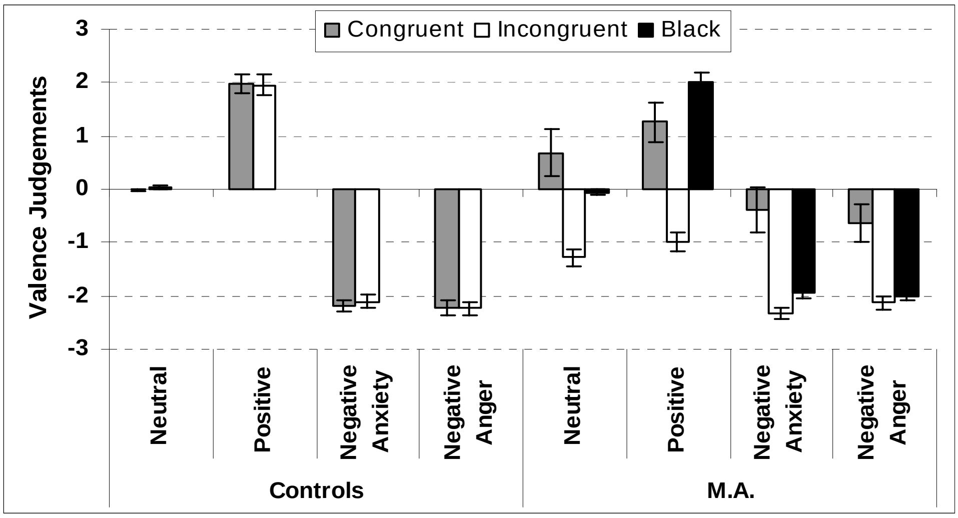
Informal reports from synesthetes lead us to think that although automatic in nature, these affective reactions might be permeable to contextual influences. Several synesthetes have reported that although acknowledging that something is wrongly colored, the incongruence can be *ignored* if necessary. Particularly, when reading books or handwriten notes, they do not seem to be so affected by the ink color in which the text is writen. Most synesthetes inform that black colored items are not as disrupting to see as any other color.

Previous reports have informed that the experience of synesthesia itself can be modulated by the context in which the elicitor is placed (Dixon et al., 2006; Myles, Dixon, Smilek & Merikle, 2003). These researchers showed that the very same perceptual shape could be experienced as a letter “S” or a number “5” depending on the context in which it was presented (i.e. HPSOA or 37564). By combining the color elicited by each grapheme (i.e. by the letter or by the number) with the context in which it was presented (i.e. letter context or number context) they showed that the very same perceptual shape with the very same color could give rise to color naming times very different for congruent than incongruent conditions (up to 300ms congruency effect).

Given this findings whereby the strong vivid experience of a color can be manipulated by the contextual cues that point to the identity of ambiguous grapheme shapes, we wanted to test whether the affective reaction resulting from the perception of an incongruently colored item could be also manipulated by the context in which the eliciting stimulus was presented. If a word is presented in a context in which all words are uniformly colored, even though not in their right color, it is possible that synesthetes would interpret that as a color-independent context and therefore try to avoid or control the affective reactions elicited by the incongruence in order to perform better (i.e. easily read a posted letter written by a friend with a blue ink ball pen).

In order to do so we systematically manipulated the color, and context in which the color was presented, of a set of neutral and emotional words.

Previous experiments were we had asked our synesthete MA to make a valence judgment of a set of words, showed that when presented with colored words her ratings were influenced by the congruency between the words color and the photism induced by the word (Callejas et al., submitted, Chapter 3). As can be seen in Graph 1, her ratings were overall more positive when the word was presented in the congruent color and more negative when the word was presented in an incongruent color as compared to a control group.



Graph 1. Results from Experiment 1a and 1b of Callejas et al. (submitted, Chapter 3). Error bars denote standard error of the mean.

We also found, as shown in Graph 1, that even though black was not the photism of any of the presented words, and therefore it is an incongruent color, when shown the very same words but now all colored in black, MA presented the same pattern of results as control participants did (compare black bars in the right side of Graph 1 with grey and white bars in the left side). That is, she correctly evaluated the words with no influence from the color congruency when they were consistently colored in black, ad it is usual in normal reading texts.

EXPERIMENT 1. EFFECT OF COLORING WORDS IN BLACK IN A COLOR-CONTEXT TASK

To test whether black is in fact considered a neutral color or the results we had found were due to the fact that it was presented in an achromatic context (grey background and all items presented in black) we carried out our first experiment where we presented the same words to MA and a group of control participants, but now in one of three different colors, randomly selected: congruent, incongruent and black. The rationale was the following: if absence of hue is the reason for black to be considered neutral, then we should still find an accurate assessment of black colored words when presented in a color context (i.e. other colors are intermixed with black). However, if the context is the determinant for a black word to be perceived as "neutrally colored" then we would expect to find the same pattern of results for black than for the incongruent color condition. After all, a black colored word is an incongruently colored word if black is not the photism elicited by such word.

METHOD

Participants

MA and a group of 10 undergraduate psychology students participated in this experiment. They all had normal or corrected to normal vision and the mean age of the group was 20. All of them were women (including MA).

Stimuli and material

Out of the 72 words used in the Callejas et al. study, a set of 58 were selected so that neither of them elicited a black or a grey photism. A total of 15 positive words, 15 neutral words and 28 negative words (14 anger related and 14 anxiety related) were selected.

Words were presented on a grey background screen where a white reproduction of the response scale was present through out the whole experiment.

Design and Procedure

The 58 words were presented in one of three different color categories depending on the condition. Congruent colors were those chosen by MA for each particular word. Incongruent colors were the color-wheel opposites of the congruent ones. Last, words were also presented in black color. To ensure good viewing conditions, a dimly lit room was used to carry out the experiment.

Participants' task was to evaluate the valence of each word in a 7-point Likert scale being -3 very negative, +3 very positive and 0 neutral. A speeded response was not requested although participants were encouraged not to engage in long decision processes. Thus, we manipulated Congruency (congruent, incongruent and black) and Valence (positive, neutral, anxiety related and anger related negative words).

On each trial, a white fixation point was presented for 1000ms prior to the appearance of the target word, right above the reproduction of the rating scale (-3 -2 -1 -0 +1 +2 +3). After subjects' response the target word disappeared and the next trial begun. The response scale was present at all times.

Four blocks of trials were run and a total of 174 trials were included in each block (58 words x 3 different coloring conditions). Conditions were randomly intermingled in each block. Prior to the experimental blocks, a set of practice trials was run. Participants were encouraged to rest between blocks.

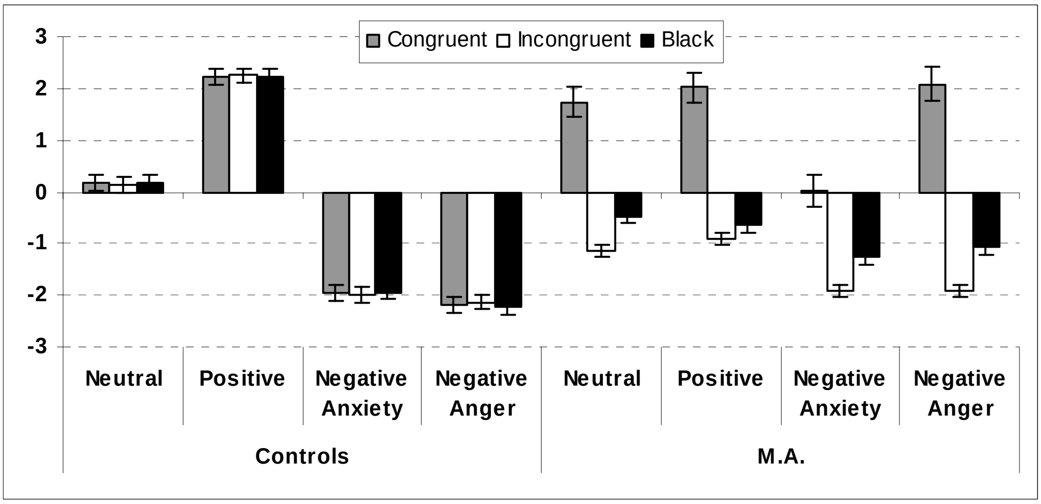
RESULTS AND DISCUSSION

For each group data was averaged for each condition and item. Items and not subjects were used as random factor. Therefore, data for the control group was averaged across participants for each item. Group and Congruency were within item factors and Valence was a between item factor. Mean rating for each group and condition can be seen in Table I.

Table I. Experiment 1. Mean valence judgment per group and condition.

		Valence			
Group	Congruence	Positive	Negative-Anxiety	Negative-Anger	Neutral
MA	Congruent	2.32	1.54	2.09	1.93
	Incongruent	-1.50	-2.11	-1.91	-1.72
	Black	-0.77	-0.91	-1.07	-0.35
Controls	Congruent	2.21	- 1.95	- 2.19	0.18
	Incongruent	2.25	- 1.98	- 2.13	0.13
	Black	2.23	- 1.94	- 2.22	0.18

The mixed 2 (Group) x 3 (Congruence) x 2 (Valence) ANOVA yielded the following results. Words were correctly rated according to their meaning ($F_{(3, 54)}$=186.8, p=.001) although there was also a significant interaction by group ($F_{(3, 54)}$=72.8, p=.001). MA's ratings were more similar for all word types. However, planned comparisons revealed that she did rate positive words more positive than negative words ($F_{(1, 54)}$=46.52, p=.001 and $F_{(1, 54)}$=6.5, p=.013 for anxiety related and anger related words respectively) although neutral words were not different from positive words (F<1). Groups were not different ($F_{(1, 54)}$=2.20, p=.140) although the Congruence effect found ($F_{(2, 108)}$=227.61, p=.001) was modulated by Group and Valence (significant second order interaction: $F_{(6,108)}$=5.91, p=.001). As can be seen in Graph 2 control participants did not differ in their ratings when words were colored or presented in black. MA showed a very intriguing evaluation pattern. A separate analysis of her data showed that she rated black words significantly higher than incongruently colored words ($F_{(1, 54)}$=42.26, p=.001) but much lower than positive words ($F_{(1, 54)}$=181.18, p=.001).

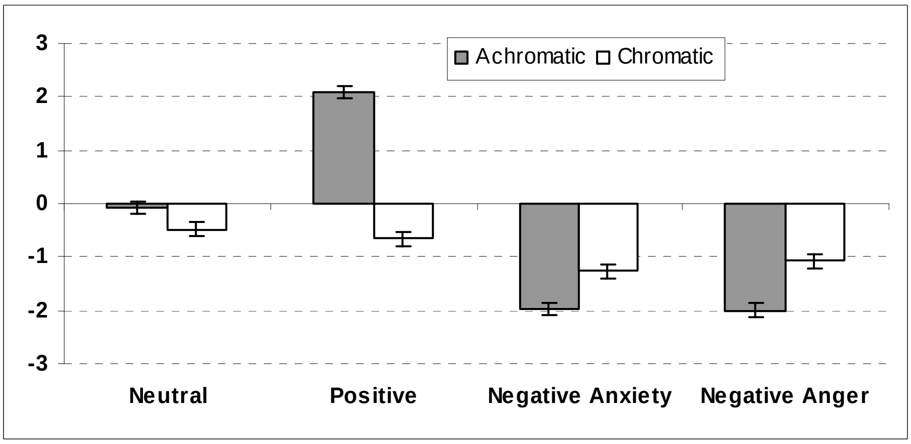


Graph 2. Experiment 1. Valence rating for congruent, incongruent and black colored words as a function of group and valence. Error bars denote standard error of the mean.

An interaction by Valence was found in MA ($F_{(6, 108)}$=5.69, p=.001) and was due to the fact that valence judgments were more extreme when words were colored congruently and specially due to negative words related to anger being rated positive when congruently colored. Although puzzling and unexpected, this could be accounted for if we take into account MA's high anxiety-trait (see Chapter 4) that would enhance the processing of anxiety related negative words and her positive mood at time of testing that might have reduced the relative connotation of anger related words in the context of congruently colored words. More testing is needed however to decipher these results.

In is interesting to see that, although overall MA is following instructions to rate words according to their semantic valence, she is still influenced by the congruency between the words connotation and the photism-color match. Overall, results from congruently and incongruently colored words resemble those found in previous experiments (Callejas et al., submitted, Chapter 3). Black colored words on the contrary, were rated much more negatively than congruently colored words. In fact, ratings of black colored words were close to those of incongruently colored words, and therefore quite different of control group ratings. Whereas MA rated black colored words exactly as control participants did when black was constant throughout the experiment (Callejas et al., submitted, Chapter 3). It therefore seems that what is seen as a neutral word under no coloring conditions (i.e. black words in an achromatic context) becomes an incongruent color under chromatic conditions.

We then compared the results of MA's original black experiment (Experiment 1b in Callejas, et al. submitted, Chapter 3) with those found here for the very same words in the very same color. Since this new experiment had eliminated some words that elicited a grey photism, those items were also eliminated from the original experiment prior to comparison. A new variable, called Context (achromatic vs. chromatic context), was coded. Graph 3 shows the results of this analysis. Valence rating was influenced by Context ($F_{(3, 54)}$=90.86, p=.001). Post-hoc tests showed that while positive words were rated more positive in an achromatic context (p=.001), negative words were rated more negative (p=.006 for anxiety related words and p=.001 for anger words). No differences were found for neutral words (p=.292). Therefore, words' rating was more accurate in the achromatic condition. This was also shown in the original paper (Chapter 3) when black was shown to be different than MA's performance under color conditions but not different from Control's performance under color conditions.



Graph 3. Experiment 1 compared to Experiment 1b from Callejas et al. (submitted, Chapter 3). Ratings for black colored words as a function of color Context and Valence.

It seems to be clear then that context plays an important role and the very same word presented in the very same color can influence behavior in one direction or another depending on the context in which it is found. Whether context can also influence the affective reaction itself (its presence or strength) will be discussed in a later section.

In this experiment we wanted to test whether black is a *universal* neutral color or it is only perceived as so when it is presented in an achromatic context. Having found that black behaves differently depending on the context, our next interest was to discern what feature of a black word presented in an achromatic context makes it turn it into a *neutral* colored word. Considering black is absence of any hue and grey is just a brighter version of black, we wondered whether absence of hue in an achromatic context would be the determinant of *neutrality* irrespective of brightness. In order to test this idea we conducted experiments 2a and 2b.

EXPERIMENT 2a AND 2b. EFFECT OF COLORING WORDS IN GREY IN A COLOR-CONTEXT TASK AND AN ACHROMATIC-CONTEXT TASK

We next wanted to test whether grey would behave just as black since it is a brighter version of black. With this new manipulation we wanted to further test whether black was considered a neutral color because it lacked a hue or just because it is the most used color when reading printed documents and therefore, the “incongruent” color that synesthetes are most used to deal with. If the first reason was correct, then grey or white would behave in a similar manner. However, if the reason is extensive practice reading black print, then we would expect to find that grey would be considered an incongruent color irrespective of its context. Again we run the same experiment but now words were presented either in a congruent, incongruent or grey color (Experiment 2a) or just in grey color (Experiment 2b).

METHOD

Participants

Experiment 2a. MA and a different group of 10 undergraduate psychology students participated in this experiment. They all had normal or corrected to normal vision and the mean age of the group was 22. Two of them were men.

Experiment 2b. MA and the same group of participants that performed Experiment 1 participated in this experiment.

Stimuli and material

Experiment 2a. Since the background was dark grey, we chose a lighter shade of grey for the words (RGB: 180,180,180). Congruent and incongruent words had the same color as in Experiment 1 and we replaced black words with the grey words. Everything else was the same as in Experiment 1.

Experiment 2b. Words were presented only in grey color and the shade of grey used was the exact same one used in Experiment 2a. The same number of trials was presented but since now only one color was used, three times as many trials as in experiment 2a were collected for each condition. Everything else was the same as in Experiment 1 and 2a.

Design and Procedure

The grey shade used for the background and the grey colored words, as well as the procedure, is shown in Figure 1.

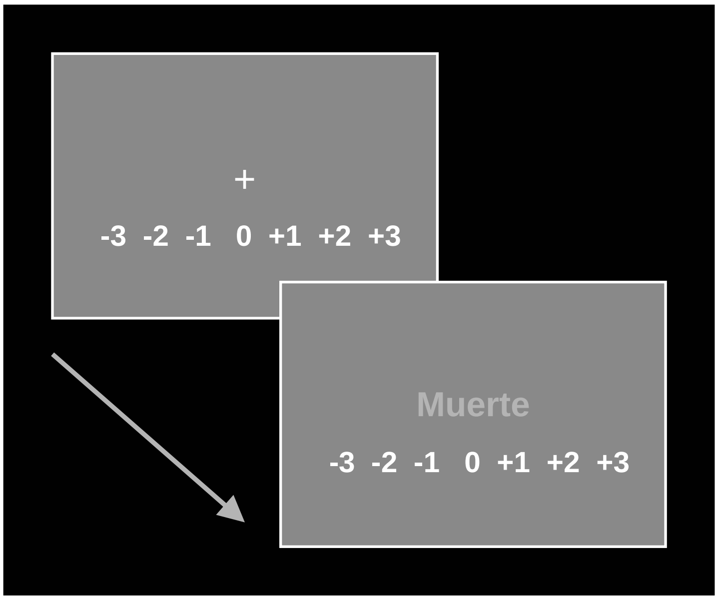


Figure 1. Experiment 2a and 2b. Stimuli and procedure used.

MA run Experiment 2a twice and Experiment 2b only once. Control participants run the experiments only once.

RESULTS AND DISCUSSION

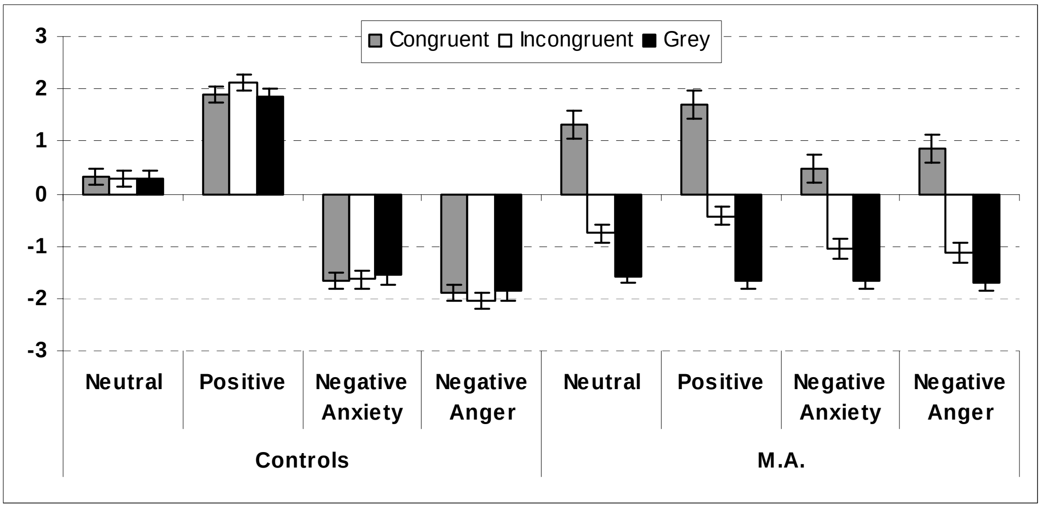
Experiment 2a.

Again, for each group, data was averaged across participants (across sessions for MA) for each one of the 58 items. Mean valence judgments for each Group and Condition can be seen in Table II. The mixed 2 (Group) x 3 (Congruence) x 2 (Valence) ANOVA yielded the following results.

Table II. Experiment 2a. Mean valence judgment per group and condition.

		Valence			
Group	Congruence	Positive	Negative-Anxiety	Negative-Anger	Neutral
MA	Congruent	1.71	0.47	0.86	1-32
	Incongruent	-0.43	-1.05	-1.13	-0.75
	Grey	-1.67	-1.67	-1.7	-1.58
Controls	Congruent	1.81	- 1.80	- 1.95	0.29
	Incongruent	2.00	- 1.74	- 2.07	0.28
	Grey	1.82	- 1.67	- 1.91	0.28

Participants followed instructions and negative words were rated more negative than positive words being neutral words in between ($F_{(3, 54)}$=117.39, p=.001). Groups were not different ($F_{(1, 54)}$=2.36, p=.130) although they did differ in their Valence judgments ($F_{(3, 54)}$=65.77, p=.001). Again MA's ratings were more uniform than those of the control group (see Graph 4). However, planned comparisons showed that she rated positive words more positive than negative ones ($F_{(1, 54)}$=14.19, p=.001 and $F_{(1, 54)}$=10.21, p=.002 for anxiety related and anger related words) and those more negative than neutral ones ($F_{(1, 54)}$=6.28, p=.015 and $F_{(1, 54)}$=3.74, p=.058 respectively).



Graph 4. Experiment 2a. Valence rating for congruent, incongruent and grey colored words as a function of group and valence. Error bars denote standard error of the mean.

The effect of Congruence ($F_{(2, 108)}$=163.55, p=.001) was modulated by Group ($F_{(2, 108)}$=188.10, p=.001) and also by Valence ($F_{(6, 108)}$=2.37, p=.035). While control participants did not show any difference as a function of the color in which the words were presented (all ps>.9), MA showed that congruently colored words were the most positively rated ones, incongruent words were more negative and grey words were the most negative ones (all ps<.001). Inspection of the modulation of Congruence by

Valence showed that the interaction could be due to the congruency effect (i.e. difference between congruent and incongruent trials) being larger for positive, neutral and anger related negative words than the anxiety related negative words. Obviously, although the second order interaction was not significant, since control participants had not shown a congruency effect in the first place, it was clear that this interaction between Congruence and Valence was due to MA's ratings. Since we predicted MA to perform differently at least between congruently and incongruently colored words we carried out a separate ANOVA for her.

The 4 (Valence) x 3 (Congruence) ANOVA showed a main effect of Valence ($F_{(3, 54)}$=6.07, p=.001) with the expected pattern and a main effect of Congruence ($F_{(2, 108)}$=191.70, p=.001). Not only congruent words were rated more positive than incongruent ones but also grey words were rated more negatively than incongruent ones (all ps<.001).

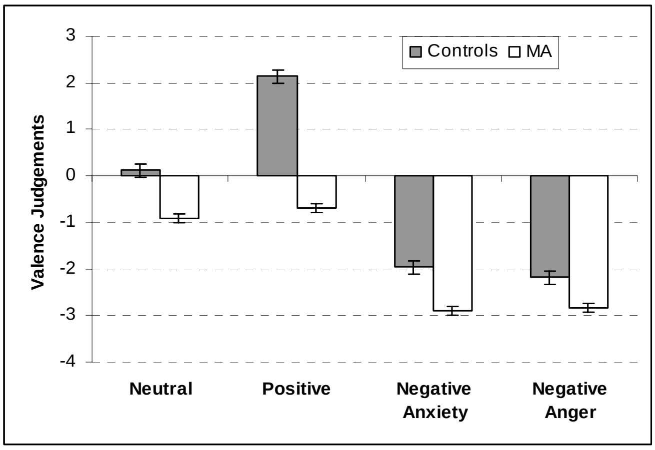
Experiment 2b

Averaged data per group can be seen in Table III. A mixed 2 (Group) x 2 (Valence) ANOVA was performed on the data.

Table III. Experiment 2b. Mean valence judgment per group and condition.

		Valence			
Group	Congruence	Positive	Negative-Anxiety	Negative-Anger	Neutral
MA	Grey	- 0.71	- 2.89	- 2.84	- 0.90
Controls	Grey	2.07	- 1.96	- 2.18	0.13

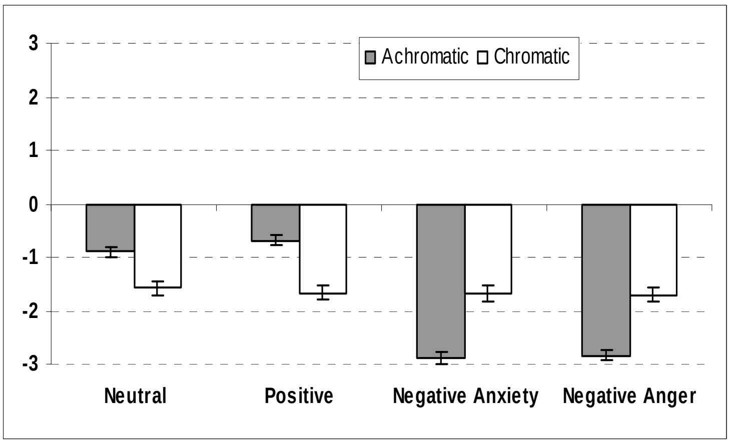
Results showed that words were assessed accurately as positive words were rated higher than neutral and both higher than negative ones ($F_{(3, 54)}$=348.26, p=.001). Groups were different so that MA tended to rate all words more negative than the control participants did ($F_{(1, 54)}$=235.72, p=.001). An interaction was found between Valence and Group ($F_{(3, 54)}$=32.19, p=.001) in the following direction. As can be seen in Graph 5 although MA was in general more negative in her ratings than the control group, this difference was maximized for the positive words. Post-hoc analysis showed that she did not rate positive words statistically different than neutral words (p=.9). All other comparisons were significant (all ps<.01).



