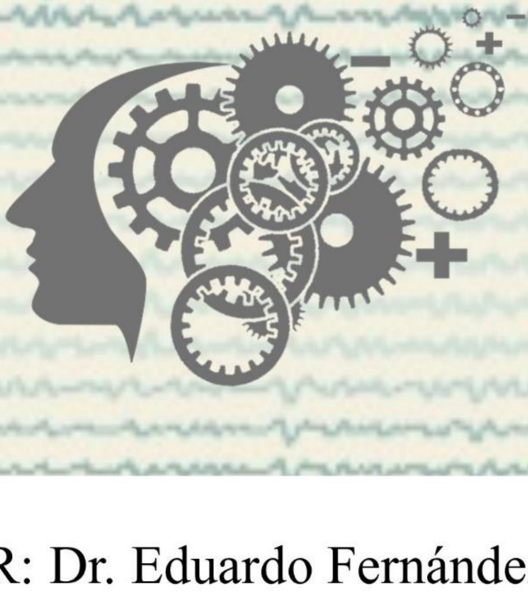
TESIS DOCTORAL

DINÁMICA DE LA ACTIVIDAD CEREBRAL ASOCIADA AL PROCESAMIENTO COMPLEJO DE IMÁGENES EMOCIONALES

M. Dolores Grima Murcia

Noviembre 2017



DIRECTOR: Dr. Eduardo Fernández Jover
CO-DIRECTOR: Dr. Miguel Angel López Gordo

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Mª Dolores Grima Murcia

MEMORIA DE TESIS DOCTORAL
Noviembre 2017

DIRECTOR: Dr. Eduardo Fernández Jover
CO-DIRECTOR: Dr. Miguel Ángel López Gordo

Organización de la Tesis

De acuerdo con la normativa vigente (Acuerdo de Normativa de Estudios de Doctorado de la Universidad Miguel Hernández con fecha 20 abril de 2016 que regula el Real Decreto 99/2011), esta Tesis Doctoral se presenta como compendio de publicaciones. No obstante, además de incluir los artículos publicados, también se añaden otros trabajos realizados en el marco de esta línea de investigación y que se encuentran en proceso de revisión en revistas de alto impacto JCR Social Edition y Social Sciences Edition.

Los trabajos incluidos en este documento son:

Publicaciones en el estudio de las emociones.

- *Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions.* **M.D. Grima-Murcia**, F.D. Farfán, V. Caruana, M.J. Ortiz, M.A. López-Gordo, A. Bernabéu, J.M. Ferrández, E. Fernández. En revisión en Frontiers in Computational Neuroscience. Factor de impacto: 1,821.
- *Spatio-temporal Dynamics of Images with Emotional Bivalence.* **Grima Murcia, M.D.,** López-Gordo, M.A., et al., In J. M. Ferrández Vicente et al., eds. Artificial Computation in Biology and Medicine. Springer International Publishing, pp. 203–212 (2015).

  http://link.springer.com/10.1007/978-3-319-18914-7_21.

Publicación en técnicas de sincronización de registros EEG

- *Asynchronous Detection of Trials Onset from Raw EEG Signals*. López-Gordo, M. A., **Grima Murcia, M. D**., Padilla, P., Pelayo, F. & Fernández, E. Int. J. Neural Syst. 26, 1–11 (2016). Factor de impacto: 6,333. https://doi.org/10.1142/S0129065716500349

Publicaciones de trabajos con registros EEG para valoración de procesos cognitivos complejos.

- *Brain processing of visual metaphors: An electrophysiological study*. Ortiz M.J., **Grima Murcia M D**, Fernández Eduardo. Brain and Cognition. 113, 117-124 (2017). Factor de impacto: 2,432. https://doi.org/10.1016/j.bandc.2017.01.005
- *Application of electroencephalographic techniques to the study of visual impact of renewable energies*. **M. D. Grima Murcia**, Sánchez Ferrer Francisco, Jennifer. Sorinas, JM. Ferrandez, Eduardo Fernandez. Journal of Environmental Management, 2017, vol. 200, p. 484-489. Factor de impacto: 4,010. https://doi.org/10.1016/j.jenvman.2017.05.096
- *Neural representation of different architectural images: An EEG study*. **Grima Murcia M.D.**, Ortiz M.J., López-Gordo M.A, Ferrández J.M, Sánchez Ferrer Francisco, Fernández E. En revisión en Integrated Computer-Aided Engineering. Factor de impacto: 5,264.
- *Neural Recognition of Real and Computer-Designed Architectural Images*. **Grima Murcia, M.D**., Ortiz, M.J., et al., In J. M. Ferrández Vicente et al., eds.