Graph 5. Experiment 2b. Mean valence judgments for MA and the Control group when words were all presented in grey color. Error bars denote standard error of the mean.

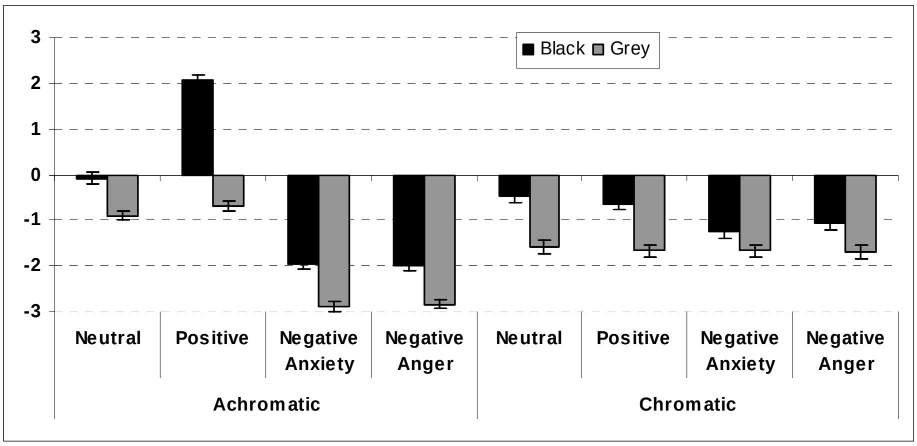
In this experiment we also studied the valence of a control group with grey color words because the original studies used to estimate mean valence of each word (unpublished data) had been carried out with black presentation and we wanted to make sure any potential effect found in MA was not due to the color itself but to its interaction with the experienced photism. Having found the already mentioned results, we can conclude that grey color on its own was not the reason for MA's pattern since control participants rated words just as they did in the original study and in the previous studies where other colors were used (Experiment 1 and Experiment 2a from this chapter and Experiment 1a from Callejas et al., submitted, Chapter 3).

In order to study the relative effect of context in MA's responses to grey colored words we carried out another analysis comparing her performance for grey words under an achromatic and a chromatic context. Therefore we had a new variable Context with 2 levels (achromatic vs. chromatic). Results are shown in Graph 6. Apart from the main effect of Valence ($F_{(3, 54)}$=63.12, p=.001) we just found a trend for a main effect of Context with chromatic context tending to produce more positive ratings than achromatic context ($F_{(1, 54)}$=3.42, p=.070). This effect was modulated by Valence ($F_{(3, 54)}$=40.17, p=.001). When grey was presented in an achromatic context judgments were more accurate. Negative words were rated as more negative than neutral ones (both ps<.001) and more negative than positive ones (both ps<.001) although there was no difference between neutral and positive words (p=.858). However, in the chromatic context all words were rated as negative irrespective of the semantics of the word (mean -1.66).



Graph 6. Experiment 2a and Experiment 2b for MA. Ratings for grey colored words as a function of color Context and Valence.

To further study the effect of color and context we carried out another ANOVA for MA in which we included all the achromatic conditions of the 4 experiments. We then had three variables: Color (black vs. grey), Context (achromatic vs. chromatic) and Valence (positive, neutral, anxiety and anger related negative). As shown in Graph 7, we found that grey words were rated as more negative than black words ($F_{(1, 54)}$=253.17, p=.001). Although the effect of Context was not significant ($F_{(1, 54)}$=2.32, p=.134), it did modulate Color ($F_{(1, 54)}$=20.53, p=.001). Again planned comparisons showed that black was highly influenced by context ($F_{(1, 54)}$=18.05, p=.001) whereas grey only tended to be influenced by context ($F_{(1, 54)}$=3.42, p=.070).



Graph 7. Comparison of results from Experiment 1b (Callejas et al., submitted, Chapter 3), Experiment 1, 2a and 2b. Ratings for Black and Grey words as a function of Valence and color Context.

The unexpected pattern of ratings found for grey when shown in a color context (i.e. all words were rated as negative irrespective of their valence) caused some other interactions to be significant. Valence was influenced by Context ($F_{(3, 54)}$=105.65, p=.001) in the sense that ratings were more accurate under achromatic context conditions. In the chromatic context, ratings were more homogeneous for all valence types mainly due to the effect of grey. Valence was also influenced by Color ($F_{(3, 54)}$=18.25, p=.001). Although grey words were consistently rated as more negative than black words, this difference was maximized for positive words. Graph 7 clearly points to the source of this interaction. Black positive words under an achromatic context were the only positively rated words.

The second order interaction between Valence, Color and Context was reliable ($F_{(3, 54)}$=13.22, p=.001). Ratings for words presented in an achromatic context followed the expected valence pattern. However, when shown in a chromatic context, ratings were much more undifferentiated across valence conditions and this was especially true in the case of grey.

These results suggest that context affects differently to grey and black words. While black words act as incongruent colors when in a chromatic context and as a *neutral* color when in isolation, grey is only marginally influenced by context and shows up as an incongruent color independent of context. Results from Callejas et al., (submitted, Chapter 3) showed that black in achromatic context did not differ from a non-synesthete's rating. Here we showed that although grey resembled the expected pattern of results under achromatic context in the sense of the relative difference between positive and negative words, it still differed from the control group because all the ratings were shifted towards the negative values. Grey does have a different status than black. It is worth mentioning that, when grey was presented in an achromatic context the actual rating values were quite similar to those originally given by MA to incongruently colored words (see Graph 1). Therefore grey seems to be as unpleasant when showed alone as any other incongruent color. A question rises then concerning the different patterns found for MA when rating congruently and incongruently colored words. Why would her ratings change over time? We will come back to this issue in a later section.

Last, while designing these experiments we realized that we could take advantage of the fact that the very same color could be subjectively perceived as grey or white as a function of the other colors presented in the screen to also test how subjective perception and not wave length affect MA's color preferences. In order to test this we carried out Experiment 3.

EXPERIMENT 3. SUBJECTIVE EXPERIENCE OF COLOR VS. COLOR WAVE LENGHT

When designing Experiment 3 we noticed that the grey shade chosen to color the words looked almost white when shown in a context where all other colors were darker (i.e. darker grey and black). However, the same shade was subjectively perceived as grey when lighter colors were in scene (i.e. darker grey and white). We took advantage of this contrast effect to test to a greater extent how color incongruence can be modulated by subjective perception.

METHOD

Participants

MA and a different group of 10 undergraduate psychology students participated in this experiment. Their mean age was 21 and all but one were females. MA run this experiment before she run Experiment 2b

Stimuli and material

For this experiment, only anxiety related negative words were used. We therefore had 15 positive words, 15 neutral words and 15 negative words (one anger-related negative word was used to make groups even in number and subjective familiarity). The fixation point as well as response scale presented on the screen were now colored in black ink (instead of white as in previous experiments) promoting the subjective experience of words being colored white. Everything else was same as in Experiment 2b.

Design and Procedure

The procedure was the same as in previous experiments. Figure 2 shows how the subjective perception of the word changes to whitish when set in a black and dark grey context.

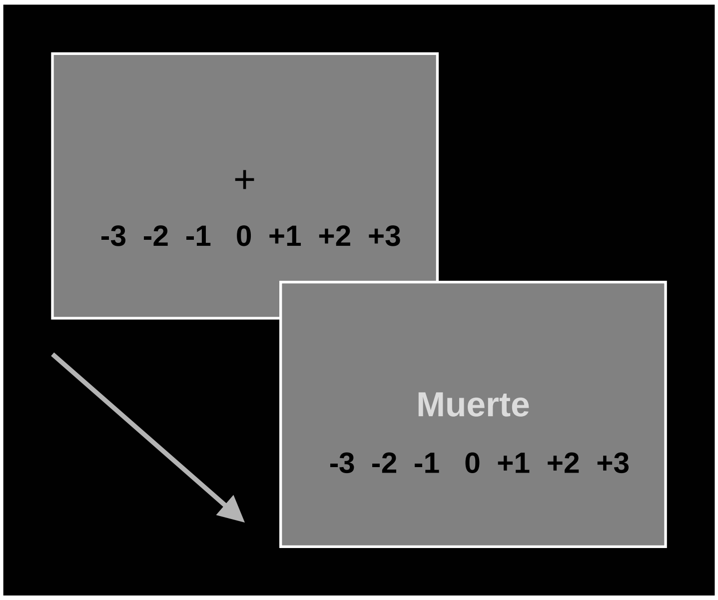


Figure 2. Experiment 3. Stimuli and procedure used.

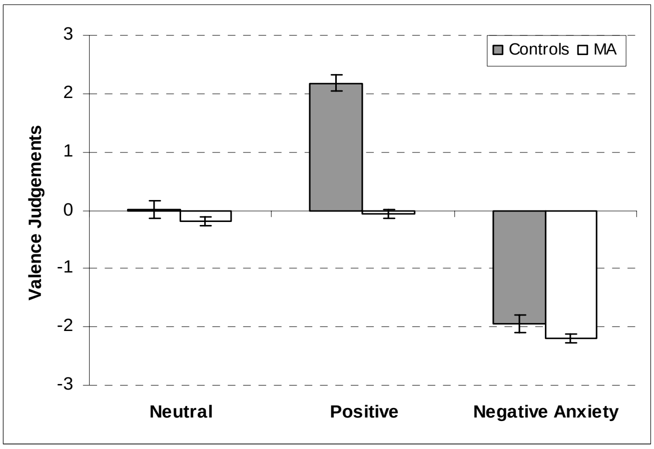
RESULTS AND DISCUSSION

Averaged data per group can be seen in Table IV. A mixed 2 (Group) x 3 (Valence) ANOVA was performed. Again, participants correctly followed instructions and evaluated positive words more positive than neutral words and negative words more negative than neutral words ($F_{(2, 42)}$=310.57, p=.001).

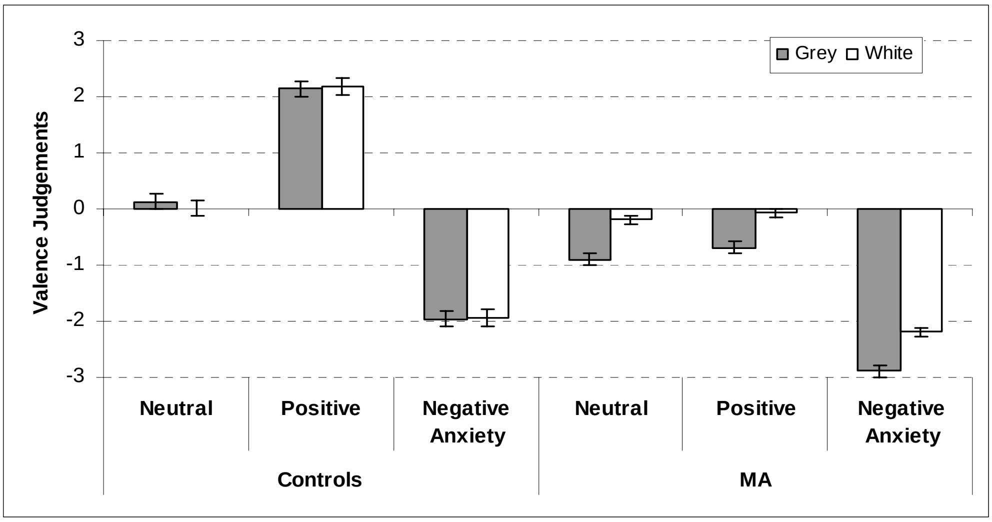
Table IV. Experiment 3. Mean valence judgment per group and condition.

		Valence		
Group	Congruence	Positive	Negative-Anxiety	Neutral
MA	Grey	- 0.07	- 2.22	- 0.18
Controls	Grey	2.18	- 2.01	0.01

As in the previous experiment, MA rated words more negative in general than the control group ($F_{(1, 42)}$=117.64, p=.001). However, this effect depended on the valence of the word as shown by the significant interaction ($F_{(2, 42)}$=70.26, p=.001). Again, (see Graph 8) positive words were rated more negative by MA than the control group (p=.001). It is interesting though to note that this was the only statistical and nominal difference between her and the control participants. For neutral words as well as for negative words there were no differences between both groups in their ratings (all ps>.6).



Graph 8. Experiment 3. Mean valence judgments for MA and the Control group when words were all presented in subjectively perceived white color. Error bars denote standard error of the mean.



Graph 9. Experiment 2b and 3. Mean valence judgments for MA and the Control group as a function of Valence and subjectively perceived color. Error bars denote standard error of the mean.

Last, we carried out another ANOVA comparing Experiment 2b and Experiment 3 in order to study the relative influence of perceived color on MA's ratings. Since Experiment 3 had been carried out only with anxiety related negative words, we only took those same words from Experiment 2b. We had a mixed 2 (Group) x 2 (Perceived Color) x 3 (Valence) design. We found that there was a difference between perceiving words as grey and perceiving them as white ($F(1, 42)=58.88$, $p=.001$). As shown in

Graph 9, grey perceived words were rated more negative than white perceived words but, as shown by the significant interaction ($F(1, 24)=86.52$, $p=.001$), this was so only for MA. Control participants, as expected, did not show any effect of color.

Experiment 3 showed how the very same color was assessed as more or less pleasant (and therefore influenced valence ratings differently) based on the subjective color experience. When the very same color is categorized as white, valence ratings are just rated about 0.7 units less negative than when the very same color is subjectively categorized as grey (given a brighter context). This is consistent with MA's reports after performing both experiments. While after having finished Experiment 2 she informed that most of the colors of the words were wrong, after finishing Experiment 3 she commented that it was not so bad since white is not such a bad color. This seems to be an interesting demonstration that a) the evaluation of the color-photism fit is not a set process but one that is affected by different factors and b) not all wrong colors are equally wrong. Again, the question comes back to which are the determinants of a color being categorized as *wrong* and therefore causing an unpleasant feeling. We now turn to that question.

GENERAL DISCUSSION

The general aim of these sets of experiments was to study the factors involved in the subjective perception of a color as incongruent by a particular synesthete. In previous work (Callejas et al., submitted, Chapter 3) presented words had to be rated according to their semantic meaning and when all words were presented in black our synesthete did not behave differently than controls. Therefore we found that an isolated presentation of black words did not produce the usual pattern found for incongruently colored stimuli.

In Experiment 1 we wanted to test whether black was considered *neutral* because it was presented in isolation or because it has some intrinsic features that make it special in that sense. We found that under color context conditions (i.e., the words could be displayed either in black or in several colors) black behaved as an incongruent color although it did not seem as unpleasant as the incongruent colors we used (the color wheel opposites to the congruent ones).

In order to further test whether black had a special status when presented in isolation (maybe due to extensive practice with printed books) or the results we found were caused by its absence of hue, we used a brighter version of black (i.e. grey) and performed the very same experiments. Under color context conditions we found that grey was assessed as even more negative than the incongruent colors. Also, if grey was presented in isolation it did not induce the expected *neutral* or normal rating of words but one very similar to that found when incongruent colors were used.

Last, in Experiment 3 we compared the very same color shown in isolation with contextual cues that biased subjects to perceive it as grey or as white. Again we found that a white perceived color did not behave as a *neutral* shade but as an incongruent one although *less interfering* that grey.

It seems clear that MA was performing the task as instructed and not responding to the color while ignoring the meaning of the word. Two facts back this up. On the one hand, although fluctuating, her relative pattern of ratings for positive and negative words is stable across experiments. Positive words are always rated higher than negative ones and neutral words fall in between but closer to the rating of positive ones. This result would be difficult to accomplish on a volitional basis since her response pattern is a dynamic one that only has the commonality across experiments of keeping the relative difference between positive and negative valence. On the other hand, if MA was answering solely based on the color in which the words are presented, the pattern would look quite different. Since congruent words have the color she chose for them and incongruent ones the color wheel opposite, there is no room for mistake and she would consistently rate all congruent words with a 3 and all incongruent words with a -3. In fact, a similar experiment was carried out, in which we asked MA to respond whether the words were correctly or incorrectly colored, and she performed the task perfectly (see Chapter 4).

Thus, once again, in spite of MA responding to the word valence (i.e., according to instructions) she was influenced by the correspondence between the coloring of the words and the photisms elicited by them. The results found in these experiments when presenting the words in an achromatic shade suggest that black is special. Even more, black is only *special* under certain circumstances. As soon as a cue leads to the thought that the context is a chromatic one, black becomes just as incongruent as any other color. Also, achromatic colors seem to have different status. While black can be taken as neutral when in an achromatic context, grey is still considered as very incongruent. A white perceived color on the other hand, seems to be somewhat less interfering than grey but still more incongruent than black.

Now, if synesthetes like MA claim such a strong aversive reaction to wrongly colored words the question comes to how can they cope with black printed stimuli? Is it that they loose their synesthesia when the stimuli are presented in black? Is it that they loose the emotional reaction associated to the synesthesia experience? Experiment 1 showed that the synesthesia experience is not lost, at least when black is in a color context and neither the affective reaction as measured by the influence of congruency on the valence ratings. If the photism is still experienced in a color context, it is presumably also experienced in an achromatic context.

The fact that different samples of achromatic shades elicit different responses points to the assessment process categorizing stimuli as congruent or incongruent with the internally experienced phenomena as being flexible. And it seems that one of the factors that can influence this process is the amount of practice with such stimuli. Therefore, the fact that black is the most used color for printed books, newspapers and the like and the fact that usually printed books do not show black print mixed up with any other colors could explain the results found for black. Given this premises it is possible that after long practice with the very same words presented in the very same congruent and incongruent colors, MA has started to habituate to those incongruent colors and her ratings are not as extreme as would be initially (i.e. in Experiment 1a from Callejas et al., submitted, Chapter 3). That would explain why grey was rated as more negative than incongruent colors in Experiment 2b. While this was the first time MA was dealing with grey words, she had extensive practice with the incongruently colored words presented in the study. However, this does not explain why white (the same shade perceived as white) was rated less negative, although she had no practice rating words in this perceived color.

Extensive questioning to MA suggests that the synesthesia experience is still there and the affective reaction might be there too but synesthetes undergo an adaptation process to fit into the environment and prevent their synesthesia from becoming a challenge which might make them habituate to certain inconsistencies to better cope with them. This process seems similar to that found in certain phobia therapies where the behavioral response (i.e. escape) is controlled whereas the physiological or the cognitive one is not. Furthermore, personality traits could have an influence on how synesthetes cope with these synesthetic affective reactions, so that they do not have a great impact on their behavior. In Chapter 4 we tested MA and found she has a high score in anxiety personality trait. Several authors have related high anxiety traits with a lack of control (Lazarus, 1991; Mandler, 1984). This might explain why she has problems controlling her synesthetic affective reactions, whereas other synesthetes, which might have similar affective reactions, can control them before they have an effect on performance. In this direction, in Chapter 4 we tested PSV, who reported strong affective reactions associated to incongruently colored stimuli but did not show a hint of a congruency effect either in the rating task or a categorization task. PSV scored very low in the anxiety trait test. It does not seem to be a coincidence that both factors correlate although, of course, in order to extract conclusions, a sample of synesthetes, not single cases, would have to be tested. Although further research is needed to test this hypothesis it seems a good candidate a priori to explain some of the inconsistent patterns found.

To summarize, although more research is needed, the experiments reported in this chapter suggest that only black is processed as a neutral color under certain conditions. This might be due extensive and intensive practice with written material printed in such color. As already noted by Dixon et al. (2006), meaning has an important role in synesthesia and not only so in the process of experiencing one color or another when perceiving a stimuli but, as shown here, also when categorizing a stimulus as congruent or incongruent with the internal perception. Two factors seem to have a crucial influence on these processes. Context influences how a color is categorized (especially for black) and subjective interpretation of the perceived wave length also seems to play a role (i.e. grey vs. perceived-as-white color). Some other factors influencing the affective reaction might be personality traits or amount of practice with the presented colors.

CHAPTER 6

SYNESTHETICALLY INDUCED AFFECTIVE REACTIONS AND ATTITUDE FORMATION

ABSTRACT

Previous experiments have shown that affective reactions experienced as a side effect of synesthesia are real and quite strong (at least in some synesthetes). Here we wanted to test whether these affective reactions are strong enough as to condition co-occurring events through classical conditioning. A visual search task was devised where participants had to search for a target image shown in one of nine locations and index the location number by hitting the appropriate key in the keyboard. Congruence between the photism elicited by the number indexing the location and the color of the target image was used to condition attitudes towards that target image. Results show that when the conflicting dimensions of the stimuli are simultaneously shown on the screen, later evaluation informs of a conditioning effect whereby those target images associated to incongruently colored numbers and shown in that incongruent color are perceived as less positive than images associated to congruently colored numbers and shown in that color.

INTRODUCTION

Synesthetes usually report that the experience of synesthesia has an emotional side, a sense of certitude that what is experienced is real (Cytowic, 1993; Ramachandran & Hubbard, 2001b). In this sense, when synesthetes are exposed to material incongruent with their synesthetic perception (i.e. words colored in the wrong photism) they have emotional reactions that can vary from simple unpleasantness to intense emotional reactions even accompanied of physiological reactions and escape responses. Callejas, Acosta and Lupiáñez. (submitted, Chapter 3) have shown that this affective reaction can be reproduced and studied in a laboratory setting, it happens automatically, is difficult to ignore and influences behavior. We have also shown that these results are not an idiosyncrasy of the synesthete we tested but are generalized to other synesthetes from widely different backgrounds.

Going a step further, we next questioned whether this affective reaction would be strong enough as to affect attitude formation about a stimulus that is otherwise neutral or already has a positive or negative valence. Attitude formation has long been studied by social psychology and it is thought to occur through classical conditioning where the object for which an attitude will be formed (conditioned stimulus, CS) is encountered repeated times paired with a stimulus that has a positive or negative valence (unconditioned stimulus, US). Early research seemed to back up this idea

(Razran, 1938; Staats & Staats, 1958) and even proposed that such a mechanism happens without awareness of the CS-US pairings, but further experiments cast doubts about the lack of awareness in such conditioning process.

Recently Olson and Fazio (2001) carried out a study where they leaned on an implicit learning paradigm to study whether such attitudes were formed implicitly. The main differences between their paradigm and previously used ones was that they did not ask participants to rate stimuli prior to the conditioning phase but obtained this information form a different sample; they paired each CS with different US; both were presented simultaneously with other events and they used a cover story and a experimental task that ensured participants were paying attention while performing a task different from the detection of covariance between paired stimuli. After the conditioning phase in which participants had to detect an infrequent stimulus appearing in a sequence of other stimuli, they asked participants to rate some of the stimuli presented to make sure that affective reactions to some of them did not interfere with the detection of the target stimuli. Among the rated stimuli were a couple of filler images (US) that had been consistently paired with positive or negative attributes (CS). A subsequent awareness test showed that participants were not aware of the CS-US pairings shown in the conditioning phase.

Inspired by this experiment we sought to study whether the negative affective reaction associated to a synesthetically incongruently colored stimulus would be strong enough as to serve as a CS- and whether the positive affective reaction associated to a congruently colored stimulus would be able to act as a CS+. An in our previous studies (Callejas et al., submitted; Chapter 3) a congruently colored stimulus would be that presented in the same color as the photism that our synesthete experiences for it and an incongruently colored one would be the color-wheel opposite of the congruent color.

EXPERIMENT 1. IMPLICIT ATTITUDE FORMATION WITH IMPLICIT SYNESTHETIC INCONGRUENCE AS THE UNCONDITIONED STIMULUS.

In this first experiment we tried to apply Olson and Fazio's paradigm (2001) with an US stimulus that was not physically present on the screen. We devised a task where a 3 by 3 grid appeared on the screen and a target image would be presented on one of the 9 slots created by the grid. Each slot was identified by a number that was presented on its upper right corner. A colored target was presented on each trial on one of the grid slots and participants were required to inform of the position of the target stimulus by means of the keyboard. Since each number elicits a color, although numbers were presented in black, a color was being perceived by our synesthete but not by control participants. The color of the target image could be the same as the photism elicited by the number identifying the slot in which it had been presented or a different color. This congruency between target color and slot's number's elicited photism was expected to elicit an affective reaction that would in turn act as the Unconditioned Stimuli.

Since participants had to identify the slot's number in order to give an accurate answer about the position of the target stimulus, the number had to be processed. A good amount of papers have shown that photisms are automatically elicited by the inducer stimuli (Dixon, Smilek, Cudahy & Merikle, 2000; Mattingley, Rich, Yelland & Bradshaw, 2001; Mills, Boteler & Oliver, 1999) and our own research with our synesthete MA showed that she does experience strong automatic photisms for numbers and letters (Lupiáñez & Callejas, 2006, Chapter 1). This ensured that MA would experience the photism color associated to each number while control participants would lack this color information. Although not necessary for the experiment, we expected the color of the target image to be also processed since color processing seems to be a preattentive feature (Treisman & Gelade, 1980). If target color processing and photism elicitation occurred at the same time, both colors could either be the same (when the target was presented in the same color as the photism elicited by the number presented in the same slot) or different (when the target was presented in a color different from that elicited by the number identifying the slot where it had been shown). By manipulating the color of the target we could then create incongruent trials and congruent trials. If this incongruence was experienced with the sufficient strength, it could in turn condition the target stimulus which could be later measured as an attitude towards that stimulus.

METHOD

Participants

MA and a set of 10 Psychology Undergraduates from the University of Granada took part in this study. Their mean age was 20 and 2 of them were males.

Stimuli and material

A set of 14 target stimuli and 36 distracters were used in this experiment. Target stimuli were Pokemon images. These images were chosen following Olson and Fazio (2001) who successfully induced positive or negative attitude towards them by pairing them with positive or negative words. Distracters were nonsense images designed as to have the same perceptual features. These images are called freebles. Pokemon figures were randomly divided into pairs and each pair was colored in a different color (i.e. the colors evoked by the numbers 1-9 for MA). Once they had been colored we proceeded to normalize them with a different sample of participants. Even though the Pokemon figures chosen were not the most popular ones, participants were willing to rate them on a pleasantness scale. One Pokemon from each pair was assigned to the CS+ and one to the CS-. Since some figures tended to be categorized as more positive than others just based on their perceptual features, (i.e. face expression, round vs. angular lines, etc) elements of each pair were assigned to one group or another so that the mean rating for each group was equal. A representative subset of the distracter freebles used as well as MA’s colors for numbers 1-9 and the Pokemon images associated to each number can be seen in Table I.

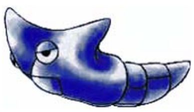
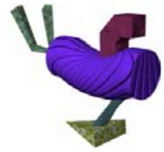
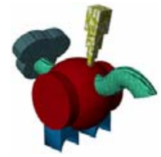
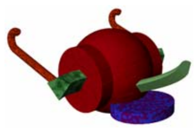
The screen was divided in a 3 by 3 matrix and was outlined resulting in a 3 by 3 table. Slots were numbered from bottom to top and from right to left being the bottom right slot numbered 1 and the top left one numbered 9. This ordering was chosen so that it did not resemble any ordering to which participants could be habituated to such as the keyboard of a portable calculator (i.e. bottom to top, left to right) or the keyboard of a cell phone (i.e. top to bottom, left to right) so that we could assure participants were actively paying attention to the number in each slot in order to respond.

Programming of the experiments, stimulus presentation and data collection were carried out on a 14” screen controlled by a Pentium computer running e-prime (Schneider, Eschman & Zuccolotto, 2002).

Design and Procedure

Two variables were manipulated in the experiment. Congruency referred to the match-mismatch between the color of the Pokemon figure that the photism elicited by the number of the slot in which the figure was presented. We could have congruent and incongruent trials. Distracter had two levels: either one or three freebles could be presented along with the target figure. Half the trials were presented with one distracter and the other half with three distracters. Distracters could appear in any random location other than the target one.

Table I. MA's colors for numbers, conditioned images and sample of distracters.

MA's colors	CS+	CS-	Distracters (freebles)
1			
2			
3			
4			
5			
6			
7			
8			
9			

The experimental session was as follows. Participants were instructed that they were participating in an experiment studying their ability to transpose one spatial arrangement into another spatial arrangement. They would be shown stimuli in a 3 by 3 matrix and had to respond with the number keys of the alphanumerical keyboard therefore having to deal with two spatial maps for numbers, the one on the screen and the lineal one on the keyboard. They were instructed to look for the target image that would be a Pokemon figure and inform as fast as possible about its location. They were instructed to lay their fingers on the keys from one to four with the left hand and six to nine with the right hand and respond to five with either index finger. Speed and accuracy were requested.

The locations matrix was presented throughout the whole block. Each trial began with the locations matrix presented alone. After one second, the images appeared in some of the slots and were present until a response was given. After the response the next trial began. Since two numbers elicited a red photism (2 and 5) and two numbers elicited a yellow photism (1 and 7), the red CS+ image as well s the yellow CS+ image were shown once in each of the two locations eliciting the color figure. To equal the number of times each Pokemon image was shown, the other five Pokemon images were shown twice in their corresponding location. The way we proceeded for the CS- Pokemon was the same. Those CS- Pokemon images shown in yellow and red were presented only once in each one of their two possible locations while the rest of the Pokemon images were presented twice in their location. Therefore in each block we presented each one of the 7 CS+ Pokemon images twice and each one of the 7 CS- Pokemon images twice. This resulted in 56 trials per block (7 Pokemon images x 2 presentations x 2 Congruency x 2 Distracter)

After participants had run 10 practice trials and five blocks of 56 experimental trials each, they turned to the second part of the experiment. Here they were told that experimenters would like to use those same stimuli for other emotion experiments and we would like them to rate the images in a 7 point scale with -3 being very negative and +3 very positive. Four blocks of trials were presented and in each block 28 images were shown one by one: the fourteen Pokemon images as well as 14 of the 36 freebles used. On each trial a reproduction of the responding scale was presented along with the fixation point for 500ms. After this, the fixation point was replaced by the image to be rated. Once a rating was emitted, the next trial began.

Last, participants were told that the images had always appeared in the same position and experimenters were interested in knowing whether they could remember the position. They were asked to inform of the position of each figure by pressing the corresponding number key. Again, after a 500ms fixation point the image was presented and kept on the screen until participants hit one of the number keys. The 14 Pokemon figures were presented as well as a subset of 14 freebles included as fillers so that participants would think that freebles were also always presented in the same location.

RESULTS AND DISCUSSION

Localization task

Since we had to compare MA to the group of ten controls, we used again items (the 14 Pokemon images) instead of participants as the random factor. Therefore reaction times were averaged across participants and blocks for the control group and across blocks for MA. Trials were the correct location was not identified accounted for 8.3% for the control group and 1% for MA and were excluded from further analysis. A 2SD cut off was applied to eliminate extreme values. Since Pokemon images were the random factor, congruency between the image's color and the photism elicited by the location number was a between items factor while number of distracters and group were within item factors. We therefore carried out a mixed 2 (Congruency) x 2 (Distracter) x 2 (Group) ANOVA that yielded the following results (see Table II).

The analysis showed that MA was about 70ms faster to respond than the control group ($F_{(1,\ 12)}$=8.11, p=.015). Also, pointing out the location of the Pokemon image was faster when only one distracter was present on the screen as opposed to three ($F_{(1,\ 12)}$=25.79, p=.001). However Distracter did not interact with Group or Congruency thus showing that MA performed the task as control participants did.

Table II. Experiment 1. Mean RT and error rate for Controls and MA as a function of Congruence and Distracter number.

	Congruent		Incongruent	
Position	1 Distracter	3 Distracters	1 Distracter	3 Distracters
Controls	1291.62 (7.3%)	1330.33 (10.0%)	1294.10 (8.6%)	1366.04 (8.7%)
MA	1228.74 (0.0%)	1262.21 (0.0%)	1219.21 (0.0%)	1282.09 (3.6%)

Regarding error rates, MA was more accurate than controls since she was errorless when one distracter was present and 1.79% errors were made when three distracters were present. Control participants on the other hand were less accurate although they did also show a slightly better performance when only one distracter was present (7.96% vs. 9.36%). In regards to congruency, all errors that MA committed were when three distracters were present and the color of the Pokemon image was incongruent with the photism elicited by the slot number. No statistical analysis was carried out.

Conditioning effect

Next we analyzed the conditioning effect. Ratings for each participant were analyzed separately. A paired samples t-test was carried out to compare each participant's ratings for the CS- items and CS+ items. The rating for each time each image was presented were taken as independent measures. Since each one of the 7 CS- Pokemon and the 7 CS+ were presented four times, 28 observations per CS group were introduce into the test. Ratings for the filler freebles were not analyzed since they had not been consistently paired with any number. Table III shows the mean rating for CS- and CS+ as well as the results for the t-tests for the ten control participants and MA. As can be seen in the table, control participants did not rate negatively conditioned Pokemon images as more negative than positively conditioned ones. Only two participants showed a significant difference and it was in the direction opposite to the one expected. This result confirms that both groups of stimuli had been correctly configured as to give rise to equal evaluation when no other factor was involved. Last, we can also see that MA did not show a conditioning effect either. Her mean rating for CS- was 1.04 and for CS+ it was 1.18.

Table III. Experiment 1. Valence ratings for CS- and CS+ and percentage of positions remembered for each control and for MA.

	Mean rating			Percentage position remembered	
Subject	CS-	CS+	T-test value	CS-	CS+
1	-0.57	-0.36	T(27)= -0.57; p=.577	28.6%	28.6%
2	-0.11	-0.25	T(27)= 0.21; p=.834	42.9%	42.9%
3	1.61	0.46	T(27)= 2.41; p=.023 *	57.1%	28.6%
4	0.96	0.21	T(27)= 1.38; p=.179	14.3%	42.9%
5	1.18	1.75	T(27)= -0.97; p=.341	42.9%	28.6%
6	0.50	0.29	T(27)= 0.39; p=.709	14.3%	14.3%
7	-0.18	0.11	T(27)= -0.42; p=.678	0.0%	14.3%

8	-0.96	0.11	T(27)= -1.90; p=.068	71.4%	14.3%
9	0.14	-1.36	T(27)= 3.45; p=.002 *	14.3%	14.3%
10	2.61	2.25	T(27)= 1.67; p=.106	28.6%	14.3%
MA	1.04	1.18	T(27)= -0.48; p=.636	28.6%	14.3%
Control's Mean	0.51	0.32	T(27)= 0.59; p=.560	31.4%	24.3%

Location recall

Table III also shows the percentage of times the location of the Pokemon image was correctly recalled. It can be seen that most participants did not show a good memory for the position in which the stimuli had appeared. MA was among those showing the least recall.

Data from this experiment shows that our procedure was not successful inducing attitudes towards otherwise neutral stimuli. Reaction time and accuracy data shows that participants were performing the task correctly and therefore paying attention to the number identifying the location where the target Pokemon appeared. The conditioning effect analysis shows however that MA did not rate positively conditioned Pokemon images as significantly more positive than negatively conditioned ones. As expected, control participants did not show differences either since numbers did not have the extra color dimension that was expected to interact with the Pokemon color. Although 2 control participants did show a difference between both groups, it was in the opposite direction as that expected (i.e. they rated negatively conditioned images as more positive than positively conditioned ones).

One explanation for this lack of an effect could be that images can not be conditioned with such an indirect method. However, another reason could be that we were not sufficiently promoting the processing of the number in order for it to elicit a photism and interact with the color of the Pokemon image. The fact that slots had fit numbers could help participants learn a spatial location to finger association that would automatically occur after a certain number of trials without activating the number concept associated to that slot. If the slot to response finger mapping was strong enough, numbers would not be needed in order to respond accurately and therefore would not be attended thus not eliciting a photism. The fact that MA showed such a high accuracy in the conditioning section of the experiment and she was also faster than controls suggest that she was in fact responding based on a location-to-finger mapping basis and not on a number-to-keyboard-number mapping fashion. Also, the fact that a speeded response was requested could have made it less probable for the number to elicit a strong photism that would subsequently interact with the color of the target image. Previous studies have shown that allocation or withdrawal of attention to the inducer stimulus can modulate the degree to which the photism influences performance (Rich & Mattingley, 2005; Sagiv & Robertson, 2005). Therefore it could be that the photism for each number was not strongly experienced and thus had not interacted with the Pokemon color.

In order to address all these issues we conducted a second experiment. To minimize possible effects of this experiment on the subsequent one, a 3 year lapse was introduced between experiments.

EXPERIMENT 2a. IMPLICIT ATTITUDE FORMATION WITH EXPLICIT SYNESTHETIC INCONGRUENCE AS UNCONDITIONED STIMULUS

In order to address the possible facts influencing the null effect found in Experiment 1 we designed this second experiment. We first changed the way slots were numbered. Three different numbering systems were used and in each trial a different one could be present. This way we ensured participants would actively pay attention to the number presented in the slot in order to give an accurate response. Also, we presented the slot numbers in different colors depending on the type of trials. In those trials were a CS- was presented all the slot numbers were colored incongruently with the elicited photism. The colors used were the same ones assigned for the CS- Pokemon. Likewise, in those trials were a CS+ was presented all the numbers in the slots were colored congruently with the photism they elicited. With these two manipulations we intended to avoid the issues that could be at the basis of our null results in Experiment 1.

METHOD

Participants

MA and a group of 10 Psychology Undergraduates run this experiment. Control participants were different from those running Experiment 1. MA run this experiment three years after the first one to assure she did not remember the specifics such as the fact that each Pokemon image was always presented in the same location. Control participants' mean age was 21 and 2 of them were males.

Stimuli and material

The very same target images and distracter images used in Experiment 1 were used here. Three different numbering systems were used to identify each slot. The first one was as that of Experiment 1 (i.e. bottom to top-right to left). The second system was also right-to-left based but the first three numbers were on the top, the second three ones on the bottom and the last three numbers in the middle row (i.e. 1 was on the right in the top row and 9 was on the left in the middle row). The last system was left-to-right based with the first row in the middle, the second one on the top and the last one on the bottom (i.e. 1 was on the left in the middle row and 9 was on the right in the bottom row). Everything else was as in Experiment 1.

Design and Procedure

The same two variables, Congruency and Distracter, were manipulated. as in Experiment 1. Since the task was somewhat more difficult now due to the random numbering of the slots, we introduced a feedback sound after response for those trials were a mistake was made. The numbering systems appeared randomly across the whole experiment.

Also, since the number of conditions was larger now (56 trials x 3 different numbering systems) we run 6 experimental blocks with 56 trials each so that there were two repetitions of each trial type.

Again after the localization task participants rated the valence of each stimuli with the excuse that they would be used for another emotion experiment and they last informed of the position in which each image had appeared.

RESULTS AND DISCUSSION

Localization task

Again we averaged RTs across blocks and participants for the control group and across blocks for MA. Control participants error rate was 2.44% while MA's was 1.2%. A 2SD cut off was used to eliminate extreme values. Table IV shows mean localization RTs and error rates per group and condition.

A mixed 2 (congruency) x 2 (Distracter) x 2 (Group) ANOVA was carried out on the filtered data. We again found that MA was about 45ms faster than the control group to inform about the location of the Pokemon image ($F_{(1, 12)}$=7.29, p=.019). We also found that the target image was identified faster when only one distracter was present on the screen ($F_{(1, 12)}$=40.77, p=.001). Again we found no other significant effect in the localization data.

Table IV. Experiment 2. Mean RT and error rate for Controls and MA as a function of Congruence and Distracter number.

		Congruent		Incongruent	
Position		1 Distracter	3 Distracters	1 Distracter	3 Distracters
Controls		1230.41 (2.6%)	1339.00 (2.1%)	1217.94 (2.3%)	1279.72 (2.7%)
MA	Session 1	1208.05 (1.2%)	1253.36 (1.2%)	1180.99 (1.2%)	1241.27 (1.2%)
	Session 2	1247.88 (0.0%)	1287.63 (2.4%)	1214.81 (0.0%)	1266.56 (0.0%)

In regard to the accuracy measures controls as well as MA committed the same percentage of errors independent of number of distracters or congruency condition (for controls 2.5% errors for one distracter and 2.5% errors for three distracters; for MA, 1.2% errors for one distracter and the same percentage for three distracters). No statistical analysis was carried out.

Conditioning effect

Again we analyzed ratings for each participant independently by means of t-tests comparing CS- with CS+. Table V shows the mean rating for each participant as well as the result of the t-test. Again, controls did not show a conditioning effect. Only participant 4 and participant 6 showed a significant difference between both ratings and only in the case of participant 6 did it go in the expected direction. It could be argued that since participant 6 showed an effect, then if we also found it in MA there was no reason to rely on emotional reactions associated to inconsistent stimuli to account for the results. We could simply argue that the perceptual inconsistency between the color in which the number was presented and the color of the target image that had to be responded to it made the task more difficult and that difficulty was in turn what made those Pokemon images be liked less. However, the fact that only one out of the 10 control participants showed the pattern expected for MA suggests a different story. As mentioned in the first experiment, the images used did have a valence associated to them and we spitted them so that both groups would have similar ratings. It could well be that the a priori valence that participant 6 was not even maybe due to greater exposure to Pokemon cartoons and that explained the pattern found in the a posteriori valence rating.

Table V. Experiment 2. Valence ratings for CS- and CS+ and percentage of positions remembered for each control and for MA.

	Mean rating			Percentage position remembered	
Subject	CS-	CS+	T-test value	CS-	CS+
1	1.61	0.36	T(27)= 1.80; p=.083	14.3%	0.0%
2	0.46	0.32	T(27)= 0.19; p=.849	14.3%	28.6%
3	0.64	0.93	T(27)= -0.75; p=.460	14.3%	14.3%
4	1.79	0.82	T(27)= 2.31; p=.028 *	14.3%	0.0%
5	0.64	0.79	T(27)= -0.21; p=.833	0.0%	14.3%
6	1.79	2.07	T(27)= -2.12; p=.043 *	71.4%	28.6%
7	0.86	0.89	T(27)= -0.07; p=.941	0.0%	71.4%
8	-0.75	-0.61	T(27)= -0.11; p=.846	42.9%	42.9%
9	0.79	0.50	T(27)= 0.71; p=.486	14.3%	28.6%
10	0.68	0.29	T(27)= 0.54; p=.596	28.6%	42.9%
MA	1.57	2.00	T(27)= -1.34; p=.190	0.0%	100.0%
Control's Mean	0.85	0.64	T(27)= 0.64; p=.531	21.4%	27.2%

As can be seen, MA did evaluate CS+ as more positive than CS- but this difference was so small that it did not reach statistical significance. We will come to this result later.

Location recall

As shown in Table V, on average, control participants recalled about one fourth of the locations (27.14% for CS+ and 21.43% for CS-). MA on the contrary recalled the exact location of all the congruent stimuli (CS+: 100%) and none of the locations where the incongruently colored Pokemon had appeared (CS-: 0%). This is an interesting result that points out two different things. One, MA was influenced by the congruency between the color of each number and the color in which the Pokemon was presented as opposed to Experiment 1 where the number was not colored. Second, this result resembles that found by Smilek, Dixon, Cudahy and Merikle (2002) where they showed that congruently colored stimuli were remembered much better than incongruently colored ones being the congruency between the presented color and the photism elicited by the stimuli presented.

This new experiment went in the same direction as Experiment 1. Although MA was now more conscious of the location in which the congruently colored Pokemon images appeared, she was not so for the incongruent ones. Most important, although she did show a small difference between CS- and CS+, it did not reach significance. It seemed then that the procedure we devised either did not elicit the affective reactions associated to perceiving an incongruently colored stimulus or they did but such an affective reaction was not strong enough as to serve the function of an US. However, a closer look to MA’s recall pattern revealed a very interesting fact. When checking her actual responses for the location of the colors we realized she was just guessing and not actually remembering their location. MA chose for each Pokemon image the location of the number with a photism that matched the color of the Pokemon. Therefore this strategy yielded 100% accuracy for the CS+ Pokemon images and 0% for the CS- Pokemon images. The fact that she did not guess for the CS- images makes us think that either she did not remember the location of any of them and just used the color as a link to guess a probable location or that she did realize that one Pokemon from each color pair was in the location congruent with such color but the other one was not but she was not able to discern which one was so she just guessed for both in hopes that at least one from each pair would be right.

EXPERIMENT 2b. SECOND SESSION

Since this closer look to the data suggested she was not aware of the underlying motives for this experiment and the consistent pattern in which the images were presented, we decided to run this experiment once more to check if the lack of significance in the conditioning effect analysis was due to a high variability of the data.

METHOD

Participants

Only MA run this second session.

Stimuli and material

The same stimuli used in Experiment 2a was used here.

Design and Procedure

Three weeks after MA had run Experiment 2a we called her up again and asked her to run it again. Since she is used to coming back for second sessions so that we obtain a more stable estimate of her performance, she was not surprised to run the experiment again with that excuse.

This time, in order to check whether the rating pattern found in Experiment 2a was still there three weeks later, we started by asking her to rate the valence of each one of the images again. In order to obtain a more stable estimate, each image appeared three times in each of the four blocks. Therefore 84 samples from each group (i.e. CS- vs. CS+) were compared.

Right after a short break we run the whole experiment again. Here the Pokemon evaluation phase was as the above mentioned one with three presentations of each image in each block.

RESULTS AND DISCUSSION

On this previous evaluation phase we found that she rated one group of Pokemon images as positive as the other group (1.20 for CS- and 1.20 for CS+). Therefore the little difference found in Experiment 2a was extinguished.

The results from this second session (Experiment 2b) are reported below and can be seen in Table IV. The mixed 2 (Congruence) x 2 (Distracter) ANOVA informed that responding when only one distracter was present was faster than when two distracters were present ($F_{(1,\ 12)}$=5.73, p=.034). Congruency did not affect reaction times nor did it interact with Distracter.

Regarding the error rates, MA was again very accurate and she only deviated from perfect performance when congruent images were shown with 3 distracters (2.38% errors).

If we turn to the recall data, we found the exact same pattern as in the first session of Experiment 2. MA correctly located each of the CS+ Pokemon images and did not get one single location right. Again, she assigned the location as a function of their color. Even more interesting, since two numbers elicited yellow and two numbers elicited red, she assigned each one of the yellow Pokemon images to one of those two numbers and each one of the two red Pokemon images to one of those two red elicitor numbers. Again, it seemed as though MA was not aware that half of the Pokemon were shown in a location different from that where the color of the image matched the photism elicited by the identifying number.

Table VI. Experiment 2b. Valence ratings for CS- and CS+ before and after the conditioning phase and percentage of positions remembered after the conditioning phase for MA.

	Mean rating			Percentage position remembered	
Measurement moment	CS-	CS+	T-test value	CS-	CS+
Pre conditioning	1.20	1.20	T(83)= 0.00; p=1.0		
Post conditioning	-0.31	1.49	T(83)= -5.63; p=.001	0.0%	100.0%

Last, we checked her valence ratings for those same images she had rated 30 minutes before as equally pleasant (1.20 for CS+ and CS-). We now found that CS+ obtained a mean rating of 1.49 and CS- obtained a mean rating of -0.31. A t-test confirmed that this difference was statistically significant (T(83)= -5.63; p=.001). Therefore it seems as though a reliable conditioning effect was found and MA rated those Pokemon shown in a color different from that of the number signaling its position as more negative than those Pokemon paired with a number in its *right* color.

GENERAL DISCUSSION

With this study we wanted to further test the strength of the affective reactions reported by many synesthetes when encountering a stimulus in a color different from that elicited by such stimulus for a particular synesthete. Synesthetes' reports of these affective reactions have been gathered by a few researchers (Cytowic, 1993; Ramachandran & Hubbard, 2001b) and found to be automatic, strong and difficult to ignore by Callejas et al. (submitted, Chapter 3). Here we wanted to test whether the strength of such affective reactions would lead to the conditioning of neutral stimuli.

Using a novel paradigm introduced by Olson and Fazio (2001) we tried to condition a set of Pokemon images (CSs) using the affective reaction elicited by the mismatch between photism elicited by the number identifying the location of the image and the color of the image itself as USs. Results showed that this manipulation was not appropriate to elicit such an evaluative conditioning. In a second experiment we tried to more clearly state the stimulus dimension that would give rise to the affective reaction. In order to do so we used three different numbering systems to ensure participants engaged in a number to number mapping when responding and not in a location to key mapping. We also presented the numbers identifying the positions either in their congruent color or in an incongruent color so that both number color and target image color would be present simultaneously. This time, a small effect was found in MA's attitudes toward positively and negatively conditioned stimuli, although this difference was far from statistical significance. However, results after a second session showed that she did acquire an attitude towards the CS+ that was more positive than that shown towards the US-.

On the other hand, an important conclusion can be extracted from the results of the location recall analysis. Note that all stimuli (both CS+ and CS- of each color) were recalled as having been presented in the location identified by the number eliciting a photism that matched the image color. This is why memory was 100% correct for CS+ stimuli, which had been in fact presented in the position corresponding to its color, and 0% correct for CS-, which never were presented in the corresponding position. Therefore, the fact that location recall was perfectly driven by the color in which the Pokemon images were presented led us to think that MA was not aware of the consistent association of half the images to locations eliciting a different photism than that of the image. Also, her repeated comments regarding this experiment being one of the experiments she had done that she enjoyed the most (as opposed to her reports after Stroop or Valence Categorization experiments were she complained of many items being colored *wrong*) backed up our beliefs that she was not conscious of the Congruency manipulation.

We therefore conclude that the affective reaction triggered by an incongruently colored stimulus acted as an unconditioned stimulus and conditioned an attitude towards an otherwise neutral stimulus.

The fact that the effect was not found in the first session could be due to an insufficient number of conditioning trials for each Pokemon image. Although CS+ images were shown 168 times and CS- images another 168 times total, each Pokemon was presented only 24 times paired with its corresponding colored number. It could well be that these were not enough conditioning trials to evoke a statistically reliable effect.

Having previously found that MA rated those same Pokemon images equally independent of their CS group assured that she did not have an a priori differential preference for any of them and thus the results found in the second session of Experiment 2 can not be attributed to personal preferences for certain Pokemon images.