Bioinspired Computation in Artificial Systems. Springer International Publishing, pp. 451–458 (2015).

http://link.springer.com/10.1007/978-3-319-18833-1_47.

Publicaciones de trabajos con técnicas eye tracking

- *Use of Eye Tracking as an Innovative Instructional Method in Surgical Human Anatomy*. Sánchez-Ferrer María Luisa, **Grima Murcia M D**, Sánchez-Ferrer Francisco, Hernández-Peñalver Ana Isabel, Fernández-Jover Eduardo, Sánchez del Campo Francisco. Journal of Surgical Education. 74(4), 668-673 (2017). Factor de impacto: 2,163.

  https://doi.org/10.1016/j.jsurg.2016.12.012
- *Case study: using a portable eye tracking during objective structured clinical examination (OSCE) of medical students.* **María Dolores Grima Murcia**, Francisco Sánchez Ferrer, José Manuel Ramos Rincón, Javier González de Dios, Antonio Compañ Rosique, Eduardo Fernández. En revisión en BMC Medical Education. Factor de impacto: 1,572.

Eduardo Fernández Jover, Catedrático de Biología Celular y Director del Grupo de Neuroingeniería Biomédica de la Universidad Miguel Hernández, y

Miguel Ángel López Gordo, profesor del Departamento de Teoría de la Señal, Telemática y Comunicaciones, E.T.S. de Ingenierías Informática y de Telecomunicación de la Universidad de Granada,

CERTIFICAN

Que la memoria presentada para optar al grado de Doctor por la Universidad Miguel Hernández por Dña. María Dolores Grima Murcia, titulada "Dinámica de la actividad cerebral asociada al procesamiento complejo de imágenes emocionales", ha sido realizada bajo su dirección y co-dirección.

Que han supervisado los contenidos científicos y los aspectos formales del trabajo y dan su conformidad para su presentación como compendio de publicaciones y defensa pública.

Elche a 6 de Noviembre de 2017

Fdo.: Eduardo Fernández	**Fdo.: Miguel Ángel López**
(Director de la tesis)	(Co-director de la tesis)

JOSÉ MANUEL PÉREZ PÉREZ, Coordinador del Programa de Doctorado en Bioingeniería de la Universidad Miguel Hernández de Elche por Resolución Rectoral 0169/17, de 1 de febrero de 2017:

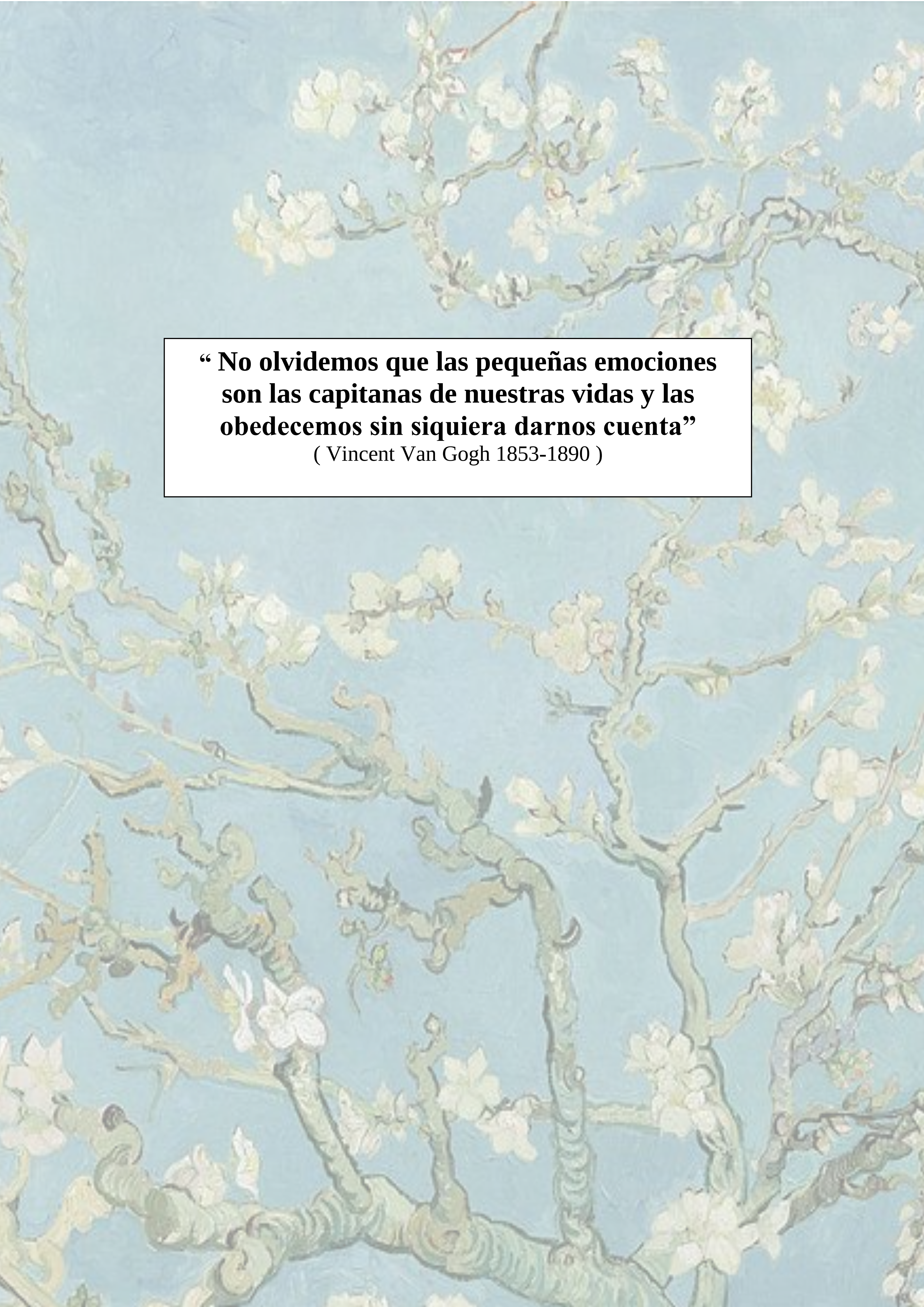
HACE CONSTAR

Que da su conformidad a la lectura de la Tesis Doctoral presentada por Dña. **MARÍA DOLORES GRIMA MURCIA**, titulada "Dinámica de la actividad cerebral asociada al procesamiento complejo de imágenes emocionales", que se ha desarrollado dentro del Programa de Doctorado en Bioingeniería bajo la dirección del profesor EDUARDO FERNÁNDEZ JOVER.

Lo que firma a instancias de la interesada en Elche, el 20 de septiembre de 2017.

Profesor JOSÉ MANUEL PÉREZ PÉREZ
Coordinador del Programa de Doctorado en Bioingeniería

A mis príncipes



“ No olvidemos que las pequeñas emociones son las capitanas de nuestras vidas y las obedecemos sin siquiera darnos cuenta”

(Vincent Van Gogh 1853-1890)

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Abstract

Understanding the processing of emotions has always been a topic of interest, nevertheless, little is known about the temporal and spatial dynamics of early processing of emotions. Whereas recording systems such as “Electroencephalography” (EEG) gives us very good temporal information, - in millisecond range -; other systems such as Functional Magnetic Resonance Imaging (fMRI) are able to give us an excellent spatial resolution. In this document, we propose to combine EEG techniques with fMRI and with mathematical calculations of connectivity between electrode nodes in order to be able to better understand the processing of emotional information and the temporary windows and spatial locations. As an emotion stimulus, we use standardized images obtained from the International Affective Picture System (IAPS) database and distinguish between biphasic (positive and negative) emotions. Results indicate that this system can be of great help to provide Information on neuro-emotional processing. We see the existence of a lateralization in the processing: positive emotions are processed with the left frontal hemisphere whereas the right frontal hemisphere is in charge of the negative ones; In addition, we observe a greater intensity of the negative emotions. On the other hand, with the aim of adding systems that allow us to locate the points of interest of fixation of the look in the processing, studies concerning the following of these looks have been made in other lines of investigation. The complex EEG system has allowed us to carry out valuable scientific research in other areas of knowledge, such as landscape visual impacts and interior design.