These results have wide implications in the understanding of how synesthesia influences synesthetes and their way to go about in a normal day basis. If a couple of hundred trials showing an image paired with a certain incongruence results in a negative attitude towards that image, a lifetime of encounters with incongruent stimuli paired with different objects could be determining their attitudes towards situations or objects such as a milk bottle for which the TV commercial shows the brand name next to the word milk in an incongruent color. Research in the field of marketing and advertising has been interested in classical conditioning as a form of attitude formation (Allen & Janiszewski, 1989; Kim, Allen & Kardes, 1996) and it is now the time to see how those findings of non-synesthetes relate to people experiencing different types of synesthesia.

CHAPTER 7

ARE SYNESTHETES THE END OF A CONTINUOM? COLOR-EMOTION RELATIONS IN NON-SYNESTHETES

ABSTRACT

It has been shown that synesthetes experience affective reactions as a consequence of interacting with a stimulus presented in a color different from the one they experience due to their synesthesia. Color congruence effects have also been found in non-synesthetes as a function of the color in which words are presented but no study has tested the factors underlying this unexpected and interesting phenomena. Here we test three variables that could modulate emotional categorization of words. We presented a group of non-synesthetes with a set of emotional words to be categorized as positive or negative according to their meaning. Words were shown in the four basic colors (i.e. yellow, blue, red and green), and either above or below the fixation point. Color preference and subjective color lightness were coded subsequently and data was analyzed as a function of these two variables together with the position. The three variables had an influence on the emotional categorization responses. Results show that participants color preference influences their categorization ratings in the same manner as color-photism match-mismatch does in synesthetes.

INTRODUCTION

Affective reactions associated to the perception of incongruently or congruently colored stimuli have long been reported by synesthetes and captured in experimental papers (Cytowic, 1993, 1995; Ramachandran & Hubbard, 2001b). Callejas, Acosta & Lupiáñez (submitted, Chapter 1) studied this issue experimentally. In a first experiment they asked MA, a previously studied female synesthete (Lupiáñez & Callejas, 2006), to rate the emotional valence of different words. Words were either congruently or incongruently colored, according to MA's photism for each word. Results clearly showed that the ratings of all kind of words were affected by their coloring, although color was completely irrelevant to the task. MA rated words as more negative when incongruently colored and more positive when congruently colored.

In order to assess the automaticity of this effect of color-photism congruence on emotional valence rating MA was asked to categorize words as either positive or negative according to their meaning. In order to make sure that MA followed instructions to focus attention on the meaning of the words, while ignoring the color, authors put great emphasis on accuracy and provided feedback on wrong categorization responses. In spite of this, results again showed that coloring affected emotional categorization. The congruency effect typically seen in synesthetes when they have to respond to a stimulus colored inconsistently with their synesthetic perceptions (i.e., faster responses to congruently colored than to incongruently colored stimuli) was only observed under certain conditions whilst it was eliminated or even reversed under certain other conditions. In the case of semantically negative words, MA was faster to categorize them as negative when they were incongruently colored than when they were colored congruently with their photism.

The authors proposed that a double assessment being carried out by synesthetes could explain the observed pattern of results. Synesthetes assess the semantic valence of the word but they also assess the congruence of the word with their subjective perception. If a positive word is colored “right” (i.e. with the color of their photism for that word), the outcome of both assessments is of the same sign. Similarly, if a negative word is presented in the “wrong” color, the outcome of both assessments is again of the same sign (in this case both outcomes would be negative). Alternatively, when a positive word is presented in the “wrong” color or a negative word is presented in the “right” color, the outcome of both evaluation processes is of a different sign. This inconsistency is ultimately what drives their performance increasing their RT and decreasing accuracy in the task. Further studies replicated this finding with another group of synesthetes (Chapter 4).

It is interesting to note however that in all experiments a congruency effect was also found for the control participants that do not experience synesthesia or explicitly reported experiencing any affective reaction when faced with words in a particular color. This congruency effect, although of a much smaller magnitude, was randomly found either in RT or accuracy measures and in the same line as the effect found in synesthetes or in the opposite direction. Since it did not follow any understandable pattern, it was discarded as an unknown effect of the colors used.

Previous work have posited the possibility that synesthesia shares the same neural mechanisms as normal multi-sensory perception (Gevers, Reynvoet & Fias, 2003; Rich, Bradshaw & Mattingley, 2005; Sagiv & Ward, in press; Simner et al, in press; Ward, 2004; Ward, Huckstep & Tsakanikos, 2006, to cite some) and have found some similar trends between synesthetically experienced colors and colors that non-synesthetes tend to associate with the same stimulus. In this sense, synesthetes would be not qualitatively different from non-synesthetes, but the extreme pole of a continuum.

Therefore, a possible explanation for the random effects that we found in the previous experiments with control participants could be that some underlying trends of color-emotion associations found in control individuals (non-synesthetes) would be influencing their semantic valence categorization of words. Supporting this explanation, early studies have associated less saturated colors with negative emotions and lighter and more saturated colors with positive emotions (Collins, 1929; Cutsforth, 1925; Hemphill, 1996) although some other researchers suggest that more liked colors are associated with more positive emotions and less liked colors with more negative emotions (Terwogt & Hoeksma, 1995). It could then be that one or both of these factors would be playing a role in our previous experiments and thus introducing noise in the overall results of the control group. Since reanalyzing this data on the basis of the fore mentioned factors was quite unattainable (for one thing, we could not go back and ask participants which color they liked more, and for another thing, congruent and incongruent colors were tailored for each synesthete), we decided to carry out a new experiment in which we systematically measured these two dimensions and tested how they affected the categorization responses.

Therefore, our aim in this study is to test whether the effects found in those previous works could be explained on the basis of subjective color preferences or subjective perceived lightness of the colors used. In order to do so we asked participants, as in previous experiments, to categorize emotional words as either negative or positive. All words were presented in different colors and, after the categorization task, participants were asked to rate these colors according to their subjective preference and their subjective lightness perception. These 2 factors were subsequently used to analyze their performance on the categorization task.

EXPERIMENT 1. VALENCE CATEGORIZATION AS A FUNCTION OF COLOR PREFERENCE AND SUBJECTIVE COLOR LIGHTNESS

In this first experiment we tested the relative influence of the four primary colors on a valence categorization task. Previous studies had suggested a link between color and emotion (Adams & Osgood, 1973; Kreitler & Kreitler, 1972; Terwogt & Hoeksma, 1995). We expected that if participants had clear preferences for a particular color and clear dislike for a particular color, their performance in the valence categorization task would be influenced by those colors and a pattern of results similar to that found in synesthetes would emerge. Positive words would be easily categorized when colored with the preferred color and negative words would be easily categorized when colored with the disliked color. Alternatively, if colors are associated to either positive or negative emotions according to their lightness (lighter colors associated to positive emotions and darker colors to negative emotions), the positive words would be easily categorized when colored with light colors, whereas negative words would be easily categorized when colored with darks colors.

Finally, we were also interested in studying the emotion-space metaphor by which emotions are associated to the up-down axis. It has been proposed that all concepts are structured through metaphoric mappings, being representative of one of the proposed primary metaphors the mapping of negative emotions down and positive emotions up (Lakoff & Johnson, 1980). Provided evidence for this metaphor, Meier and Robinson (2004) showed that positive words presented on the top half of the screen were categorized faster than when presented in the bottom half and conversely, for negative words, they were categorized faster when presented on the bottom half. In order to test this hypothesis in our study we randomly presented colored words above or below the fixation point. Our results would support the psychological reality of the *positive emotion is up-negative emotion is down* metaphor, if categorization responses for positive words were faster above fixation, whereas categorization responses for negative words were faster below fixation.

METHOD

Participants

A set of 39 Psychology undergraduate students participated in this experiment in exchange for course credits. Seven of them were males and participants' mean age was 21.

Stimuli and material

A set of 36 emotional words was used here. Half of them were negative and the other half were positive. These words were the same used in Experiment 2a of Callejas et al. (submitted, Chapter 3). Words subtended 4.7º to 9.9º horizontally and 1º vertically. Each word was presented in one of four colors: yellow (255,255,0), blue (0,0,200), green (0,225,0) and red (255,0,0). Words were presented on a neutral grey background (125,125,125)

Programming of the experiments, stimulus presentation and data collection were carried out on a 14” screen controlled by a Pentium computer running e-prime (Schneider, Eschman & Zuccolotto, 2002)

Design and Procedure

Words were presented in one of two different locations (above or below fixation point) and in one of four different colors. Therefore, three a priori variables were coded: word Position (up-5.3º above fixation point-, down-5.3º below fixation point-), word Color (yellow, blue, red and green) and word Valence (positive, negative).

Participants run 8 blocks of 72 trials each (a total of 576 trials: two trials per word, color and position). Conditions were randomly selected. Ten practice trials randomly chosen from the 72 possible conditions were run prior to the experimental blocks.

After these 8 experimental blocks, participants were asked about their color preferences for the colors presented and their subjective lightness. In order to do so, pairs of color patches were presented on the screen and participants had to choose one color from each pair. Each color was paired with the other three colors totaling 6 different combinations (12 if we take into account the two positions in which the pair of colors could be presented –one color of the pair either to the left or to the right of the other-). Each of the 12 combinations was presented on 3 different occasions in a random order to obtain a more stable judgment. In the first assessment block participants were asked to choose the color of the pair they liked the most. In the second of these assessment blocks participants were asked to choose the color they thought was the lightest as opposed to the darkest one.

Two new variables were coded once the experiment was run to take into account participants’ responses in these last two blocks. These variables were called color Preference (most liked vs. most disliked) and color Lightness (lightest vs. darkest). The procedure used to code these variables is explained in the results section.

At the beginning of each trial a black fixation point appeared on a grey background for 500ms. It was then followed by the target word that was kept on the screen until subject’s response. Participant’s task was to categorize words as positive or negative according to their meaning. Auditory feedback was given if the word was not categorized correctly. After response (or feedback sound) the next trial began.

For the last two blocks, after fixation, two colored rectangles appeared at either side of the fixation point. Participants had to choose the preferred one or the lightest one (depending on the block) by pressing the key that was aligned with the color in the screen (left key if they chose the color of the left rectangle and right key if they chose the color of the right rectangle). As mentioned above, each color pair was presented in both positions so that half the time one color of the pair appeared on the left and the other half on the right. Rectangles were presented on the screen until response, after which the next trial began.

RESULTS AND DISCUSSION

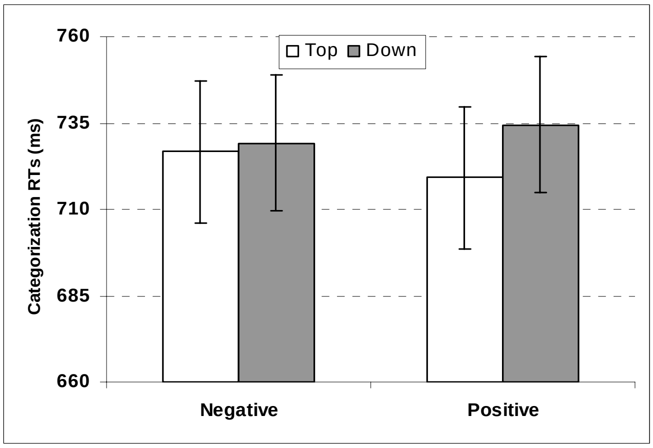
Reaction time analysis.

Trials were words had been incorrectly categorized (5.6%) were eliminated from the RT analysis. A 2SD cut off was set to eliminate outliers. Two different analysis were carried out, one taking items (I, i.e., words) as random factor (as in Experiment 2a of Callejas et al., submitted, Chapter 3) and another taking participants (P) as random factor[1]. Response times for each word and coloring condition were averaged across blocks and participants. A mixed ANOVA was carried out on the a priori set of variables with 2 (Valence), 2 (Location) and 4 (Color) as factors. Table I shows the mean reaction times and error rates for the item analysis.

Table I. Experiment 1. Mean reaction times and error rates (in parenthesis) per experimental condition for the general analysis.

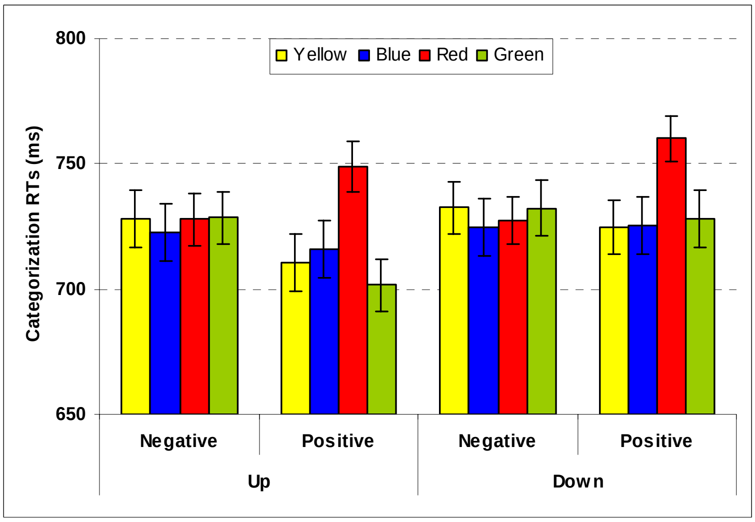
	Valence							
	Positive				Negative			
Position	Yellow	Blue	Red	Green	Yellow	Blue	Red	Green
Top	710.60 (7.1%)	715.66 (6.6%)	748.93 (8.4%)	701.59 (6.6%)	727.89 (10.0%)	722.83 (9.7%)	727.71 (8.3%)	728.45 (13.2%)
Down	724.71 (7.5%)	725.24 (6.5%)	760.24 (9.5%)	727.80 (6.2%)	732.42 (10.0%)	724.76 (10.6%)	727.40 (8.5%)	732.38 (12.5%)

[1] Graphs and Tables shown were elaborated with the means for the item analysis.



Graph 1. Experiment 1. Reaction times as a function of valence and location. Error bars denote standard error of the mean.

Words presented on the upper half of the screen were responded to faster than those presented on the bottom half (I: $F_{(1, 34)}$=10.70, p=.002; P: $F_{(1, 38)}$=6.91, p=.012). This location effect was modulated by Valence (I: $F_{(1, 34)}$=5.50, p=.025; P: $F_{(1, 38)}$=6.47, p=.015). As shown in Graph 1, when words were negative, the location in which they appeared did not influence response times (I: F<1; P: F<1). However, when positive words were presented on the upper part they were responded to faster than when presented in the lower part (I: $F_{(1, 34)}$=15.77, p=.001; P: $F_{(1, 38)}$=18.63, p=.001).



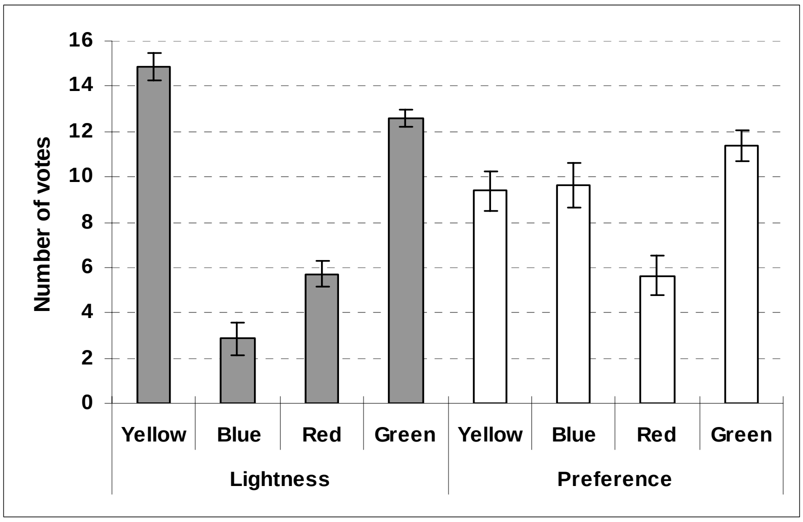
Graph 2. Experiment 1. Reaction times as a function of color, valence and location. Error bars denote standard error of the mean.

The Color in which the word was presented also influenced categorization times (I: $F_{(3, 102)}$=20.38, p=.001; P: $F_{(3, 114)}$=20.97, p=.001). Red was slower than any other color (I: all ps<.001; P: all ps<.05) and all other colors did not differ (I: all ps>.9; P: all ps<.9). This influence was modulated by Valence (I: $F_{(3, 102)}$=23.19, p=.001; P: $F_{(3, 114)}$=13.64, p=.001). As can be seen in Graph 2, red positive words were slower than all other positive words (I: all ps<.001; P: all ps<.05).

This result clearly shows that red does not seem to be associated with positive emotions, since positive red colored words where slower than any other word type irrespective of subjective color Preference or Lightness. Previous work carried out in the field of anthropology (D'Andrade & Egan, 1974) showed that across cultures, terms with negative connotations were paired with purplish and yellow-red hues while terms with positive connotation were more consistently paired with blue-green colors. In respect to location, we found that it does in fact play a role in the conceptualization of emotions although its specific influence is yet not clear-cut.

In order to discern whether these effects were modulated by participant's preferences in color and their subjective perception of lightness, we carried out another analysis with the aforementioned a posteriori coded variables Color Preference and Color Lightness. We first coded the number of votes that each participant assigned to each color in the Preference Judgment and in the Lightness Judgment. Graph 3 shows the results for those ballots. A subsequent ANOVA was carried out in order to check which of those differences were statistically significant. The analysis for Preference showed that green was the most preferred color and red the most disliked color. Blue and yellow obtained intermediate values. A post hoc test showed that only red was different from the other three colors (all ps<.5). For the Lightness ballot we found that yellow and green were the lightest colors (no difference among them, p<.07) and blue was the darkest one (all ps<.02).

By looking at Graph 3 we cannot discern whether the slowest RT for positive words presented in red is due to red being the most disliked color or to red being one of the darkest colors. Therefore, in order to distinguish between these two possibilities we recoded the color variable as color Preference and color Lightness. In order to code for Preference we assigned a value from 1 to 4 to each color for each participant according to their Preference votes. The four-value was assigned to the most voted color and the one-value was assigned to the least voted color. We then recoded the different conditions as a function of the assigned values. This way, the subsequent analyses did not take into consideration the specific color that was presented but the subject's rating for that color and so the most preferred color could be yellow for one subject and blue for another. The coding of the Lightness variable followed the same logic but now using the Lightness voting in order to assign values to colors.



Graph 3. Experiment 1. Mean number of votes per color for Subjective Lightness and Subjective Preference.

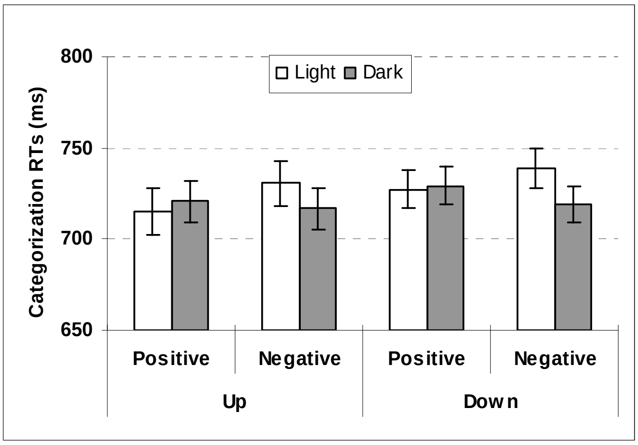
Although this method introduced a considerable amount of data noise since the preferences for some subjects were much more defined than for others, we believed this was the most recommendable way to proceed as opposed to only taking into account those participants with a clear Preference choice. In any case, if we still found any statistically significant results that would add strength to our conclusions. Mean reaction times and error rates for the Lightness analysis and the Preference analysis can be seen in Table II.

Table II. Experiment 1. Mean reaction times and error rates (in parenthesis) per experimental condition for the Lightness analysis and the Preference Analysis.

	Lightness analysis				Preference analysis			
	Positive		Negative		Positive		Negative	
Position	Light	Dark	Light	Dark	Preferred	Disliked	Preferred	Disliked
Top	715.29 (6.7%)	720.71 (7.4%)	730.49 (10.6%)	716.64 (8.9%)	707.69 (6.1%)	737.14 (7.8%)	728.68 (10.8%)	726.38 (9.8%)
Down	727.40 (7.7%)	729.33 (7.7%)	738.56 (9.8%)	719.32 (9.7%)	719.90 (6.6%)	741.38 (8.6%)	732.91 (10.8%9	729.33 (10.0%)

Lightness analysis.

A mixed ANOVA was carried out with the factors Valence x Position x color Lightness. Only the lightest and darkest rated colors were introduced in the analysis. Data was again averaged across participants and repetitions for the item analysis, and across items for the subject analysis. As shown in Graph 4 responses to negative words were not different from responses to positive words (I: F<1; P: F<1). When the words were displayed in the darkest color, responses were faster than when they were presented in the lightest color, although this was significant only for the items analysis (I: $F_{(1, 34)}$=5.48, p=.025; P: F<1). This effect was modulated by word Valence (I: $F_{(1, 34)}$=13.52, p=.001; P: $F_{(1, 34)}$=6.48, p=.015), since negative words were categorized faster when colored in dark colors (I: $F_{(1, 34)}$=18.11, p=.001; P: $F_{(1, 34)}$=6.74, p=.014,) while positive words were categorized slightly faster when colored in light colors, although the difference was clearly not significant (I: F>1; P: $F_{(1, 34)}$=1.93, p=.174). Last, location influenced reaction times (I: $F_{(1, 34)}$= 3.45, p=.072; P: $F_{(1, 34)}$=4.38, p=.044) and words presented on the top half were categorized faster. However, it did not modulate Valence or Lightness.



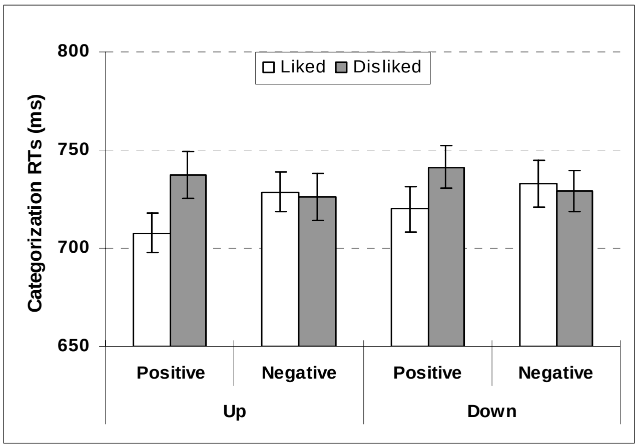
Graph 4. Experiment 1. Lightness analysis. Mean RTs for light and dark colors as a function of position and valence. Error bars denote standard error of the mean.

Results show that perceived lightness does influence responses to word categorization although this effect seems to only be present for negative words. It could be the case that negative words are more susceptible to color lightness than positive words are. However it is more probable that the effect might have to do with the colors chosen and while the darkest colors we presented seemed to actually be *coherent* with negative emotions, the lightest colors might not have been the most adequate ones. Nevertheless, the fact that an effect was found is in itself an encouragement to extend research and fully understand the factors that play a role in the relationship between lightness and emotions.

Regarding location, the previous analysis showed that location did influence word categorization in a different manner in negative and positive words. The fact that this effect was not found here could be due to the smaller sample used. While in the previous analysis all the experimental trials were included, here only those trials for which the color present had been categorized as the darkest or lightest one were introduced. Therefore, only half of the data is shown here. Again, such a subtle effect might need of a large sample to show in statistical analyses.

Preference analysis.

Another mixed ANOVA was carried out taking Valence, Position and Preference as factors. Again, only the most liked and most disliked colors were included into the analysis. Once more, responses to positive and negative words were similarly fast (I: F<1; P: F<1). Subjects' color Preference did influence response times (I: $F_{(1, 34)}$=12.76, p=.001; P: $F_{(1, 38)}$=13.81, p=.001) as words presented in the disliked color took longer to respond than those presented in the liked color. This effect modulated Valence (I: $F_{(1, 34)}$=20.28, p=.001; P: $F_{(1, 38)}$=15.16, p=.001).



Graph 5. Experiment 1. Preference analysis. Mean RTs for liked and disliked colors as a function of position and valence.

As shown by planned comparisons (see Graph 5), participants were faster to categorize a positive word if it was colored in their preferred color (I: $F_{(1, 34)}$=32.5960, p=.001; P: $F_{(1, 38)}$=30.41, p=.001) and slower to categorize a negative word when it was colored in their preferred color although this last difference did not approach significance (F<1; P: F<1). Location did not influence categorization times.

Results show that categorization times were also influenced by the color preference that participants had. As found with our synesthetes, when a positive word was presented in the preferred color, it was categorized significantly faster than when presented in a disliked color. Negative words did not seem to be permeable to color preference influence. This result is interesting in the sense that it mirrors that found in several occasions with different synesthetes who do report experiencing discomfort when perceiving incongruent stimuli.

Accuracy analysis.

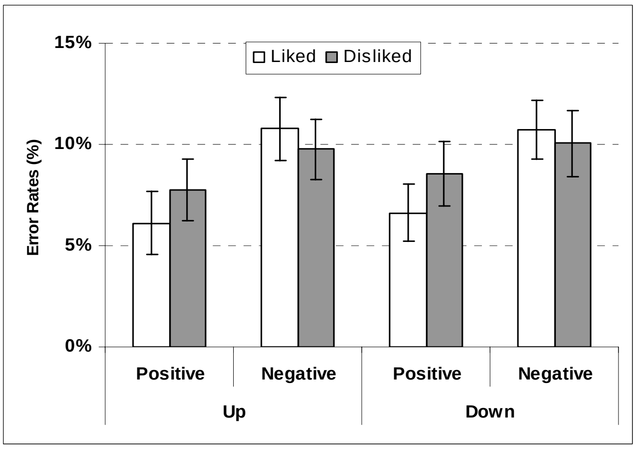
The ANOVA with Valence, Position and Color as factors showed a main effect of Valence but only significant for the subjects analysis (I: $F_{(1, 34)}$=2.06, p=.160; P: $F_{(1, 38)}$=14.53, p=.001) where negative words were more error prone than positive words. Color also influenced accuracy (I: $F_{(3, 102)}$=2.74, p=.047; P: $F_{(3, 114)}$=2.55, p=.059) with green being the color that led to more categorization mistakes. This effect was influenced by Valence (I: $F_{(3, 102)}$=18.41, p=.001; P: $F_{(3, 114)}$=9.77, p=.001) due to the fact that while negative words tended to give rise to more mistakes than positive words, this was not the trend for green where a similar amount of errors were made independent of word valence.

Lightness analysis.

The same ANOVA was carried out for the error rate using the recoded variable Lightness. None of the main effects or interactions reached significance for the items analysis. Negative words were less accurate than positive words for the subjects analysis (I: $F_{(1, 34)}$=1.49, p=.230; P: $F_{(1, 34)}$=6.13, p=.018). The patterns of results mirrored that of the RT data.

Preference analysis.

The Valence x Position x Preference ANOVA yielded a significant main effect of Valence for the subjects analysis (I: $F_{(1, 34)}$=2.37, p=.133; P: $F_{(1, 38)}$=9.96, p=.003), which was modulated by Preference (I: $F_{(1, 34)}$=7.70, p=.009; P: $F_{(1, 38)}$=3.76, p=.060). As can be seen in Graph 6, planned comparisons showed that positive words were categorized more accurately if they were presented in the preferred color (I: $F_{(1, 34)}$=7.00, p=.013; P: $F_{(1, 38)}$=6.12, p=.018) whereas negative words were influenced by color Preference in the opposite direction, although not significantly (I: $F_{(1, 34)}$=1.64, p=.209; P: $F<1$). Therefore the results went in the same direction as the reaction time data. Positive words were easier to categorize if colored on the preferred color while negative words were not significantly influenced by color.



Graph 6. Experiment 1. Preference analysis. Mean error percentage for liked and disliked colors as a function of position and valence. Error bars denote standard error of the mean.

Experiment 1 showed that the evaluation of the valence of the word can be modified by certain factors. Specifically we found that the three variables analyzed did show an influence on performance. Location mainly influenced positive words but not negative words. When a positive word was presented on the upper part of the screen, response was facilitated as compared to when it was presented on the lower half. It is interesting that this effect was only found for positive words. Negative words were categorized as fast when presented on the top or the bottom. This result partially replicates Meier and Robinson’s study (2004) where they found that positive words were categorized faster when presented on the upper part and negative words categorized faster when presented on the bottom half. Their words were presented 4 inches above fixation. At normal viewing distance 4 inches would entitle about 10º visual angle. Our stimuli were presented at 5.7º; about half way. It could be that these distances were not good enough to completely activate the up-down representation of emotions.

Also, contrary to what would be expected, we found that red was not associated with positive emotions since positive red colored words were the slowest ones to be categorized. This finding clearly contradicts common sense dictating that warm colors are associated to positive emotions while cold colors are associated to negative emotions.

Regarding Lightness, we did find that it influenced response times. Negative words were responded to faster if colored dark than when colored light. Positive words were not influenced by color. If we turn to the Preference analysis positive words are responded to faster if colored with the preferred color while negative words were not influenced by coloring preference. Therefore the hypothesis about the possible relationship between Lightness, Preference and emotions were somehow backed up by the data. It could be concluded that positive material is susceptible to location and color preference while negative material is susceptible to lightness influence. However, the selection of colors used was not wide enough as to make such strong claims. It could well be that the colors used and their specific shade interacted in such a way but other colors would behave differently. It could also be that the effects are subtle and the sample size was not large enough to extract such a subtle difference from the general variability. In our view, the critical conclusion from this first experiment is that the three variables manipulated do influence valence categorization.

Observing the voting patterns we noticed that in the Lightness ballot Yellow and Green were the lightest colors and Red and Blue the darkest ones. In the Preference ballot, although more distributed, Green was the most liked one and Red the most disliked one. The same color that was most consistently liked by participants was also a color that was most consistently though of as the lightest color. Similarly, the most disliked color was also in the darkest color category. Except from Blue, the other three colors seemed to follow a light-liked dark-disliked pattern.

Although Lightness seemed to only affect negative words and Preference only positive words, when looking at the patterns of results it can be observed that the influence of Lightness for one level of valence is usually eliminated or reversed for the other level of valence. It is likewise for color although some of the post-hoc comparisons are not significant). Therefore, it could be that since this is a subtle effect, more observations were needed to eliminate noise.

One way of doing so would be to obtain data from some more participants and another way would be to bias their responses in the color evaluations and see if that influenced the results. In an attempt to do so we run a second experiment in which we studied the possible relationship between color Preference and color Lightness and how using slightly different colors would influence valence categorization. We turned green into a dark color. If participants now chose green as the most disliked color, we would have evidence in favor of the hypothesis that color preference is based on lightness and independent of hue. In order to still have two darker and to lighter colors we changed blue into a very light version of the same hue. Also, to try to maximize the location effect we used a larger screen so that the top and bottom conditions were even more distinctive.

EXPERIMENT 2. FOLLOW UP

This experiment was designed to study the influence of different lightness-hue combinations on color Preference. We also tried to maximize the Location effect previously found by using a larger distance between from the up and down words to the central fixation point. Last, we expected to replicate and extend the results found in Experiment 1.

METHOD

Participants

A different set of 42 Psychology undergraduate students participated in this experiment in exchange for course credits. Seven of them were males and participants mean age was 21.

Stimuli and material

The same set of 36 words was used in this experiment. Each word was presented in one of four colors: yellow (255,255,0) and red (255,0,0) were exactly the same as in the previous experiment. Blue was lighter (100,100,255) and green was darker (0,100,0). The size of the screen was now 19”. Therefore the words were 7.28º below or above fixation point. Everything else was kept the same as in Experiment 1.

Design and Procedure

Everything was exactly the same as in Experiment 1.

RESULTS AND DISCUSSION

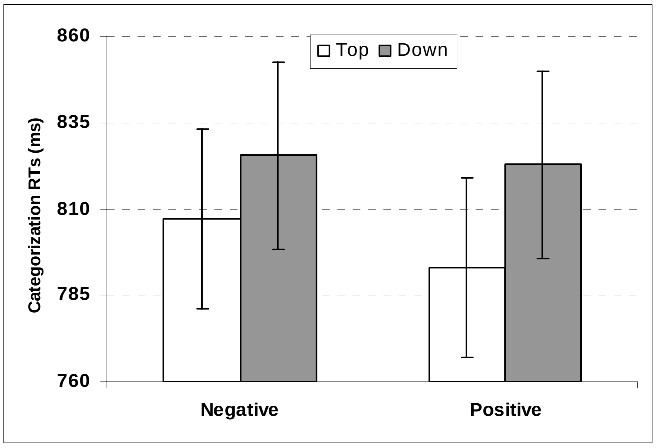
Reaction time analysis.

Trials were words had been incorrectly categorized (7.32%) were eliminated from the analysis. A 2SD cut off was set to eliminate outliers. Again items (words) and participants were used as random factor in separate analyses. A mixed ANOVA was carried out on the a priori set of variables with 2 (Valence), 2 (Location) and 4 (Color) as factors and the mean reaction times and error rates are shown in Table III.

Table III. Experiment 2. Mean reaction times and error rates (in parenthesis) per experimental condition for the general analysis.

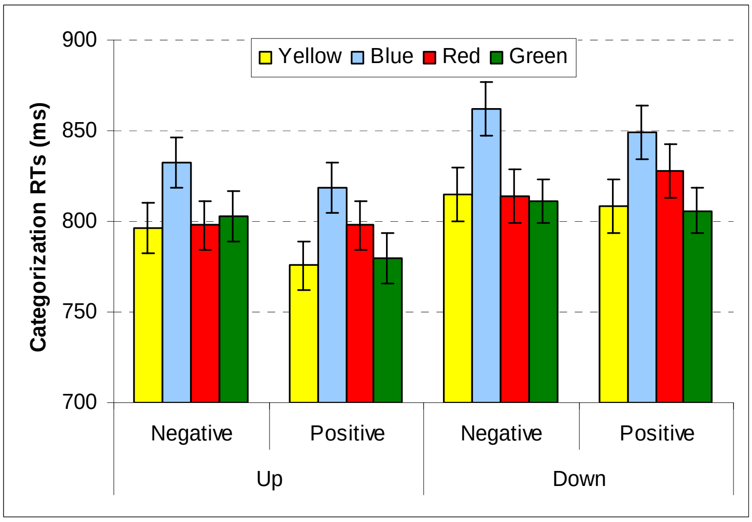
	Valence							
	Positive				Negative			
Position	Yellow	Blue	Red	Green	Yellow	Blue	Red	Green
Top	775.52 (4.0%)	818.76 (4.2%)	797.74 (5.6%)	779.66 (3.9%)	796.27 (7.1%)	832.46 (8.3%)	797.76 (5.5%)	802.60 (8.5%)
Down	808.14 (3.9%)	849.13 (4.2%)	828.21 (6.7%)	805.73 (3.3%)	814.68 (6.2%)	861.78 (6.6%)	814.16 (5.0%)	811.16 (7.7%)

The main effect of Location was again significant, as words presented on the upper half of the screen were responded to faster than those presented on the bottom half (I: $F_{(1, 34)}$=116.26, p=.001; P: $F_{(1, 41)}$=55.99, p=.001). This location effect was again modulated by Valence (I: $F_{(1, 34)}$=6.90, p=.013;S: $F_{(1, 41)}$=4.57, p=.038, see Graph 7). When words were negative, the location in which they appeared influenced reaction times less than when words were positive although in both cases presenting the word on the top half yielded faster reaction times (I: both ps<.05; P: negative words: p=.078; positive words: p=.002).



Graph 7. Experiment 2. Reaction times as a function of valence and location. Error bars denote standard error of the mean.

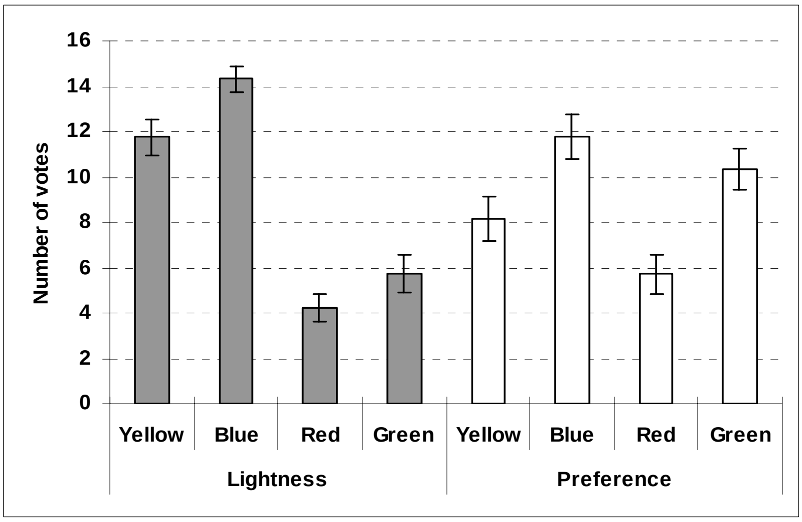
The Color in which the word was presented also influenced categorization times (I: $F_{(3, 102)}$=55.18, p=.001; P: $F_{(3, 123)}$=48.85, p=.001). Blue was now slower than any other color (I: all ps<.001; P: all ps>.001) and all other colors did not differ (I: all ps>.1; P: all ps>.5). This influence was modulated by Valence (I: $F_{(3, 102)}$=3.86, p=.012; P: $F_{(3, 123)}$=3.42, p=.019). Although blue was the slowest color, the interaction was not due to this color but again to red. As shown by separate analysis, when only yellow, blue and green were taken into account, no hint of interaction was found (I: F<1; P: F<1) whereas when the same analysis was done now including only yellow, red and green, the interaction was significant (I: $F_{(2, 68)}$=5.46, p=.001; P: $F_{(2, 82)}$=5.80, p=.005). As can be seen in Graph 8, red colored words were slower only when positive.



Graph 8. Experiment 2. Reaction times as a function of color, valence and location. Error bars denote standard error of the mean.

The fact that blue showed the same pattern as green and yellow and also the same pattern found in Experiment 1 for those three colors, with the only difference of a constant 40ms increase, might be showing that this increase in reaction time for blue was due to perceptual factors. In fact the light blue color used was slightly more difficult to see against the grey background than the other colors and this could be accounting for such a constant increase in RTs.

A subsequent ANOVA was again carried out in order to check the pattern of color subjective Lightness and color Preferences. The analysis for Preference showed that green was still highly preferred although blue was now very popular too. Yellow obtained intermediate values and red was again the least liked color. A post hoc test showed that only red was different from the other three colors (all ps<.05). As for the Lightness ballot we found that now yellow and blue were categorized as the lightest colors (no difference among them, p<.1) and red and green the darkest ones (no difference between them, p<.5). Both light colors were statistically different than both dark colors (all ps<.001). Therefore our manipulation was successful and participants did perceive green as darker and blue as lighter now (see Graph 9).



Graph 9. Experiment 2. Mean number of votes per color for Subjective Lightness and Subjective Preference. Error bars denote standard error of the mean.

An ANOVA comparing the Preference ballots for both experiments showed that there was no interaction between Experiment and color Preference ($F_{(3,\ 213)}$=1.15, p=.331). This shows that subjects were in fact giving their Preference judgment in Experiment 1 and it was not influenced by the Lightness of the color. Green and blue are widely liked colors independent of their lightness. This was well complemented with the analysis for Lightness judgment across experiments. Here we found a significant interaction between both variables ($F_{(3,\ 237)}$=56.01, p=.001) due to blue and green. Blue was now categorized as much lighter ($F_{(1,\ 79)}$=164.79, p=.001) and green as much darker ($F_{(1,\ 79)}$=52.28, p=.001).

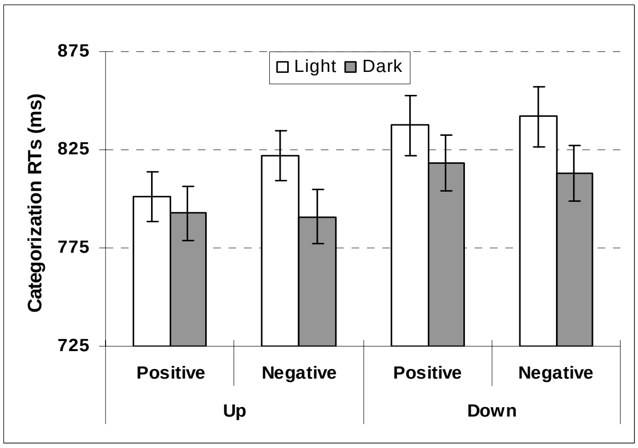
Again a separate analysis was carried out for Lightness and for Preference and mean reaction times and error rates can be seen in Table IV.

Table IV. Experiment 2. Mean reaction times and error rates (in parenthesis) per experimental condition for the Lightness analysis and the Preference Analysis.

	Lightness analysis				Preference analysis			
	Positive		Negative		Positive		Negative	
Position	Light	Dark	Light	Dark	Preferred	Disliked	Preferred	Disliked
Top	801.13 (4.8%)	792.71 (4.9%)	822.10 (7.2%)	790.88 (6.7%)	791.64 (3.7%)	790.24 (4.5%)	816.97 (8.5%)	791.73 (5.8%)
Down	837.47 (3.9%)	817.99 (4.8%)	841.88 (6.7%)	813.18 (6.7%)	820.36 (4.1%)	826.00 (4.2%)	837.66 (7.5%)	820.48 (6.2%)

Lightness analysis.

A mixed ANOVA was carried out with the factors Valence x Position x color Lightness. Only the lightest and darkest rated colors were introduced in the analysis. Data was again averaged across participants and repetitions in item analysis and across items and repetitions in the subject analysis. As shown in Graph 10 responses to negative words were not different from responses to positive words (I: F<1; P: F<1). Responses when the words were displayed in the lightest color were slower than responses when they were presented in the darkest color (I: $F_{(1, 34)}$=40.25, p=.001; P: $F_{(1, 41)}$=15.20, p=.001). This effect was modulated by word Valence but only for the items analysis (I: $F_{(1, 34)}$=5.35, p=.027; P: $F_{(1, 41)}$=1.85, p=.181). Negative words were categorized faster when colored in dark colors (I: p=.001; P: p=.018) while positive words were not influenced by the lightness of the color (I: p>.2; P: p>.3). Last, location influenced reaction times (I: $F_{(1, 34)}$= 59.01, p=.001; P: $F_{(1, 41)}$=37.21, p=.001) and words presented on the top half were categorized faster. However, it did not modulate Valence or Lightness.

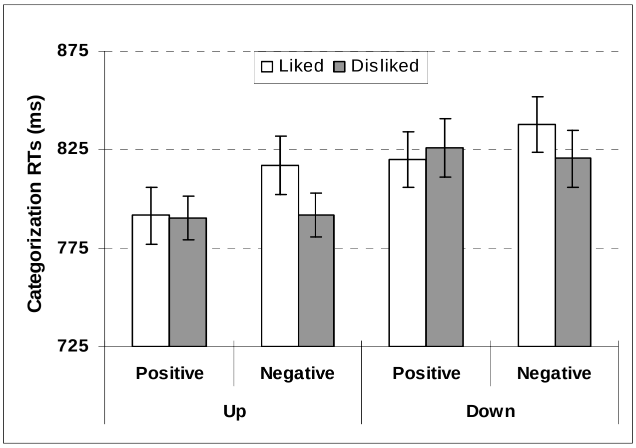


Graph 10. Experiment 2. Lightness analysis. Mean RTs for light and dark colors as a function of position and valence. Error bars denote standard error of the mean.

All the results found in Experiment 1 were replicated here. Darker colors were responded faster, color Lightness only influenced negative words and words presented on the top half were categorized faster. It seems then that the effects found in the previous experiment were not due to the specific shades used but to the relative brightness of the colors presented since in the previous experiment the light color category was mostly made out of green and yellow and the darkest category made out of blue and red and in this experiment blue was now a light color and green a dark one.

Preference analysis.

Another mixed ANOVA was carried out taking Valence, Position and Preference as factors. Again, only the most liked and most disliked colors were included into the analysis. As in previous analyses words were rated as fast when they were negative or positive (I: F<1; P: $F_{(1, 40)}$=1.03, p=.317). Position did influence response times now (I: $F_{(1, 34)}$=63.67, p=.001; P: $F_{(1, 40)}$=31.94, p=.001) and the pattern went in the same direction as in the previous analysis (i.e. words presented on the top were categorized faster). The main effect of Preference was significant (I: $F_{(1, 34)}$=6.23, p=.017; P: $F_{(1, 40)}$=6.12, p=.018) but now preferred words took longer to respond than disliked words. This effect modulated Valence (I: $F_{(1, 34)}$=9.32, p=.004; P: $F_{(1, 40)}$=6.25, p=.017). As shown by planned comparisons (see Graph 11), participants were much slower to categorize a negative word if it was colored in their preferred color (I: $F_{(1, 34)}$=15.39, p=.001; P: $F_{(1, 40)}$=11.55, p=.002) and were not influenced by color when categorizing a positive word (I: F<1; P: F<1).



Graph 11. Experiment 2. Preference analysis. Mean RTs for liked and disliked colors as a function of position and valence. Error bars denote standard error of the mean.

Therefore, we found some apparent contradictions with the previous experiment. Location showed up to influence reaction times here as it did in Experiment 1. However, the interaction with Valence was somewhat more confusing here. Even though it was reliable and we replicated the results from Experiment 1 because positive words presented on the top were responded to faster than positive words presented on the bottom, the same pattern was found for negative words. We expected negative words to be responded to faster if presented on the bottom part but we found the opposite. They, as well, were categorized faster when presented on the top. This advantage was of a smaller magnitude than the one found for positive words.

In any case, this result does not fit well with Meier and Robinson (2004). Nevertheless, their paradigm differed from ours in an important point. While we just presented a fixation point followed by the target word, they presented, prior to the target word, a cue at fixation and subsequently at 1.5 and 3 inches away from it. This was followed by the target word at distance 4 in. They were therefore promoting the allocation of attention to the hemifield (upper vs. lower) where the word would appear. It could be that our manipulation was not good enough to activate the up-down axis representation of emotions and it just shows a general tendency to stimuli appearing on the top to be processed faster. It might be that the spatial metaphor only acts when the Upper vs. Lower location where the word appears is the location being attended. The faster RT to words appearing at the upper hemifield might be taken as evidence that participants were attentionally biased towards the upper hemifield, especially in this experiment in which the eccentricity was increased as compared to the previous experiment.

Regarding color preference, while in Experiment 1 words in the preferred color were categorized faster than those in the most disliked color, here we found the opposite pattern. Also, while in Experiment 1 positive words were categorized faster when colored in the preferred color and no influence was observed for negative words, the contrary was found here. No color Preference was seen in positive words whereas a significant effect emerged for negative words. Although contradictory at first, these results could be explained by the abnormal effect of blue. Blue was found to be the slowest color to be responded to and we suggest this was due to the increased difficulty in reading blue colored words when shown in the neutral grey background.

If we go back to the Preference results, blue was the most liked color in Experiment 2. Therefore, trials with blue colored words were the ones contributing the most to the preferred color condition in this analysis. Blue was a constant 40ms slower than yellow and green. Adding this general increase in RT could account for the inverted main effect of Preference given that in Experiment 1 disliked colors were on average 11ms slower than liked colors and here liked colors were on average 9ms slower than disliked colors. Likewise, a general increase in the preferred color RT (blue) would make RTs go up leaving disliked color RTs unaffected (darker colors). A general increase in preferred color RT would make preferred color positive words slower than before and therefore as fast as disliked color positive words. It would also slower reaction time for preferred color negative words and since they were already equal to those of disliked color negative words, they would become slower giving rise to the observed pattern of results.

Accuracy analysis.

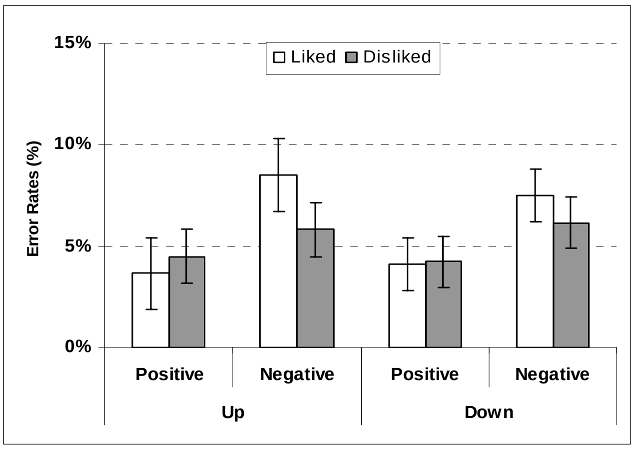
The ANOVA with Valence, Position and Color as factors showed no main effect of Color (I: F<1; P: F>1) but a Color modulation by Valence (I: $F_{(3, 102)}$=12.46, p=.001; P: $F_{(3, 105)}$=8.92, p=.001) due to the fact that positive words were usually more correctly categorized than negative words except when they were colored red. Last, negative words tended to be less accurate but only in the subjects analysis (I: $F_{(1, 34)}$=1.54, p=.223; P: $F_{(1, 35)}$=11.78, p=.002). No other effect was significant.

Lightness analysis.

The same ANOVA was carried out for the error rate using the recoded Lightness variable. Only Valence was significant and only in the subject analysis (I: $F_{(1, 34)}$=1.38, p=.249; P: $F_{(1, 41)}$=10.71, p=.002). No other main effect or interaction reached significance. The pattern of results mirrored that of the RT data.

Preference analysis.

The Valence x Position x Preference ANOVA yielded a significant Effect of Valence (I: $F_{(1, 34)}$=2.32, p=.137; P: $F_{(1, 40)}$=18.76, p=.001) and Preference (I: $F_{(1, 34)}$=2.81, p=.103; P: $F_{(1, 40)}$=5.51, p=.024) but only in the subject analysis. Negative words gave rise to more mistakes as well as preferred words. This last effect could be due to blue words being amongst the preferred ones and also the most difficult color to perceive because of the grey background. Also the interaction between Valence and Preference was reliable (I: $F_{(1, 34)}$=7.39, p=.010; P: $F_{(1, 40)}$=3.99, p=.053).