Resumen

Entender el procesamiento de las emociones siempre ha sido un tema de interés, no obstante, poco se sabe de las dinámicas temporales y espaciales del procesamiento temprano de las emociones. Mientras que sistemas de registro como el electroencefalograma (EEG) nos aporta muy buena información temporal, del rango de milisegundos, otros sistemas como la Resonancia Magnética Funcional (fMRI) son capaces de darnos una excelente resolución espacial. En este trabajo, se propone combinar técnicas de EEG con fMRI y con cálculos matemáticos de conectividad entre nodos de electrodos para poder entender mejor el procesamiento de la información emocional y las ventanas temporales y localizaciones espaciales del mismo. Como estímulo de emociones utilizamos imágenes estandarizadas obtenidas de la base de datos International Affective Picture System (IAPS) y distinguimos entre emociones bifásicas (positivas y negativas). Los resultados indican que este sistema puede ser de gran ayuda y aportar información del procesamiento neuroemocional. Obtenemos la existencia de una lateralización en el procesamiento, emociones positivas son procesadas con el hemisferio frontal izquierdo y negativas con el derecho, además de observarse una mayor intensidad de las emociones negativas. Por otro lado, con el objetivo de añadir sistemas que nos permitan localizar los puntos de interés de fijación de la mirada en el procesamiento, se han realizado estudios de seguidor de mirada en otras líneas de investigación. El complejo sistema de EEG nos ha permitido obtener valiosos trabajos científicos en otras áreas de conocimiento como en los impactos visuales paisajísticos y en diseño de interiores.

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Índice de abreviaturas

A continuación, se muestras las abreviaturas utilizadas en el texto.

IAPS: International Affective Picture System

EEG: Electroencefalografia

PPSE: Potenciales postsinápticos excitados.

PPSI: Potenciales postsinápticos inhibidores.

ECOG: Electrocorticograma.

E-EEG: Estéreo electroencefalograma.

BCI: Brain computer interface.

fMRI: Resonancia magnética funcional.

BOLD: Blood oxygenation level dependent.

MEG: Magnetoencefalografía.

PET: Tomografía por emisión de positrones.

GSR: Galvanic Skin Response.

EMG: Electromiografía.

ECG: Electrocardiografía.

1.-Introducción

1.1.-Emociones y sentimientos.

Definir el término emoción puede resultar sencillo, a simple vista podríamos hacerlo; sin embargo, conseguir una definición consensuada de esta palabra, es una tarea más complicada (Moltó Brotons 1995)(Whissell 1984)(Scherer 2005).

La palabra emoción, proveniente del latín *emotio* es definida según la Real Academia Española de la Lengua (RAE) como “alteración del ánimo intensa y pasajera, agradable o penosa, que va acompañada de cierta conmoción somática”, también es definida como “interés, generalmente expectante, con el que se anticipa a algo que está ocurriendo”.

Charles Robert Darwin en 1872 publicó la obra más importante sobre emociones hasta la fecha “*La expresión de las emociones en el hombre y los animales”* (Darwin 1872) donde trata el origen del hombre y también de las emociones. En este libro, Darwin hizo una comparación entre las expresiones humanas y de otras especies animales, describiendo posibles orígenes de algunas expresiones corporales y faciales. Realizó su estudio incluyendo a misioneros que provenían de otras culturas, para investigar si existían similitudes en la forma de expresión de ciertas emociones concretas y se producía de igual manera en todas las poblaciones humanas. Su conclusión, que se mantiene hoy en día, es que algunas expresiones de la emoción son universales mientras que otras son más variables.