Graph 12. Experiment 2. Preference analysis. Mean error percentage for liked and disliked colors as a function of position and valence. Error bars denote standard error of the mean.

As can be seen in Graph 12., planned comparisons showed that negative words were categorized more accurately if they were presented in the disliked color (I: $F_{(1, 34)}$=9.66, p=.004; P: $F_{(1, 40)}$=6.06, p=.018) whereas positive words were not influenced by color Preference (I: F<1; P: F<1). Again, this is the same pattern we found for the RT analysis.

Results from this second experiment seem to replicate those found in Experiment 1. The same results were found regarding the influence of Position, color Lightness and color Preference than in Experiment 1. Independent of the hue, lightness influenced valence categorization. In a similar manner, independent of lightness, color hue influenced valence categorization. Last, position of the word also affected performance although the larger screen and therefore larger difference between both positions didn't seem to have a clear influence on performance in the expected direction.

GENERAL DISCUSSION

The main goal of these experiments was to study the extent to which colors can affect non-synesthete individuals in a valence categorization task. Since previous works had related color preference with emotions as well as color lightness (Collins, 1929; Cutsforth, 1925; Hemphill, 1996; Terwogt & Hoeksma, 1995) and we had previously found random color congruency effects in other valence categorization experiments (Callejas et al., submitted, Chapter 3) we wanted to test whether those effects were due to some identifiable factor.

In order to test these ideas we modified the experiment previously used to assess color effects on synesthetes and adapted it to the present situation. We manipulated the color in which the words were presented as well as the lightness of those colors and their position in the screen.

Results across experiments showed that positive words are consistently mapped onto the top-down axis although negative words did not clearly show the opposite effect. While negative words did in fact take longer to be categorized if presented on the top half (as compared to positive words) they were still faster than if presented on the bottom half. This result replicates previous findings in our lab where words were presented in neutral color on the top vs. bottom of the screen and vocal response was given. A significant interaction was found between position and emotion.

Last, our failure to completely replicate Meier and Robinson's results (2004) could be due to the fact that prior to word presentation they repeatedly cued the location in which the word was going to appear and therefore further testing will be necessary to check this possibility.

In regards to lightness again we found a modulation of categorization times in Experiment 1 and replicated it in Experiment 2. Negative words were more influenced by lightness than positive words. This could be due to the small range of lightness we used. Even though different colors had different lightness, extreme values such as extremely dark blue or extremely light green (i.e. bluish-black or greenish-white) were not used. It could be the case that those more extreme lightness levels would modulate categorization times for positive words.

Likewise, a color preference effect was found where preferred colors aided in the categorization of positive words (Experiment 1) and hindered the categorization of negative words (Experiment 2). Again, these results show that subtle but consistent color preference effects are found when non-synesthetes categorize emotional words. It is important to note that these effects were found using an extremely low number of colors and it is more than possible that none of the presented colors were in fact the favorite color for many of the participants. Still, with a forced choice among 4 colors we found these stable effects. If we tailored the experiment for each participant as we do for synesthetes showing them a wide variety of colors and obtaining their most liked and most disliked colors, we would predict that the effects we glanced here would show in much larger degree.

The question now remains whether this effect found in non-synesthetes shares any resemblance to the congruency effect found in synesthetes when categorizing the valence of emotional words presented either in the congruent color or in the incongruent color. Assuming that synesthetes' results are due to the affective reaction caused by the match-mismatch between the presented color and the internally experienced photism as Callejas et al. (submitted, Chapter 3) showed, the question would be whether color preference in non-synesthetes is also accompanied by an affective reaction although of a much smaller magnitude. By definition, a preference towards something implies that the valence of that something is larger than that of the alternative choice. What makes these results interesting then is that we do not seem to be conscious of the fact that our color preferences affect our performance. This seems to be an implicit influence. Nonetheless, a post experimental questionnaire investigating the subjective experiencing when categorizing words in different colors was not collected so we cannot categorically state whether participants clearly felt that some words were colored *wrong* according to their meaning or not. Further research will show to what extent this influence of color Preference on emotion categorization is similar to that found in synesthetes.

Last, regarding the proposed relationship between colors and emotions (Terwogt & Hoeksma, 1995) we can conclude that, although general trends might be there in the general population that point to some colors being more associated to positive emotions than others, it seems to be the individual color preference what sets the individual correspondences between colors and emotions. A possibility that is worth investigating is that cultural color-emotion associations are part of our explicit knowledge and individual color-emotion pairings are more implicit and depending on the context and task we explicitly use the cultural correspondences or implicitly get affected by the individual correspondences.

RESUMEN DE RESULTADOS

En la primera sección de esta investigación estudiamos el efecto de la atención en la sinestesia. En el Capítulo 1 utilizamos una tarea de Stroop sinestésico. Presentamos un conjunto de letras y números coloreados y pedimos a nuestra participante sinestésica (MA) que nombrara el color en que estaba presentado cada estímulo. Mediante la manipulación del color presentado en la pantalla y el experimentado por MA, para cada letra o número, obtuvimos condiciones congruentes e incongruentes. Cuando, tanto el color presentado como el fotismo experimentado eran iguales, encontramos que MA era más rápida que en las condiciones en la que el color no encajaba con el fotismo experimentado. Por lo tanto se encontró un efecto Stroop.

Para averiguar si los colores reales interfieren con los fotismos y comparar la magnitud de ambos efectos realizamos un segundo experimento Stroop, en el que MA tenía que nombrar el color del fotismo experimentado para cada estímulo e ignorar el color en que se presentaba dicho estímulo. De nuevo el color presentado podía encajar o no con el fotismo experimentado para cada letra o número. Aquí encontramos que, de nuevo, MA era más lenta al nombrar el color del fotismo cuando no encajaba con el color en que el estímulo estaba presentado. No obstante, mientras que nombrar el fotismo de un estímulo coloreado de manera incongruente la hacía ser unos 47ms más lenta que nombrar el fotismo de un estímulo coloreado congruentemente, cuando la tarea era la contraria y tenía que nombrar el color de un estímulo coloreado incongruentemente MA tardaba 285ms más que cuando el color a ser nombrado encajaba con el fotismo evocado por el estímulo. Esos resultados se interpretaron como evidencia a favor de que la activación del fotismo es bastante fuerte e interfiere con la tarea de nombrar el color real en que el estímulo está coloreado.

Este experimento se diseñó para que, reanalizando los mismos ensayos, se pudiera tomar una medida de Priming Negativo (PN, Tipper, 1985). Analizando los ensayos en los que el color de la dimensión previamente ignorada se convertía ahora en el color de la dimensión a la que había que responder pudimos medir la capacidad de MA para inhibir la información relevante y así realizar la tarea correctamente. Encontramos un efecto significativo de priming negativo para la tarea de nombrar el fotismo pero no para la tarea de nombrar el color. Esto es, cuando MA tenía que ignorar el color presentado en la pantalla, para responder diciendo el fotismo experimentado, ella era capaz de inhibir de manera satisfactoria la activación proveniente del color presentado en la pantalla y, como consecuencia, en el ensayo posterior en el que el nombre del fotismo evocado por el estímulo presente era el mismo que el del color que se había ignorado en el ensayo previo, su respuesta era más lenta. Sin embargo, cuando el fotismo era la dimensión distractora que tenía que inhibir, para responder correctamente al color presentado, MA no era capaz de inhibirlo y por lo tanto, cuando esa misma información era necesaria en el ensayo posterior, estaba fácilmente accesible (cuenta de ello fue la presencia de un efecto de priming positivo, aunque no significativo desde el punto de vista estadístico).

En el Capítulo 2 continuamos con el estudio del papel de la atención en la sinestesia. Siguiendo estudios previos (Smilek, Dixon, Cudahy y Merikle, 2001; Palmeri y cols., 2002; Ramachandran y Hubbard, 2001a) diseñamos una tarea de búsqueda visual en la que nuestra participante sinestésica tenía que encontrar un rectángulo creado con una de tres posibles letras e informar de si se encontraba en posición horizontal o vertical. Las letras utilizadas se escogieron de manera que dos de ellas compartían el mismo fotismo (letra “M” y letra “N”) y dos de ellas compartían las mismas características de percepción (“M” y “W”). Con este diseño podíamos, por lo tanto, disociar el grado relativo con que la forma de la letra ayudaba a la búsqueda y compararlo con el beneficio obtenido por el fotismo evocado por cada letra. Por lo tanto predijimos que, si los fotismos se experimentan antes de que la letra sea reconocida, entonces encontrar un rectángulo echo de letras “W” y escondido entre letras “N” y letras “M” sería más fácil que buscar un rectángulo hecho de cualquiera de las otras dos letras puesto que la “W” evocaba un color rosa-violáceo mientras que las otras dos letras evocaban el color amarillo. Por otro lado, si el fotismo se experimenta tras el reconocimiento explícito de la letra, entonces no sería capaz de ayudar en la búsqueda puesto que para el momento en que el fotismo se experimentara, la letra ya se había identificado y por lo tanto se había encontrado el rectángulo. En este caso esperaríamos que un rectángulo creado con letras “N” sería el más fácil de encontrar puesto que era perceptivamente distinto de los distractores. En el primer experimento encontramos que MA realizó la tarea igual que los participantes control. Era más rápida en encontrar un rectángulo cuando estaba formado por letras “N” y no mostró un patrón distinto en la búsqueda de la “M” y la “W”. No obstante, tendió a cometer más errores cuando el rectángulo estaba formado por “Ms” que cuando estaba formado por “Ws”.

En un segundo experimento incluimos una clave previa que informaba a los participantes de la letra que formaría el rectángulo para que supieran qué letra (o color en el caso de MA) buscar. De nuevo encontramos que su ejecución era mejor para la

“N” que para cualquier otra letra y era tan rápida encontrando un rectángulo formado de “Ms” que de “Ws”. No obstante, volvimos a encontrar que era mucho más exacta por los conjuntos estimulares en los que tenía que encontrar una “N” o una “W” que en los que tenía que encontrar una “M”.

Puesto que los controles mostraron el mismo patrón de resultados aunque con una magnitud menor y, por lo tanto, las diferencias mayores entre MA y el grupo control se encontraban con medidas de exactitud, llevamos a cabo otros dos experimentos en los que estudiamos estas diferencias de exactitud. Mediante la presentación del conjunto estimular durante un intervalo temporal relativamente corto (1000ms o 1500ms) medimos la cantidad de ensayos en los que la dirección del rectángulo era indicada correctamente. Los participantes sin sinestesia cometieron más errores cuando tenían que identificar un rectángulo hecho de letras “M” o de letras “W” y no encontraron una mejoría en la condición en la que los estímulos se presentaban durante más tiempo. Para MA encontramos que cuando el conjunto estimular estaba presente durante poco tiempo, la búsqueda de un rectángulo hecho de letras “M” era más difícil que la búsqueda de cualquier otra letra. En la condición donde el conjunto estimular estaba presente durante más tiempo volvimos a encontrar que la letra “M” era la más difícil de localizar. Además, ahora la letra “N” era más fácil de encontrar que la “W” por lo que el mayor tiempo de presentación del conjunto estimular mejoró de forma diferencial la búsqueda basada en la forma pero no la búsqueda basada en el color.

Por último, estábamos interesados en comparar los resultados descritos con aquellos que se encontrarían si los colores evocados por las letras estuvieran de hecho presentes en la pantalla. En el último experimento mostramos los mismos conjuntos estimulares hasta que los participantes indicaban una respuesta, pero ahora las letras “N” y “M” se presentaban coloreadas de amarillo y la letra “W” coloreada de violeta. Al contrario de lo realizado en otros estudios (e.j. Hubbard, Arman, Ramachandran y Boynton, 2005), también pedimos a MA que realizara esta versión de la tarea. Encontramos que realizó la tarea de forma similar a los controles, aunque ella fue en general más rápida en responder. Esto pudo deberse al hecho de que tenía práctica extensiva con esta tarea. En particular, encontró los rectángulos formados por la letra “W” más rápido que los formados por la letra “M” y estos a su vez más rápido que los formados por la letra “N”. Estos resultados muestran claramente que en los experimentos anteriores MA estaba identificando los rectángulos formados por la letra “N” con más facilidad debido a su forma. Por lo tanto, parece que por lo menos para

MA, el reconocimiento consciente de la letra es necesario para experimentar el fotismo asociado a la misma y beneficiarse de ello.

En este segundo capítulo también estábamos interesados en estudiar la capacidad de MA para ignorar una dimensión de un estímulo que era incongruente con el fotismo evocado por el estímulo, cuando atendía a otra dimensión que sí era congruente con dicho fotismo. Realizamos una versión mejorada del estudio de Rich y Mattingley (2003), en el que presentamos un conjunto de estímulos jerárquicos del estilo Navon, donde una forma global estaba hecha a base de distintas formas locales. Manipulamos la consistencia entre la letra formando la forma global y la letra formando la forma local y también manipulamos la congruencia entre el color presentado y el fotismo evocado por cada una de las formas. Por último, también manipulamos la dimensión del estímulo a la que había que prestar atención (la dimensión global o la dimensión local) y pedimos a nuestra participante sinestésica y al grupo control que nombraran el color del estímulo presentado en la pantalla. Entre otros resultados encontramos que, cuando una de las dos dimensiones estaba coloreada incongruentemente con el fotismo evocado, independientemente de que fuera la dimensión a la que se prestaba atención o la dimensión ignorada, la ejecución se vio afectada en comparación con los casos en los que ambas dimensiones estaban coloreadas congruentemente. Este resultado es consistente con los encontrados en el experimento de Stroop-Priming Negativo llevados a cabo en el capítulo anterior ya que habíamos encontrado que ignorar el fotismo era más difícil que ignorar el color presentado. Aquí había que ignorar el fotismo evocado por la dimensión atendida y el evocado por la dimensión ignorada (a veces eran iguales y a veces distintos) para poder responder al color presentado en la pantalla. Los resultados muestran que MA no fue capaz de ello y el fotismo de la dimensión a ignorar afectaba la ejecución aumentando el efecto de congruencia.

Tras encontrar que la atención es necesaria para procesar la identidad del estímulo, para que este a su vez evoque un fotismo, pero insuficiente para ignorar la dimensión irrelevante de un estímulo, en la segunda sección nos interesamos por estudiar las reacciones afectivas comentadas por nuestra partícipante sinestésica así como por algunos investigadores (Cytowic, 1993; Ramachandran y Hubbard, 2001b).

En el Capítulo 3 mostramos, por primera vez, que estas reacciones afectivas son verdaderas, automáticas y difíciles de ignorar y que ocurren como un efecto secundario de la percepción de un estímulo coloreado de forma congruente o incongruente con el fotismo que evoca para una persona sinestésica particular. En primer lugar pedimos a MA que evaluara la valencia de un conjunto de palabras claramente emocionales o claramente neutrales como pueden ser amor, miedo o mesa. Encontramos que aunque las palabras se evaluaban correctamente y las positivas obtenían valores más positivos que las negativas, el color en que las palabras se habían presentado influía en sus juicios de evaluación. Cuando las palabras estaban presentadas en el mismo color en que MA las había coloreado previamente las evaluó como más positivas en general que cuando estaban presentadas en un color incongruente. En un nuevo experimento se comprobó si MA había obtenido este patrón de resultados porque no entendió las instrucciones y también intentamos medir la automaticidad de estas reacciones afectivas. En esta ocasión solo mostramos las palabras emocionales y no las neutrales y le pedimos que las categorizara a la mayor brevedad como positivas o negativas presionando una de dos teclas. Si la reacción afectiva experimentada como consecuencia del encaje o ausencia del mismo entre el color presentado y el fotismo experimentado es automática, entonces interactuaría con la valencia de la palabra y daría lugar a más errores porque una respuesta rápida no daría lugar a que los procesos de control actuaran para hacer que se emitiera una respuesta de acuerdo con las instrucciones. Esto es exactamente lo que se encontró. Cuando las palabras positivas se coloreaban congruentemente, MA daba una respuesta rápida y acertada. Cuando las palabras positivas se presentaban en color incongruente era más lenta y cometía más errores. Sin embargo, para las palabras negativas se obtuvo el patrón contrario. Si estaban coloreadas congruentemente, los tiempos de reacción eran más largos y se cometían mas errores. Si estaban coloreadas de manera incongruente, los tiempos de reacción eran más rápidos y la respuesta más exacta. Aunque lo único que MA debía hacer era informar de la valencia de las palabras y no tenía que dar un juicio subjetivo, y aunque se emitiera un sonido de retroalimentación cuando cometía errores, incluso así, le resultó relativamente difícil responder en los casos en los que la valencia de la palabra no encajaba con la reacción afectiva producida por la relación entre el color presentado y el fotismo evocado.

En el Capítulo 4 estudiamos a otros tres participantes sinestésicos con el mismo procedimiento y encontramos el mismo patrón de resultados. Mostraron un efecto de congruencia APRA las palabras positivas y una modulación del mismo para las palabras negativas. Sin embargo, la tercera participante sinestésica que estudiamos ni siquiera mostró un efecto de congruencia. Tardaba lo mismo en categorizar una palabra emocional, cuando estaba coloreada congruentemente con su fotismo, que cuando el color era incongruente. Experimentos posteriores mostraron que presentaba un gran efecto Stroop muy similar al mostrado por MA en el Capítulo 1. Le costaba más trabajo ignorar sus fotismos, cuando tenia que responder al color en que se presentaba un estímulo, que ignorar dicho color para responder nombrando sus fotismos. Sin embargo no mostró indicios de efecto de priming negativo para la tarea de nombrar el fotismo ni para la tarea de nombrar el color. El hecho de que no se encontrara dicho efecto indica que esta participante sinestésica no era capaz de inhibir sus fotismos pero tampoco de inhibir el color real presentado en la pantalla. Uniendo esto a los resultados de la tarea de categorización, los resultados sugieren que cuando la tarea a realizar es difícil y se promueve el procesamiento del color (como es el caso en las tareas Stroop), los fotismos sí influyen en su ejecución y esta influencia es fuerte y difícil de inhibir. Sin embargo, cuando la tarea es más difícil y el procesamiento del color no se promueve (cual es el caso en la tarea de categorización emocional de un conjunto de palabras) sus fotismos sí son capaces de ser inhibidos o simplemente no son lo suficientemente fuertes como para influir en su ejecución.

Otro experimento se llevó a cabo para comprobar esta hipótesis. Se presentaron a esta participante sinestésica el mismo conjunto de palabras en los mismos colores y a la estudiada en el capítulo 1 y se les pidió que las categorizaran en función de otra dimensión que esperamos que activara el fotismo de manera más potente. Les pedimos que indicaran si las palabras estaban coloreadas correcta o incorrectamente de acuerdo a sus fotismos. En esta ocasión encontramos que en ambas participantes se observaba un patrón de respuesta más lento y más errores cuando las palabras positivas estaban coloreadas incorrectamente que cuando las negativas lo estaban correctamente.

Por último, para asegurarnos de que este resultado no se debía a una contaminación del hecho de que responder “si” es más fácil cuando la palabra es positiva y responder “no” más fácil cuando la palabra es negativa que en las condiciones inversas, realizamos un experimento control en el que pedimos a personas sin sinestesia que indicaran si las mismas palabras estaban coloreadas correctamente o incorrectamente basándose en un criterio que aseguraba que accederían a su representación semántica. Encontramos que los participantes control no eran más rápidos respondiendo “si” a palabras positivas y “no” a palabras negativas de lo que lo eran en las situaciones opuestas. Por lo tanto, los resultados de nuestras dos participantes sinestésicas no se debían a esta variable extraña sino a una interacción entre la valencia de la palabra y el encaje entre color y fotismo.

A continuación estábamos interesados en explorar los factores que influían en la percepción de un color particular como incongruente. Estaba claro que una palabra o letra presentada en el color en el que el sinestésico había informado percibirla era una palabra coloreada congruentemente. Sin embargo, en los Capítulos 3 y 4 observamos que presentar palabras en negro no parecía influir a los sinestésicos cuando era en un contexto bloqueado. Hasta este momento habíamos utilizado el color opuesto, en la rueda de color, al color congruente como color incongruente para asegurar que era claramente distinto del congruente. Para explorar las razones por las que el negro no parecía interferir en la ejecución de las participantes sinestésicas condujimos una serie de experimentos presentados en el Capítulo 5.

Pedimos a nuestra sinestésica MA que realizara una tarea de evaluación de valencia emocional similar a la realizada en el Capítulo 3, pero ahora manipulamos los colores que presentábamos y el contexto en que se presentaban. Palabras coloreadas en negro se presentaron en un contexto cromático (es decir, mezcladas de forma aleatoria con palabras coloreadas congruente e incongruentemente) para comprobar si el estatus del negro como color neutral cambiaba y si ahora se percibía como un color más. También presentamos las palabras en gris que es un tono más luminoso de blanco en un contexto cromático y en uno acromático para comprobar si produciría los mismos efectos que el negro. Por último, aprovechando el hecho de que la percepción de color está basada en claves contextuales de contraste relativo entre el objeto percibido y los que lo rodean, presentamos el mismo tono de gris pero cambiando las claves contextuales para que se percibiera como blanco. Con estos experimentos encontramos que el negro producía un patrón similar al de los colores incongruentes cuando se presentaba en un contexto de color y algo similar ocurrió para el gris. Cuando se presentaba aislado, los juicios de valencia eran más acertados que cuando se presentaba en un contexto de color. Sin embargo, esta diferencia seguía siendo mucho más pequeña que la encontrada para el caso del negro. Por último, cuando las mismas palabras en el mismo color eran percibidas como blancas dieron lugar a un patrón de evaluación más positivo en general. Este último resultado subraya la importancia de la experiencia subjetiva en la evaluación de lo agradable que es un estímulo.

En el Capítulo 6 avanzamos un paso más y estudiamos la fuerza de estas reacciones afectivas. Para ello comprobamos si eran lo suficientemente fuertes como para servir de estímulo incondicionado en un paradigma de condicionamiento clásico. Intentamos inducir de forma implícita actitudes hacia un conjunto de imágenes (dibujos de Pokemon) colocándolas en una localización espacial identificada con un número y coloreándolas de manera que encajaran con el color evocado por el fotismo del número o no. Si las reacciones afectivas eran suficientemente fuertes, entonces deberían de servir como estímulos incondicionados.

En un primer experimento no encontramos ningún efecto de condicionamiento y eso puede deberse al hecho de que la relación entre el fotismo evocado por el número y el color del Pokemon no era suficientemente explícita. En un segundo experimento incrementamos el nivel de procesamiento del número que indicaba la localización en que se presentaba la imagen y también mostramos el número en color congruente o incongruente en vez de mostrar en color sólo la imagen del Pokemon. Después de dos sesiones de condicionamiento encontramos que las actitudes de MA a cerca de las imágenes estaban influidas por el emparejamiento con un estímulo incondicionado positivo o negativo y por lo tanto los estímulos condicionados positivos eran evaluados como más positivos que los condicionados negativamente. Por lo tanto condicionamos un conjunto de imágenes mediante su emparejamiento con la ocurrencia de una reacción afectiva positiva o negativa fruto de la congruencia o incongruencia entre el color presentado y el fotismo evocado.

En nuestro último capítulo experimental (Capítulo 7) nos interesamos por estudiar la población no sinestésica y exploramos el patrón de resultados que habíamos obtenido para los participantes control a lo largo de los experimentos ya comentados. Los participantes no sinestésicos mostraban un efecto de congruencia por el cual realizaban la tarea de forma distinta en función de la congruencia sinestésica. No obstante, este patrón aparecía de forma aleatoria en tiempos de reacción o en porcentaje de errores y en unas ocasiones iba en la misma dirección que en el grupo control y en otras en dirección opuesta. Aunque el patrón exacto parecía aleatorio, el hecho de que este efecto se encontraba en muchos de los estudios realizados nos llevó a explorarlo con más detalle e intentar encontrar una explicación para él.

Para comprobar qué variables estaban influyendo en este resultado estudiamos el efecto de la claridad de los colores y de la preferencia de color de los participantes. También comprobamos el efecto de la localización espacial en que se encontraba el estímulo objetivo. En dos experimentos mostramos a un amplio grupo de participantes no sinestésicos un conjunto de palabras que se habían utilizado con anterioridad en experimentos de sinestesia y emociones. Las presentamos en cuatro colores (amarillo, azul, rojo y verde) y, tras pedir a los sujetos que las categorizaran como positivas o negativas en función de su significado, les pedimos que nos informaran sobre cuál de los cuatro colores les gustaba más y cuál de ellos era el más claro.

Los datos se recodificaron en función de la preferencia de color y de la claridad subjetiva y se encontraron algunos datos bastante sorprendentes. Los participantes no sinestésicos mostraron exactamente el mismo patrón que habían mostrado anteriormente los participantes sinestésicos, de modo que la categorización de la valencia de una palabra estaba influida por atributos del color en que se presentaba la palabra. Cuando se presentaban en el color preferidolos participantes eran más rápidos en categorizar una palabra positiva que una negativa. De manera opuesta, si se presentaban en el color menos preferido, los participantes categorizaban las palabras negativas con más facilidad que las positivas. En relación con la claridad subjetiva se encontró un patrón similar de resultados. En general, estos resultados mostraban que los efectos de congruencia aleatorios encontrados en experimentos previos para participantes no sinestésicos podrían deberse a factores como la preferencia por un color u otro.

GENERAL DISCUSSION

SUMMARY OF FINDINGS

In the first section we studied the effect of attention on synesthesia. In Chapter 1 we used a synesthetic Stroop task. We presented a set of colored letters and numbers and asked our synesthete to name the color in which they were presented. By manipulating the presented color with that experienced by the synesthete for each particular letter or number we arrived at congruent and incongruent conditions. When both presented color and experienced photism were the same we found that she was faster than in those cases were the color was not matching her experienced photism. Therefore a Stroop effect was found. In order to test whether real colors would interfere with photisms and compare both interference effects, we conducted a second Stroop experiment in which MA had to now name the photism she experienced for each stimuli and ignore the color in which it was presented. Again the color could either match or mismatch that of the experienced photism for each stimulus. Here we found that again MA was slower to name the photism when it did not match the presented color. However, while naming the photism of an incongruently colored stimulus took about 47ms longer than naming the photism of a congruently colored stimulus, naming the color of an incongruently colored stimulus took 285ms more than when the color to be named matched the photism for that stimulus. This result was interpreted as evidence that the photism activation is quite strong and it interferes with naming the actual color in which a stimulus is presented.

This experiment was designed so that the very same trials could be used to measure Negative Priming (NP, Tipper, 1985). By analyzing those trials were the color of the ignored dimension became now the color of the to-be- responded-to dimension we could measure how satisfactorily our synesthete was inhibiting the irrelevant information to correctly perform the task. Here we found that a significant NP effect for the photism naming task but not for the color naming task. That is, when she had to ignore the presented color in order to respond to the experienced photism she was able to successfully inhibit that activation coming from the presented color and therefore it was more difficult to respond in the next trial where that previously inhibited information was now the correct response. However, when she had to inhibit the distracting photism information in order to correctly respond to the presented color she was not successful in doing so and so when such information was needed in the following trial it was readily accessible (therefore a non-significant positive priming effect).

In Chapter 2 we continued to study the role of attention in synesthesia. Following previous experiments (Smilek, Dixon, Cudahy & Merikle, 2001; Palmeri et al., 2002; Ramachandran & Hubbard, 2001a) we designed a visual search task in which our synesthete had to find a rectangular shape made out of one of three letters and inform of its position (i.e. vertical or horizontal). We chose the display letters in a way that two of them shared the same photism (letter “M” and letter “N”) and two of them shared the same perceptual features (“M” and “W”). With this design we could dissociate the relative degree to which the letter shape aided in the search and compare it to the benefit obtained by the photism elicited by each letter.

Therefore we predicted that if photisms are experienced prior to letter recognition, finding a rectangular shape made out of letter “W” and embedded among letters “N” and “M” would be easier than finding a rectangle made out of any other letter since “W” elicited a purplish photism while “M” and “N” elicited a yellow photism. On the other hand, if the photism was experienced after letter recognition, then it would not aid in the search (i.e. by the time it was experienced the letter was already identified and the rectangular shape found) and we would expect a rectangle made out of letter “N” to be found faster than when it was made out of letter “M” or “W” because it was perceptually different. In our first experiment we found that MA did not perform differently than control participants. She was faster to find the rectangular shape when it was made out of letter “N” and did not show a differential pattern for letter “M” and “W”. However she tended to commit more errors when the rectangle was made out of letter “M” than when it was made out of letter “W”.

In a second experiment we included a visual cue that informed participants of the letter that would be making up the rectangle so that they knew what letter (or color in MA’s case) to look for. Again we found that her performance was better for letter “N” than any other letter and she was as fast finding a rectangle made out of “Ms” than if it was made out of “Ws”. Nevertheless we again found that she was much more accurate for displays were she had to look for an “N” or a “W” than for displays were the target as a rectangle made out of “Ms”.

Since controls showed the same pattern although with a smaller magnitude, we conducted two more experiments to test this accuracy differences. Presenting the display for a brief duration (1000 or 1500ms) we measured the amount of trials were the direction of the figure was correctly categorized. Non-synesthetes made more errors when having to identify a rectangle made out of “Ms” or “Ws” and the time the display was presented did not aid them in the search. For MA we found that she in the short display duration looking for an “M” was more difficult than any other letter. For the longer display duration, “M” was still the most difficult one. Adding to this now “N” was easier to find than “W” so a longer display differentially aided shape based search but not color based search.

Last we were interested in comparing the described results with a case were the colors elicited by the stimuli were actually present on the screen. In this last experiment we showed until response the same displays but now letter “N” and letter “M” were colored in yellow and letter “W” colored in purple. Contrary to other studies (i.e. Hubbard, Arman, Ramachandran & Boynton, 2005) we also asked our synesthete to run this version of the task. Here we found that she performed somewhat like control participants did. Although she was overall faster than them (probably due to extensive practice with this task), she found it very easy to identify the location of a rectangle made out of “Ws” and easier to identify if it was made out of “Ms” than if it was made out of “Ns”. These results clearly show that MA was performing better for letter “N” in the first experiments because she was being led by the differential shape. When that benefit was eliminated and now the letters were actually colored, she was much worse to find a rectangular shape if made out of “Ns” than if made out of any other letter. It therefore seems clear that, at least for MA, conscious recognition of the letter is necessary to experience the associated photism and find a benefit from it.

We were also interested in finding how good was MA ignoring the dimension of a stimulus that was incongruent with its elicited photism when attending to another dimension that was congruent with the elicited photism. We run an improved version of Rich and Mattingley’s (2003) experiment. We presented a set of navon like stimuli where a global form was made out of local forms. We manipulated the consistency between the letter forming the global form and the local form and also the congruency between the presented color and the photism elicited by either or both forms. We also manipulated the dimension of the stimulus to which attention was being paid (i.e. global dimension or local dimension) and asked our synesthete and the corresponding control group to name the color of the stimulus presented on the screen. Among other results we found that when either dimension was incongruently colored, irrespective of whether it was the attended or the ignored dimension, performance was hindered as compared to cases were both dimensions were congruently colored. This result is consistent with the Stroop-NP experiment we had previously carried out since there we found that ignoring the photism was more difficult than ignoring the presented color. Here she had to ignore the photism elicited by the attended dimension as well as the photism elicited by the ignored dimension (sometimes these were two different photisms and sometimes it was just one) in order to respond to the color presented. Results show that she was not successful in doing so and the photism of the to-be-ignored dimension still affected performance giving rise to a congruency effect.

After having found that attention was necessary as to process the identity of the stimulus to then elicit a photism but ineffective to filter out an irrelevant dimension of the stimulus, in Section 2 we turned to studying the affective reactions reported by our synesthete MA as well as other researchers (Cytowic, 1993; Ramachandran & Hubbard, 2001b).

In Chapter 3 we showed for the first time that these affective reactions are true, automatic and difficult to ignore reactions happening as a side effect of perceiving a stimulus colored congruently or incongruently with the photism that it elicits for a given synesthete. Here we first asked our synesthete MA to rate the valence of a set of clearly emotional or clearly neutral words such as love, fear or table. We found that, although words were correctly rated and clearly positive words were rated more positive than clearly negative words, the color in which the words were presented influenced her rating values. When words were presented in the same color that MA had previously reported seeing them, she rated them as more positive overall than in those cases where they were presented in an incongruent color.

A new experiment was run in order to test whether this effect had been due to MA not understanding the instructions and also to test the automaticity of these affective reactions. We now only showed her the emotional words and not the neutral ones and asked her to categorize them as positive or negative as fast as possible by hitting one of two keys. If the affective reaction consequence of the match-mismatch between the presented color and the experienced photism was automatic, then it would interact with the valence of the word and would give rise to more mistakes because a fast response would not allow for control processes to come into play and align the response to that requested. This is exactly what we found. When positive words were congruently colored, MA was fast and accurate in her response. When positive words were incongruently colored, she was slower and less accurate in her response. However, the opposite pattern was found for negative words. If they were congruently colored, reaction times were longer and more errors were made. If they were incongruent, reaction times were faster and fewer errors were made. Even though MA just had to inform about the word’s valence and did not have to give a subjective rating and even though auditory feedback was given when errors were made, she still found it relatively hard to respond in these cases were the valence of the word did not match her affective reaction for that word.

In Chapter 4 we tested another three synesthetes and found the same pattern of results in two of them. They showed a congruency effect for positive words and a modulation of such effect for negative words. However, the third synesthete we tested did not even show a hint of a congruency effect. She was as fast to categorize an emotional word when it was congruently colored as when it was incongruently colored. Subsequent experiments showed she presented a large Stroop effect very similar to that found by MA in Chapter 1. It was more difficult for her to ignore her photisms when having to respond to the presented color than in the opposite case. Ignoring the presented color in order to respond to the subjectively experienced photism did not seem a hard task. However, she did not show a hint of negative priming in neither the photism naming task nor in the color naming task. The fact that no effect was found indexes that this synesthete (PSV) was not able to inhibit her photisms but neither did she inhibit the real color presented on the screen. Put together with the categorization task, these results suggested that when the task is easy and color processing is promoted (i.e. in the Stroop tasks), photisms do influence her performance and such influence is strong and difficult to inhibit. However, when the task is more difficult and color processing is not promoted (i.e. valence categorization of a set of words) her photisms are either successfully inhibited or they are not strong enough as to influence performance.

Another experiment was run to test this hypothesis. The same set of words in the same colors were shown to PSV and MA and now we asked them to categorize the words according to another dimension that we expected would activate the photism to a higher level. We asked them to respond whether the words were correctly color according to their photisms or not. We now found that both of them showed increased latency and error rates when a positive word was incorrectly colored or a negative word was correctly colored.

Last, to make sure this was not due to a confound where saying “yes” to positive words and saying “no” to negative words was faster than the other two conditions, we run a control experiment in which non-synesthetes had to inform whether the same words were correctly or incorrectly colored according to a given criteria that ensured they would access their semantic representation. We found that they were not faster when responding “yes” to a positive valence word or “no” to a negative valence word than when they had to say “no” to a positive word or “yes” to a negative word. Therefore the findings of our two synesthetes were not due to this confounding but to an interaction between the color-photism match-mismatch and the word valence.

Next we were interested in exploring the factors influencing the perception of a given color as an incongruent one. It was clear to us that a word or letter presented in the color that they synesthete had chosen for it was a congruently colored stimulus. However, in Chapters 3 and 4 we observed that presenting the words in black ink did not seem to upset our synesthetes much when it was a blocked presentation. Up to this moment we had used the color-wheel opposite of the congruent color as incongruent color thus ensuring it would be clearly different than the congruent one. In order to explore the reasons why black did not seem to interfere in our synesthetes performance we run a series of experiments reported in Chapter 5.

We asked our synesthete MA to perform a task like the valence rating task of Chapter 3 but now we manipulated the colors presented and the context in which those colors were presented. Black was presented in a chromatic context (i.e. randomly intermingled with congruent and incongruent colors) to check whether its neutral status would change and it would now be interpreted as an incongruent color. We also presented grey, a lighter shade of black in a chromatic context as well as an achromatic one to check whether it would behave as black did. Last, we took advantage of the fact that color perception is driven by the relative contrast of the objects surrounding the perceived object and presented the same grey words but changing the context cues so that it would now be perceived as white.

With these experiments we found that black behaved as an incongruently colored when presented in a color context (i.e. mixed with congruently and incongruently colored words) and something similar was found for grey. When it was presented in isolation ratings were more accurate than when presented in a color context. However, this difference was by no means as apparent as that found for black words. Last, the very same colored words, when induced to be perceived as white were categorized as more positive overall than when they were subjectively perceived as grey. This last piece of data highlights the value of the subjective experience in the evaluation of a stimulus as more or less pleasant.

In Chapter 6 we went a step further and studied the strength of these affective reactions by testing whether they would be strong enough as to serve as unconditioned stimuli for a classical conditioning paradigm. We tried to implicitly induce attitudes towards a set of images (Pokemon cartoons) by placing them in a position identified by a number and coloring them so as to match the color of the photism elicited by such number or a different color. If the affective reactions were strong enough, they should be able to serve in this procedure. In a first experiment we failed to find any conditioning and this might have been due to the fact that the relationship between the number's photism and the Pokemon color was too subtle. In a second experiment we increased the processing level of the number signaling the Pokemon location and we also showed the number colored in a congruent or incongruent instead of only showing the Pokemon image in that color. After two conditioning sessions we found that MA's attitudes towards these images were influenced by the conditioning pairings and CS- were rated as more negative and CS+ as more positive. We therefore conditioned a set of images by pairing them with the occurrence of a positive affective reaction or a negative affective reaction fruit of a photism-color congruence or incongruence.

In our last experimental chapter (Chapter 7) we turned to the non-synesthete population and explored a pattern that had been found throughout the different experiments. Non-synesthete participants showed a congruency effect by which they were different in their performance as a function of synesthetic congruence. However, this effect randomly appeared in reaction time or in error rates and sometimes went in the same direction as that of the synesthetes and most of the times in the opposite direction. Even though the exact pattern seemed random, the fact that it emerged in many of the studies led us to explore it in more detail and try to find some possible explanation for it. In order to check the variables driving this result we tested the effect of color Lightness and color Preference in participants' performance. We also checked whether showing the target stimuli in different locations would influence performance.

In two different experiments we showed a large group of non-synesthetes a set of words that had been previously used in our synesthesia and emotions experiments. We presented them in four different colors and after having them categorize the words as positive or negative we asked them to gives us their preference ratings for each color as well as their subjective perception of the colors' lightness. Data was then recoded as a function of color preference or color lightness and not as a function of actual color presented and we found some quite surprising findings. Non-synesthetes showed the exact same pattern that synesthetes had previously shown where valence categorization was influenced by the attributes of the color in which the word was presented. Then they were presented in the preferred color, participants were faster to categorize a positive word than a negative one. On the contrary, if presented in the most disliked color they readily categorized negative words but found more difficulty to categorize positive ones. In regards to color Lightness a similar pattern was found. These results were showing us that the random congruency effects found for control participants in previous experiments could be due to factors such as their color preference.

SYNESTHESIA AND ATTENTION

One question we wanted to answer with this research was related to the influence of synesthesia in attention. Aware of the fact that general conclusions could not be drawn from our data, we still wanted to learn how synesthesia was influenced by attention at least in our sample. Not only would this add to the already collected data from other single case studies in other laboratories but it could also give us information about the features of our synesthetes that might be helpful to later understand their results in other tasks such as the ones investigating the affective reactions when dealing with incongruently colored stimuli.

1 How automatic is synesthesia?

In Chapter 1 we found that our synesthete MA showed a fairly large Stroop effect when she had to name the ink in which a letter or number was presented when such color was not the same one she internally experiences for that stimulus. In Chapter 4 we found that our synesthete PSV showed the same pattern when naming the color of the presented stimulus. Such a Stroop effect has been previously found by a large number of researchers (Dixon, Smilek, Cudahy & Merikle, 2000; Mattingley, Rich, Yelland & Bradshaw, 2001; Mills, Boteler & Oliver, 1999; Odgaard, Flowers & Bradman, 1999; Wollen & Ruggiero, 1983) and it has been taken as evidence of genuine synesthesia. Going further we also tested the ease to name the photism when the displayed color did not match. In this case interference would indicate that the processing of the color was hindering the response to the photism. For both synesthetes we found that there was an interference effect (i.e. longer RTs when the color and photism did not match compared when they did match) in this photism naming task. Nevertheless, the effect was surprisingly smaller than that found in the regular color-naming Stroop task (284.5ms vs. 47ms for MA and 105ms vs 41ms for PSV).

A recent paper (Dixon, Smilek & Merikle, 2004) proposes that the different patterns of results in these two experiments can account for the subjective reports of synesthestes who inform that they experience their colors in the mind’s eye or out there in space. According to Dixon et al. (2004) projectors find more difficulty in ignoring their photisms since they are projected out there in space. Therefore, a much larger Stroop effect is found for them when having to ignore the photism to name the color. Adding to this, since photisms are presented out there, they are faster to name them than to name the real displayed color. On the other hand, associators who see the color in their mind’s eye do not find so much trouble in naming the presented color and ignoring their internal photisms and show a smaller Stroop interference for the color naming task. Also, since their photisms are experienced in the mind’s eye, they are more readily able to name the presented color than their internal photism thus showing slower reaction times in the photism naming task than in the color naming task. Neither of our synesthetes reported experiencing their photisms out there in space even though their performance resembled that of projectors more than that of associators.

Recently Ward, Li, Salih and Sagiv (2006) suggested that the associator-projector distinction might be orthogonal to the higher-lower distinction made by Ramachandran and Hubbard (2001b). Therefore a lower synesthete could also be associator in the sense that he or she experienced her colors in the mind’s eye. Ward et al. (2006) showed data from six associators and six projectors who showed a quite similar pattern of results in some tasks such as the crowding experiment (Ramachandran & Hubbard, 2001a) that was thought to provide a stronger evidence for the perceptual nature of synesthesia than other tasks such as the embedded figures test (Ramachandran & Hubbard, 2001). However, this hypothesis needs a set of experiments that we did not perform in order to collect evidence in favor of our synesthetes being what Ward would call lower-associators or higher-associators. So far, independent of which system to categorize synesthetes proves to be more useful, we can only say that although our synesthetes report experiencing color in their mind’s eye, their behavioral data suggest that they experience a quite strong and automatic synesthesia that leads them to show a faster and more impermeable to interference performance when dealing with their photisms than when dealing with the visually perceived colors.

2 Can synesthesia be suppressed?

Scant data has been collected to study whether synesthesia can be actively suppressed. A way to study this is by means of the Negative Priming paradigm (Tipper, 1985) where a set of two stimuli is shown and participants have to respond to one of them while ignoring the other one so that it does not affect their performance. In the following trial, the to-be-responded-to stimulus might either be different from the ignored one in the previous trial (control trial) or might be the same as the previously ignored stimulus (ignored repetition trial). It is usually found that participants are slower to respond to the target when it had been previously ignored and this result is explained alluding to the fact that in order to ignore the stimulus in the previous trial, it was inhibited thus being it more difficult to activate it now to the level of response in the present trial. Another way to do so is by asking participants to attend to one dimension of a stimulus and ignore the other dimension and test how the information presented in the ignored dimension affects performance. One way to do so is by means of hierarchical images where a larger stimulus is made out of smaller stimuli (i.e. Navon like stimuli; Navon, 1977) and participants are asked to attend one dimension while ignoring the other. The global precedence effect usually found in these experiments assumes that the processing of the global level of a hierarchical pattern precedes that of the local level. One study using each paradigm has been reported in the synesthesia literature.

Odgaard, Flowers and Bradman (1999) carried out a Negative Priming experiment in which they presented a synesthete with a list of colored digits and asked her to read aloud the color in which the digits had been printed. Each color was incongruent with her photism for the digit. They found an increased time to identify and name the color of the targets when she had to pronounce the color name that designated the color of her photism for the previous incongruently colored digit. Based on this NP effect, Odgaard et al. (1999) concluded that the photisms elicited by stimuli such as numbers can be inhibited to a considerable level when they interfere with the task.

Rich and Mattingley (2003) reported a study using the navon-type stimulus in which they tested and averaged a set of 14 synesthetes while they performed a color naming task. In a first experiment, participants were requested to name the color of a hierarchical stimulus while the congruency between the presented color and the photism elicited either by the global, the local or both levels was manipulated. In a second experiment they asked participants to perform the same task but now they had to do it while paying attention to either the global or the local form. They computed the congruency effect as the difference between those trials where both the global and local form elicited the same photism as the color used to display the stimulus and those trials where the displayed color only matched the photism elicited by the stimulus in one of the two dimensions, either the global one or the local one. They subsequently compared the congruency effect found in the first experiment with that found for the same conditions in the second experiment. They found that, when attention was paid to the global form and the color presented was incongruent with the photism elicited by the local form, the congruency effect was no different from that found in the first experiment. However, when attention was paid to the local form and the photism elicited by the local form was different than the displayed color, the congruency effect diminished as compared to the first experiment. This was taken as evidence that actively ignoring the global form aided in the suppression of the interference coming from the photism elicited but that dimension of the stimulus

We tried to improve both paradigms and tested MA on both of them and PSV on the negative priming one. In Chapter 1 and Chapter 4, by presenting trials pseudo-randomly ordered in the color naming and photism naming Stroop experiments we were able to reanalyze that data as a function of the previously presented stimuli and measure negative priming, not only in the regular Stroop task but also in the reversed Stroop task. This enabled us to obtain measures from the same synesthete regarding her ability to suppress information related to the visually presented colors or the internally perceived photisms. MA showed a negative priming effect in the photism naming task but not in the color naming task. That is, she was able to inhibit the distracting information coming from the presented color when she had to name the internally perceived photism. However, we did not find any negative priming but a non significant positive priming trend in the color naming task. Hence, she was not able to suppress information coming from the irrelevant photisms. This result suggests that, at least for some synesthetes, photisms are difficult to suppress even when doing so would aid performance. However, our second synesthete PSV who also showed a quite apparent Stroop and reverse Stroop effect showed no hint of negative priming neither for the Stroop experiment nor for the reversed Stroop experiment. Whereas the differences between Odgaard et al.'s (1999) results and our results for MA could be accounted for on the basis of methodological differences (see Chapter 1 for a more detailed discussion), the same did not apply for MA and PSV. It could be suggested that PSV has a defective control mechanism and thus is not able to inhibit interfering information.

MA also run a modified version of the global-local experiment in which we tried to improve some of the methodological downsides of Rich and Mattingley's (2003) design. Here we found that when both dimensions of the stimulus were congruent with the presented color (i.e. both the global and the local letter elicited the same photism as the color presented) as expected, MA was quite fast in her response. When both levels induced a photism different from the presented color she was considerably slower to name the color. Also as expected, when the attended dimension elicited a photism incongruent with the presented color MA was as slow as when both dimensions were incongruent. Critically, when the ignored dimension was incongruent with the presented color the task was as effortful as when both dimensions were incongruent. That is, she was not able to ignore the irrelevant-interfering photism elicited by the to-be-ignored dimension.

Our results show that, at lest for MA, the photisms are very difficult to ignore even when doing so would aid in her performance. Previous results (Odgaard, et al., 1999; Rich & Mattingley, 2003) point in a different direction. Information about Odgaard's synesthete is not available and neither is it about Rich's fourteen synesthetes. Given the variability of results found by those researchers who take the time to analyze individual synesthetes although they may group them on the basis of some objective factor, it is more than probable that out of the 14 synesthetes tested by Rich and Mattingley (2003) a good amount of them showed the described patter but some others showed a performance more similar to that of MA. Individual differences between synesthetes have been highlighted repeatedly (Hubbard et al., 2005; Dixon et al., 2004; Dixon & Smilek, 2005) and until we reach a comprehensive understanding of the factors determining synesthesia and its different manifestations, we can not discard them as idiosyncratic features since they may hold the key to the understanding the different varieties of synesthesia.

3 Is synesthesia preattentional?

An extensive debate regarding the necessity of attention for synesthesia has filled journal pages in the last half decade (see Chapter 2 for a more detailed review). Here we tried to answer this question for our synesthete MA with a visual search task where the target was an embedded rectangle that could be either horizontal or vertical. By manipulating the perceptual characteristics of the possible target letters as well as the photism they elicited we were able to compare the benefit obtained from looking for a perceptually salient stimulus (looking for an “N” among “Ms” and “Ws”) with the benefit obtained when looking for a synesthetically salient stimulus (looking for a “W” eliciting purple among “Ns” and “Ms” eliciting yellow).

Across a set of four experiments we consistently found that looking for a rectangle made out of “Ms” yielded more errors than any other condition while a rectangle formed out of “Ns” seemed to obtain some benefit due to its shape. If photisms are elicited prior to conscious perception of the inducer we would expect MA to perform much better than controls for the “W” condition. However, if prior identification of the elicitor letter is necessary in order to experience the color, then “N” would be the easiest condition since perceptual features made it easier to detect. The results we found would suggest that for MA photism experience only happens after the stimulus has been consciously perceived and therefore, it does not aid in the search. However, the fact that looking for a rectangle made out of “Ms” consistently yielded more errors than looking for one made out of “Ws” does not easily accommodate to this conclusion.

By using Duncan and Humphrey’s (1989) explanation of visual search results on the basis of target to non-target similarity and non-target to non-target similarity we were able to explain the results shown by MA. Following this theory to explain the data we can conclude that, even though photisms are not experienced prior to the conscious perception of the shape, they do play a role in the visual search task by influencing the similarity between target and distracters and among distracters themselves. Again, many of the inconsistencies in the published data might be due to the specific features of each synesthete and we can only conclude that in our case, MA does not show any evidence for pre-attentive photism experience.

SYNESTHESIA AND EMOTION

The main aim of our work was to study the claims of synesthetes about disliking stimuli that were not perceptually consistent with their subjective experience for them. Since no research had been previously carried out on this topic, the questions we wanted to answer started out at the most basic level. That is, are these reported affective reactions actually there?. From here we built up knowledge based on the previous step taken and the results obtained in our experiments. In the following we provide some tentative answers to the questions we tried to solve.