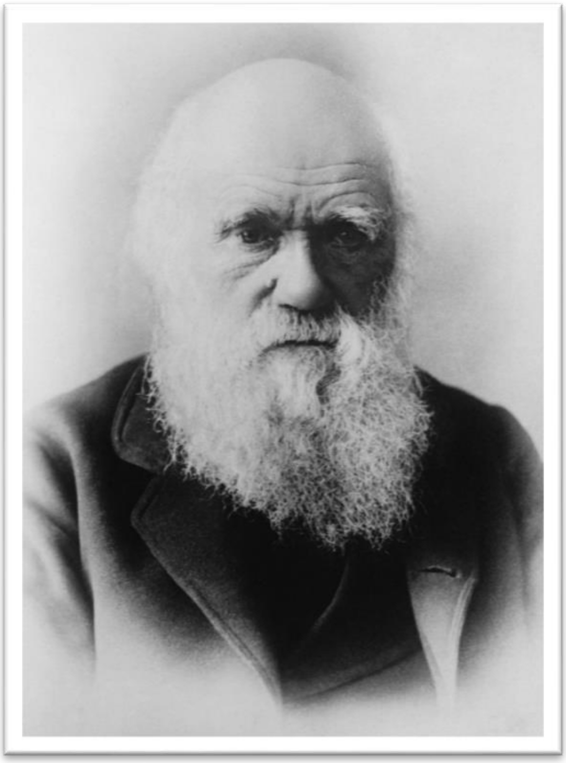

Imagen 1: Charles Robert Darwin (1809-1882).
Fotografía tomada por Elliott & Fry en 1979.

Las emociones, hasta entonces, habían sido consideradas como unos estados cambiantes que alteraban el organismo y que debían ser dominadas y controladas por el pensamiento racional (Platón afirmó que las pasiones son como bestias sin control que intentan escapar del cuerpo humano). Durante los siguientes 100 años de la historia después del trabajo de Darwin, el estudio de las emociones quedo olvidado hasta la aparición a partir de los años 60 de las obras de autores como Plutchik (Plutchik 1962), Tomkins (Tomkins & S. 1962) o los trabajos de Paul Ekman (Ekman 1972). Estos iniciales trabajos evolucionistas fueron luego complementados por teorías más actualizadas (Barrett & Campos 1987)(Davidson et al. 1990)(Tooby & Cosmides 1990) así como por estudios etológicos (Davies et al. 2012) y análisis filosóficos(Wright 1973) dando lugar todo ello un acercamiento evolucionista a las emociones.

Lo primero que hizo el enfoque evolucionista fue redefinir lo que es una emoción. Ellos plantearon que las emociones desempeñan unas funciones esenciales que permiten que el individuo pueda responder de modo efectivo tanto a los desafíos como a las oportunidades que le plantea el entorno y por lo tanto son completamente necesarias para la supervivencia en el mundo que nos rodea.

1.1.1.-Funcion que cumplen las emociones

Podríamos suponer que las emociones constituyen una serie de mecanismos corporales perfeccionados durante la historia evolutiva de los organismos (filogenia), capaces de modificarse en parte, a través de la experiencia y el aprendizaje (ontogenia) y cuyo objetivo principal es amplificar la homeostasis, la supervivencia y el bienestar del organismo (Adolphs 2002). Podríamos establecer tres funciones principales de las emociones (tabla 1).

Función	Objetivo
Adaptativa	Facilitar el ajuste del organismo a nuevas condiciones ambientales. Cada emoción, tanto las consideradas positivas como las negativas, tienen una utilidad determinada.
Motivacional	Potenciar y dirigir conductas (atracción-repulsión).
Comunicativa	Intrapersonal: Sirve como fuente de información
	Interpersonal: ayudar socialmente al individuo, anunciando sentimientos e intenciones (principalmente de manera no verbal), interviniendo en la conducta de otros y potenciando las relaciones.

Tabla 1: Principales funciones que cumplen las emociones.

Las emociones juegan un papel fundamental acercándonos a aquello que nos resulta agradable y apartándonos de aquello que percibimos como desagradable, alcanzando gran importancia en la toma de decisiones y en la resolución de problemas o conflictos. Así, las reacciones emocionales son especialmente útiles cuando nos enfrentamos a información diversa e incompleta o a condiciones demasiado difíciles como para ser resueltas únicamente a través de razonamientos.