1 Are there affective reactions associated to the experience of synesthesia?

First we wanted to test whether claims made by synesthetes and collected by researchers (Cytowic, 1993; Ramachandran & Hubbard, 2001) about affective reactions when perceiving incongruent stimuli were actually observable and reproducible in a laboratory setting.

In Chapter 3 (Experiment 1a) we tested our synesthete MA and asked her to rate the valence of a set of positive, neutral and negative words in a 7 point scale. Even though the words were presented in color, we told her that the color was completely irrelevant for her task and she was to judge the valence according to the semantic meaning of the word. The colors we used to present the words were chosen so that in half the trials they matched the photism previously reported by MA for such word and in the other half they were the color-wheel opposite of her chosen color. Therefore we had trials were the color presented was congruent with the photism experienced and trials were the color and the photism were incongruent. MA showed the expected pattern where the relative difference between positive, neutral and negative words was found. In spite of this and although we had instructed MA to ignore the color and respond to the semantics, we found that her ratings were overall more negative when words were presented in an incongruent color independent of the semantics of the word and overall more positive when the words were presented in the congruent color. In Chapter 4 we briefly reported the results of another two synesthetes when performing the same task but under time pressure conditions. Again we found that although giving an accurate judgment of the word's valence, this rating was influenced by the color in which the word was presented. When asking participants about their performance, they reported that they had followed the instructions but that some words were "just wrong".

It is crucial to note that this effect is not comparable to the congruency effect found in Stroop experiments (Lupiáñez & Callejas, 2006; Hubbard & Ramachandran, 2005 for a review) where the color of the stimulus is the dimension to which participants have to attend and respond and where the stimuli used are as simple as digits or letters. Here, the presented stimuli are complex words that have to be semantically processed in order to give an answer and, more important, the color in which the word is presented is completely irrelevant for the task to be performed. Therefore, an influence of color on the answer indicates that color is processed, a photism-color matching process is taking place and the result of such process is in turn modulating the otherwise accurate rating of the emotional words. Thus, this influence of color on the present valence judgment task is attributed to the affective reaction produced by the mismatch between perceived color and subjectively experienced photism.

2 Are these affective reactions automatic? Can they be ignored?

We carried out a set of experiments (Experiment 2a and 2b of Chapter 3 and Experiment 1a and 1b of Chapter 4) to test this. Participants now had to categorize words as being positive or negative by pressing one of two keys as fast as possible. If the affective reaction result of the external stimuli vs. internal experience comparison and evaluation happens in an automatic fashion, when synesthetes are requested to give a fast response while maintaining a low error rate, this affective reaction will interfere with the task at hand and will therefore influence performance. If such assessment is a more conscious process that takes place later in processing, then it should not influence a fast response aimed at a different dimension of the stimulus.

We found that MA's categorization was influenced by the match-mismatch between the presented color and the induced photism in a revealing way. When positive words were congruently colored she was faster than when positive words were incongruently colored. This was not a surprise. However, when negative words were congruently colored, she was now slower than when they were incongruently colored. A reversal of the congruency effect was found. Again, the congruency effect and the reversed congruency effect were caused by an irrelevant dimension of the stimulus. A very similar pattern was found in experiment 1b (Chapter 4) for two other synesthetes (EL and PR). EL showed a reduced congruency effect for negative words (i.e. congruently colored words were more difficult to categorize if they were negative) and PR showed an absence of congruency effect for the negative words.

These results can be readily explained if we assume that synesthetes are carrying out two different evaluation processes. On the one hand they are voluntarily accessing the meaning of the target word and assessing whether it has a positive or negative connotation. On the other hand they are automatically, and perhaps involuntarily, assessing the fit between the externally perceived stimulus and the internally experienced color sensation. This second assessment interacts and influences the final response. If the result goes in the same direction as that of the word's connotation, the summation of both results aids in the execution of a fast response in the correct direction. That is, if a positive word is shown in a congruent color, the semantic assessment voluntarily carried out will signal for a "positive" response. The automatic match-mismatch computation will also give a “positive” result because the match between the perceived color and the internal experience is good. Evidence from both processes will add up and a response will be executed. However, if the positive word is incongruently colored, while the access to the word’s semantics will be unchanged, the outcome of the match-mismatch computation will be of a different sign. A “negative” outcome will now emerge since the perceived color does not match the internally experienced one. When the result from both computations merges a conflicting situation is created and it requires effortful control to be solved. Thus longer reaction times are found.

Crucially, this hypothesis predicts that a negative word incongruently colored will be responded to faster than when congruently colored. The semantic assessment will analyze the word’s meaning and give a “negative” response as a result of such process. In a parallel fashion, the match-mismatch computation will inform that both experiences are contradictory and will therefore send a “negative” response as a result. Again, information coming from these different processes will accumulate and a fast response will be executed. Again, when the negative word is congruently colored, the information coming from both processes will be of different sign and control will have to be exercised in order to solve it and give an accurate response.

Our data from the error rates also show the same pattern described here. MA was far more error prone for those inconsistent conditions (i.e. positive incongruent words and negative congruent words) than for those conditions where both dimensions went in the same direction (i.e. positive congruent words and negative incongruent words). EL also showed a large congruency effect for positive words and an inverted pattern for negative words. PR was very accurate and those few mistakes she made showed no differential error rate pattern for any of the conditions.

The fact that a large percentage of errors was found, especially large for MA helps us in addressing our second question. The task to be performed was fairly simple because we used words that had already been rated by a large sample and were clearly positive and negative and even the synesthetes had already been exposed to them in the rating experiment and had a clear opinion about their connotation. Adding to this, feedback was given for inaccurate responses. Considering all these facts, it is surprising to find such a high percentage of mistakes especially for MA but also for EL. We suggest that a considerable control effort was being made to correctly respond but the affective reaction resulting from the match-mismatch could not be successfully suppressed and it still influenced behavior. The absence of an effect for PR in error rates could point to a better control mechanism.

Again, large differences could be found between different synesthetes and while some might be able to ignore this affective reaction elicited by the match-mismatch between external and internal experiences, some others can not control them and this shows in their performance.

3 Are affective reactions a ubiquitous phenomenon?

If possible, we were also interested in answering the question of how common it is to experience affective reactions associated to a color-photism mismatch. Out of the four synesthetes tested, one of them PSV showed no hint of a congruency effect in the word categorization and valence rating experiments (Chapter 4, Experiment 1a) although she did show a large Stroop and reverse Stroop effect (Chapter 4, Experiment 2a and 2b). Further testing was carried out to check whether the lack of an effect was due to an absence of synesthesia for words or to a weaker photism for them. The fact that PSV reported realizing that some words were *wrongly* colored suggests that she did experience her photisms for the stimuli. In Experiment 3 (Chapter 4) we asked her and MA to categorize the very same words as correctly or incorrectly colored according to the photism they experienced for them.

By promoting the processing of the photism we found that MA and, most important, PSV both showed an interaction between color-photism congruency and the valence of the word that was now the irrelevant dimension of the stimulus. That is, the word was processed to a high extent (at least enough as to induce the activation of the corresponding photism although probably more) and the color in which the word was presented had to be compared to the internally experienced photism. Now when these three dimensions were processed we found that, again, those cases where both assessments yielded a result in the same direction (i.e. positive correctly colored words or negative incorrectly colored words) were responded to faster than the cases where mixing results were coming from one and another assessment even when this meant congruently colored words taking longer to be categorized as “colored right”.

These results suggest that Mattingley and Rich (2004) might be right when they suggest that the difference in the strength of the synesthetes’ photisms could be the factor underlying the variability among synesthetes in different tasks. Although we do not agree with them when stating that this is the only factor that explains the different patterns found for different groups of synesthetes, we do think that it might be one of the influencing factors that explains the lack of a congruency effect in PSV when having to give an emotional categorization of a set of words. We also suggest that another variable that could be playing a role has to do with personality traits such as anxiety. It has been shown that one of the defining features of anxious people is a lack of an efficient control mechanism to deal with the ongoing events (Lazarus, 1991). Anxious people would be less able to deal with conflicting situations and control those dimensions of the stimuli they are dealing with that interfere in their performance. We found a nice correspondence between anxiety trait measures (STAI) and our synesthetes' performance on the emotional categorization task (Experiment 2a in Chapter 3 and Experiment 1a in Chapter 4). MA showed a high influence of the color-photism match-mismatch on her valence categorization times and she also showed quite high levels of anxiety (percentile 80). On the other hand, PSV did not show a hint of a congruency effect in this task and this correlated with very low levels of anxiety as a trait (percentile 11). It could well be that MA is not able to control the irrelevant information coming from the color dimension when performing this task while PSV concentrates on the task required and is able to completely control the influence of the perceived incongruence on her performance.

This discussion merges with that of the previous section and points some of the conditions that might play a role in the ability to suppress or at least ignore the affective reaction coming from the photism-color incongruence. As more synesthetes are tested in these tasks we will be able to explore this and other factors that could be explaining such individual differences found here.

4 Can these affective reactions be modified or extinguished?

A fortuitous observation made us realize that while rating a set of black words was not different between our synesthete MA and her control group if they were presented in a blocked fashion, when the very same words were presented randomly mixed with congruently and incongruently colored words they were rated in a different way by MA. Her pattern for black colored words resembled now the one found for incongruent words (Chapter 3, Experiment 1a and Chapter 5, Experiment 1).

We asked ourselves about the mechanism subtending this pattern of results. If MA was now rating the very same words in the very same color differently, either she voluntarily decided to do so or something about the situation involuntarily influenced her. The fact that across experiments she was always showing a valence effect (i.e.

more positive ratings for positive words than for negative words) made us think that she was actually performing the task according to the specified instructions and not based on her subjective approval or disapproval of the presented stimuli. Having discarded the first possibility, we now faced different alternative involuntary mechanisms that could be influencing MA's ratings.

The starting point for a synestheticaly affective reaction is a) a stimulus eliciting a synesthetic perception, b) the stimulus being inconsistent with the synesthetic perception and c) a comparison process that checks the match-mismatch between the perceptual and the synesthetic dimension and outcomes a *right* vs. *wrong* verdict. Since the stimuli were the very same ones in both mixed and blocked situations, the stimulus was inconsistent with the synesthetic perception, that is, the second factor was also present. Thus, the results found could be due to one of two different possibilities. Either the stimuli were not eliciting a synesthetic perception when shown in a blocked presentation, or the comparison process was not performing properly under these circumstances. Last, a third possibility was that the comparison mechanism was active but its outcome was somehow inhibited so as to not affect performance. Again the first option did not seem too plausible considering the data patterns found throughout all our investigations. MA showed a considerably strong synesthesia and its influence on performance is difficult to inhibit as seen in the Negative Priming experiments, the hierarchical figures task or the valence categorization studies (Experiment 2 and 3 in Chapter 1, Experiment 5 in Chapter 2, Experiment 2a in Chapter 3, etc.).

Experiments 2a, 2b in Chapter 5 showed that the second or the third options were more plausible. That is, the comparison process either was not performing properly or was being inhibited under some circumstances. In Experiment 2b we found that presenting the same words all colored in grey resulted in a rating pattern very similar to that found for black words when mixed with colored words. In the same manner, when grey was intermingled with congruently and incongruently colored words, the pattern found treated grey words as very incongruent. It seems very improbable that the very same word would elicit a photism if presented in black in a color context but not when presented in an achromatic context. It becomes even more improbable taking into account that grey, a lighter version of black, did not behave in the same manner and behaved in a way very similar to incongruently colored words irrespective of its context.

Last, extensive questioning as well as Experiment 3 in Chapter 5 hinted in the direction of the comparison process taking place and the outcome being somehow more or less ready to influence behavior. The very same words in the very same grey color, when presented in a context of darker colors were interpreted by MA as being white. When they were perceived as white and were presented in an achromatic context, their evaluation still resembled that of incongruently colored words. However, it was significantly less negative than that given to the grey words presented in an achromatic context. Analyses of MA's reports suggest that black ink in an achromatic context has a special status and it is due to intensive and extensive practice with reading print in black ink. If books and computers printed by default in green, for example, it is very probable that reading a uniform green page was not found aversive by a synesthete the same way that no reports of reading a black printed page being aversive have been found. This explains why grey behaved as an incongruent color even when shown in isolation.

Nevertheless, our results were not able to clearly differentiate between the last two possibilities. In order to discern whether the comparison does not take place or is somehow inhibited, other paradigms would be more conclusive. Event related potentials measured while performing a speeded categorization task might be a good way to study this. If the outcome of the comparison process is somehow suppressed but not completely inhibited we might find a more subtle version of the pattern we would normally find for incongruently colored words. If the evaluation process does not even take place, the pattern of brain activity would presumably show topographic or component differences.

Last, the proposal that the comparison process is still taking place and its outcome does not exert a complete influence on the subsequent processing and further, the suggestion that this is due to extensive practice, inevitably leads to the prediction that any given color can become a *neutral* color through practice and give rise to a pattern similar to that found for black ink when presented in isolation. Obviously ethical matters make it difficult for such a study to be conducted.

5 Are synesthetic affective reactions strong enough as to condition co-occurring events?

Previous research has shown that positive and negative valence words can serve as unconditioned stimuli in a classical conditioning procedure and they can influence the posterior attitude towards otherwise neutral stimuli they are paired with

(Olson & Fazio, 2001). In this study they used normalized images and pre-tested words as US. Therefore both types of US were clearly positive or negative. They obtained, after conditioning, a 0.64 differential evaluation score between the CS+ and the CS- with a sample of 45 participants. We attempted to use the postulated affective reaction result of the incongruence between presented color and experienced photism as the US stimulus in our procedure. Therefore when a number signaling a spatial position was presented in a color incongruent with its photism, a negative affective reaction was expected to occur. Conversely, if the number indexing the location was colored according to the elicited photism, a positive affective reaction was expected. By consistently presenting a neutral stimulus in one of these two conditions we expected to condition it with the affective reaction taking place so that after conditioning it would turn to be perceived as positive or negative instead of neutral. We found a difference between CS+ and CS- of 1.8 (-0.31 vs. 1.49).

These results clearly suggest that the affective reaction experienced when a color-photism mismatch is perceived is of a strong nature and can account for effects such as those described here. A neutral stimulus can acquire a positive or negative connotation as a function of the stimuli that co occur with it. Although no test was carried out to check the decline of this effect over time, it was presumably quite fast. Nevertheless, the crucial fact is that, if a simple task like the one carried out here is able to condition an attitude towards a previously neutral stimuli in less than thirty minutes, a life-long series of synesthesia experiences interacting with objects in the real world that may or may not show a correspondence with the internally perceived colors could be a potentially strong determinant of synesthetes attitudes towards different objects, persons or situations.

6 Proposal of the bidimensional assessment hypothesis

Taking into account the results from the several series of experiments, it can be concluded that synesthetic affective reactions seem to be strong enough as to have an influence on valence categorization and rating of emotional words, and even to condition neutral stimuli, thus influencing attitudes towards them. In the following we suggest a model that could account for these results. We propose that, a comparison mechanism that we term *synesthetic assessment* (SynA) is continuously checking for inconsistencies between both perceptual and synesthetic experience. Some factors modulate whether the results of this synesthetic assessment influence performance or not.

We suggest that when an experimental task has to be carried out as in our studies, the SynA modulates the result of the task being performed by adding evidence that biases the outcome of the required task. Specifically, when participants had to perform a semantic categorization task regarding the connotative meaning of a set of words, a semantic assessment process (SemA) checks the meaning of the word and sends information about the word's connotation. In our tasks where positive and negative valence words were used, this SemA process informs whether the semantic dimension of word is positive or negative. At the same time, the SynA process informs about the synesthetic dimension of the stimulus and its relation to the external world. Its outcome can be positive (i.e. when internal and external features match) or negative (i.e. when internal and external features do not match). In a later stage, information from both assessment processes is compared and ultimately, the result of this comparison is sent to the response mechanisms.

As shown in Figure 1, when a positive word is presented in a congruent color, the outcome of the SemA is of a positive sign and the result of the SynA is also of a positive sign. When the same positive word is now presented in a different color, while the SemA is still producing the same outcome, the SynA is now informing of a negative result: the perceived color does not match the internally experienced one, and thus a negative affective reaction is elicited. When in the next stage of processing these two sources of information are combined, the result can be a coherent one (both processes yielding the same outcome) or an incoherent one (each process yielding an outcome of different sign). For consistent outcomes information is sent to the execution modules and in turn a response is performed. For inconsistent outcomes a control mechanism has to bias the competition so that the outcome of the stimulus dimension to which the participant has to respond to is the one that ultimately gets relayed to the execution modules. Therefore, more errors and longer reaction times are expected under these circumstances.

This model predicts that for negative words presented in a congruent color, the response will resemble that of incongruently colored positive words. Although intuitively it could be thought that since words are colored congruently they are processed faster, this model proposes that, given the automaticity of word reading, what is crucial is the coherence between information coming from different assessment processes. For example, in a negative congruently colored word, the SemA yields a negative outcome while the SynA yields a positive outcome. A conflicting situation is encountered and control processes have to bias the competition. Therefore, this model would propose that negative incongruently colored words would be easier to respond to because both SemA and SynA provide similar outcomes.

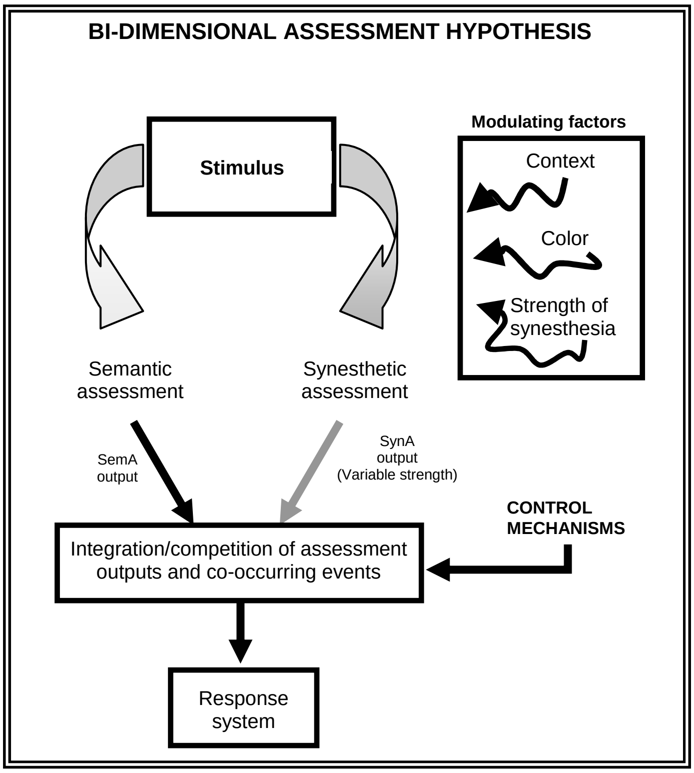


Figure 1. Depiction of the Bidimensional Assessment Hypothesis proposed to explain the affective reactions found in synesthetes when perceiving a stimulus colored congruently or incongruently with their internal experience.

As shown by our experiments, the results are not as clear cut as predicted by a simple version of the model, as different factors have been shown to influence the outcome. In order to account for the variable results found with other synesthetes we propose that, although the SynA process is present in all synesthetes, it might be more active in some synesthetes and therefore influence their performance to greater levels. Its effect can also depend on the strength and specificity of the synesthetic associations of each synesthete.

Regarding the noisier results found for negative words we propose that again, the strength of both assessment processes can account for this patterns. The processing of negative stimuli seems to be fairly automatic and it could be that the outcome of the SemA when categorizing negative words was stronger than the outcome of the SynA. Only if synesthesia is strong enough would the SynA outcome have the ability to influence the SemA.

Our context experiments informed that not all colors are equally incongruent and that other factors, such as the context in which the task is performed, can also influence performance. We propose that the SynA process does not only take into account the photism and presented color but SynA is a more complex process shaped by the needs of synesthetes to adapt to their environment. Thus, it is influenced by factors such as the specific color presented or the context in which the synesthete is (i.e. performing a task with plenty of colors, reading a printed book, etc.). In turn, this context and color modulations have been shaped by adaptation and we propose that their mechanism of action is to weaken the strength of the SynA outcome.

Last, the fact that attitudes can be formed as a result of pairing a stimulus with a synesthetically incongruent situation supports the claim that this SynA process is ubiquitous. Nevertheless, the demands of the task being performed could influence the outcome of the process and make it more available to conscious report while in other situations it would just be implicitly acting on the behavior without the synesthetes noticing it.

FUTURE DIRECTIONS

These series of experiments have provided a starting point for the empirical study of affective reactions experienced as a side effect of the synesthetic perception. Future research based on these findings should aim at answering, among others, the following questions.

Individual differences

As already mentioned, most synesthesia researchers agree that synesthetes are a very heterogeneous group in regards to the inducers and concurrents they experience and even within the same subtype of synesthesia, in regards to the way they experience those concurrents and how that affects performance.

It is a natural deduction that the affective reactions experienced as a side effect of synesthesia might also vary in degree among different synesthetes. We have shown that this phenomenon seems to be consistently found in different synesthetes of quite varied backgrounds. However, we have also shown that some synesthetes, although reporting the experience of such reactions, do not behaviorally show it, or only show it under certain circumstances where the affective reaction is measured quite indirectly.

Future research should extend these findings to a larger population of grapheme-color synesthetes and face the challenge of studying it in other subtypes of synesthesia such as lexical-gustatory synesthesia or music-color synesthesia. It would also be interesting to check whether the proposed subtypes of grapheme-color synesthesia (Ramachandran & Hubbard, 2001b and Smilek et al., 2001) show different affective patterns when facing incongruently colored stimuli. Furthermore, it will be interesting to investigate whether the differences among synesthetes regarding the affective reactions elicited by incongruent stimuli are determined by the type of synesthesia, by personality traits or by an interaction between these two factors.

Factors influencing synesthetic affective reactions

Another area of research inspected here is that of the factors that influence the synesthetically induced affective reactions. Future research should test the influence of the proposed factors with other paradigms and test the extent to which they give rise to a fully differentiated behavioral pattern. Personality traits such as anxiety or self regulation abilities as well as cognitive factors such as the efficiency of control mechanisms should be studied together with other factors such as the amount of exposure to different incongruent pairings.

Some synesthetes have argued that another factor influencing the perception of a stimulus as incongruent with the internal experience is that of its authorship. According to this reports, even a congruently colored stimulus would induce a negative reaction because it is an artificial display presented to the synesthete. Likewise, if it is the synesthete who voluntarily writes a correspondence letter with a green ball pen, the inconsistencies will not be experienced as negative because it was one’s own decision.

Last, it would also be interesting to check whether spatially closer hues interfere to a lesser degree than further located hues. In our studies we used the color-wheel opposite of the congruent color to assure an effect was found. It would be interesting to study whether the magnitude of the effect is kept constant despite of the color presented as incongruent or whether as that color approaches the photism color in the color wheel, the affective reaction decreases.

Physiological measures of synesthetically elicited affective reactions

Although we showed here that there is an affective reaction associated to the perception of incongruently colored stimuli, we did not show whether that reaction is also physiological. This could be studied with the use of psycho-physiological techniques such as skin conductance response. Pilot experiments carried out in our laboratory suggest that this technique might be a good candidate to show convergence of results with different approaches.

Event related potentials can also shed some light to the processes underlying affective reactions in synesthesia and whether the absence-presence of such reactions in the behavioral measures is correlated to quantitative or qualitative differences in cerebral activation patterns.

Similarities between synesthetes and non-synesthetes

Last, it is also worth noting that one of the reasons why synesthesia is such an interesting phenomenon is because knowledge about its underlying processes can illuminate the investigation of cross-modal integration in non-synesthetes. Here we showed that control participants produce reaction time patterns very similar to those of synesthetes when presented with words where the relevant dimension (word's connotation) was not matching an irrelevant and probably implicit dimension (the participant's color preference). Although the sources of mismatch are different from those present in synesthetes, it could well be that the underlying mechanisms responsible for both patterns were shared by synesthetes and non synesthetes. Studies bridging the gap between synesthetic affective reactions and preferences in non-synesthetes regarding their modulation of emotional processing will be a good attempt to increase our knowledge emotional evaluation of stimuli.

CONCLUSSIONS

Our main goal was to study the automaticity of synesthesia and whether it is subject to inhibition and to empirically test for the existence of affective reactions resulting from a mismatch between what a synesthete internally experiences when confronted with a stimulus and what is actually present and sensory processed.

We found that synesthesia is a fairly strong phenomenon that happens automatically and is difficult to ignore. Therefore, it affects performance even when it is detrimental for the task at hand. Adding to this, we also found that an affective reaction is experienced as part of the synesthesia phenomenon and it clearly influences behavior. This pleasantness or discomfort feeling is experienced automatically and it is difficult to ignore. We also found that it can be modulated by contextual features or learning and adaptation. Depending on some personality traits such as anxiety and on the control mechanisms of the synesthetes its effect on performance might be controlled under certain circumstances when trying to accurately perform a task. Last, it can influence co-occurring events and bias the subjective attitude towards them.

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