Los compromisos sociales, por lo tanto, son permitidos gracias a las emociones. Las largas relaciones sociales que son esenciales para la supervivencia (relaciones de pareja, familiaridades padres-hijos, alianzas cooperativas, pertenencia a grupos) necesitan brindar costosos recursos a los demás, así como impedir conductas egoístas que podrían dañar a los integrantes del grupo. Las emociones nos favorecen a resolver estas complicaciones de compromiso de dos maneras. Por una parte, las emociones promueven cursos de acción que fortifican los lazos a largo plazo como el compromiso de pareja o la conducta de altruismo recíproco. Por otro lado, las emociones valen para indicar a los demás nuestro compromiso a largo plazo. Por ejemplo, demostraciones de gratitud y amor son marcadores fiables y buscados de compromiso de pareja o de colaboración respectivamente.

Los primeros problemas que el humano debe solventar en el entorno son las dificultades de supervivencia física incluyendo la muerte a través de depredadores, la violencia entre grupos de sociedad y la enfermedad. La emoción fundamental del sistema de "Lucha-Huida" es el miedo, gracias a él podemos evitar a los depredadores y ser sometidos a ataques físicos. Actualmente, se sabe bastante de la fisiología del miedo (LeDoux 1998). La amígdala es la encargada de escanear la información que recibimos de los sentidos en busca de patrones (zonas peligrosas, caras amenazantes, ruidos sospechosos…) que se relacionan a peligro. Al detectar estos patrones inmediatamente se dispara el sentimiento del miedo con activación del eje hipotálamo-hipófisis-adrenocortical preparándose al organismo para la lucha o la huida gracias a la liberación de cortisol y demás hormonas.

Emociones como el amor y el deseo resuelven los problemas de encontrar y mantener pareja y facilitan la identificación, establecimiento y mantenimiento de relaciones reproductivas. Estas emociones suponen percepciones y experiencias que son sensibles a puntos como la belleza, la castidad, la fertilidad, el estatus social y la personalidad, así como conductas precisas de interés y compromiso, acompañado todo ello por un correlato fisiológico hormonal y nervioso que facilita la conducta sexual.

Los recién nacidos humanos son enormemente dependientes y vulnerables a la depredación y mantienen esta característica durante un periodo de tiempo bastante más largo que en otras especies, por ejemplo, el caballo es capaz de levantarse y correr a las pocas horas de su nacimiento, necesitando el humano más de un año para poder ponerse en pie. Por ello, las especies sociales han desarrollado sentimientos de cuidado como el amor parental y filial y el apego que facilitan las relaciones de protección entre padres e hijos (Bowlby 1969). Este sistema de protección da lugar a conductas coordinadas entre los padres y los hijos (sonrisas, miradas, etc.) completado con respuestas fisiológicas nerviosas y hormonales (oxitocina p.ej.) que posibilitan al cuidador responder a las necesidades del otro.

Otros de los problemas que surgen en la convivencia grupal y que según los evolucionistas son solucionados gracias a las emociones son la distribución de los recursos existentes y la división del trabajo.

Los humanos viven en comunidad y por ello deben solucionar cuestiones de organización del grupo. Se establecen las jerarquías de estatus que proveen soluciones prácticas a los problemas que van planteándose tales como distribución de posesiones (parejas, comida y atención social) así como del trabajo demandado en las tareas del día a día. Estas jerarquías no permanecen inalterables en el tiempo y necesitan una renegociación y redefinición permanente. Gracias a emociones relacionadas con la dominancia y la sumisión se puede establecer y mantener estas jerarquías tan importantes para el grupo.

Poniendo varios ejemplos de sentimientos que intervienen en el grupo podríamos señalar por ejemplo la vergüenza que marca obediencia y tranquiliza a los dominantes, el desprecio se asocia a sentimientos de dominancia y superioridad ante sujetos inferiores, la admiración se relaciona con la sensación de estar con alguien más grande que el sujeto, como personas de gran estatus y envuelve a estas personas admiradas de respeto y autoridad.

Dentro del grupo social las emociones propias nos permiten responder a las emociones de los demás, conductas que relacionan admisión de emociones de los demás y manifestación de nuestras propias emociones han evolucionado de manera paralela ayudando así a estructurar las interacciones sociales. Un claro ejemplo podría ser la emoción de vergüenza, que se asocia a un rubor que despierta en el observador un sentimiento de simpatía o diversión y ayudan a la reconciliación. Dentro de las parejas, sentimientos de amor y deseo provocan de igual manera respuestas coordinadas entre los sujetos integrantes.

La comunicación emocional nos permite detectar de otros sujetos información también acerca de las intenciones, estado mental y disposiciones de las otras personas, lo que es de vital importancia para la interacción social.

El contagio emocional es un sistema que ayuda a entender mejor los estados mentales de los demás, provocando en el sujeto respuestas similares a los compañeros que le rodean, coordinando de esta manera las acciones de los individuos dentro de un mismo grupo. (por ejemplo, contagio de risas).

Las emociones propias de cada uno también pueden reforzar o suprimir conductas en los demás, actuando como alicientes. Un claro ejemplo sería las emociones positivas en los padres que pueden funcionar como estímulo de conductas deseables en los hijos mientras que emociones negativas pueden reducir la repetición de conductas indeseables en los mismos. Como señalo Sigmund Freud (1856-1939) en una de sus célebres frases: "No me cabe concebir ninguna necesidad tan importante durante la infancia de una persona que la necesidad de sentirse protegido por un padre", podríamos decir que sentirse protegido es sentirse aceptado.

En resumen, podemos concluir que el ser humano debe afrontar problemas diariamente, de organización de su grupo, de reproducción, supervivencia etc., para poder sobrevivir han evolucionado sistemas que se ocupan de estos problemas y/o oportunidades. Las emociones son las encargadas de detectar estos problemas y oportunidades y permiten la coordinación del grupo para actuar de manera consecuente.

1.1.2.-El principio del detector de humo

Randolph M. Nesse (Nesse 2005) es el encargado de aplicar a las emociones lo que se llama el detector de humos, una teoría de dilatada aplicación en cuestiones evolucionistas que se aplica al manejo de los errores por la selección natural. Este principio de manera resumida, nos dice que la selección natural siempre va a elegir entre dos tipos de errores (error tipo I o falso positivo y error tipo II o falso negativo) el que menos coste reproductivo tenga para el individuo Para entender mejor este concepto podemos poner un simple ejemplo. Nos encontramos solos en un monte y oímos un ruido sospechoso detrás de un arbusto que puede ser un tigre, pero podría ser un ratón, suponiendo que el ruido es lo bastante escandaloso para que exista el 10% de probabilidad de que se a un tigre, la opción óptima es huir, huir tan rápido como nos permita un ataque de pánico.). La huida no será necesaria 9 veces de cada 10 no obstante eso es lo normal y lo que menos coste tiene para el organismo. Aunque sólo exista una posibilidad entre 10 de que sea un tigre si nos quedamos a comprobarlo puede ser nuestro fin. El coste del pánico es pequeño, unos cientos de calorías consumidas y unos minutos perdidos, frente al hecho de ser comido por un depredador (final de la transmisión de genes, fin de la historia).

Los detectores de incendios están diseñados de esta manera y por eso dan lugar a muchas falsas alarmas para evitar que se pase ningún fuego y por eso esta regla se llama el principio del detector de humos o de incendios. Esta norma nos revela entonces por qué sentimos emociones negativas muchas veces sin que ello simbolice la presencia de un trastorno mental, sino que se trata de una respuesta normal a una situación de riesgo y explica por qué estas emociones negativas suelen ser más intensas que las positivas.

1.1.3.- Componentes de las emociones.

En las emociones podemos decir que intervienen distintos componentes:

- Fisiológicos: Son procesos involuntarios como presión sanguínea, la respiración, secreciones hormonales, tono muscular, ritmo cardíaco etc., que implican cambios en la actividad del sistema nervioso central y autónomo, así como cambios neuromodulares y neuroendocrinos.
- Cognitivos: Relacionados con el procesamiento de información, tanto conscientemente como inconscientemente que influye explícita e implícitamente en nuestra cognición y en nuestra vivencia subjetiva de los acontecimientos.
- Conductuales: Movimientos corporales, expresiones faciales, tono de voz, volumen, ritmo, etc., que establecen distintivas conductas de especial utilidad comunicativa.

Estos componentes interactúan a través de relaciones bidireccionales para generar las complejas respuestas emocionales.

El esquema del triple sistema de respuesta propuesto por Lang (Lang 1979) es ya un clásico y, en general, aceptado por todos (imagen 2).

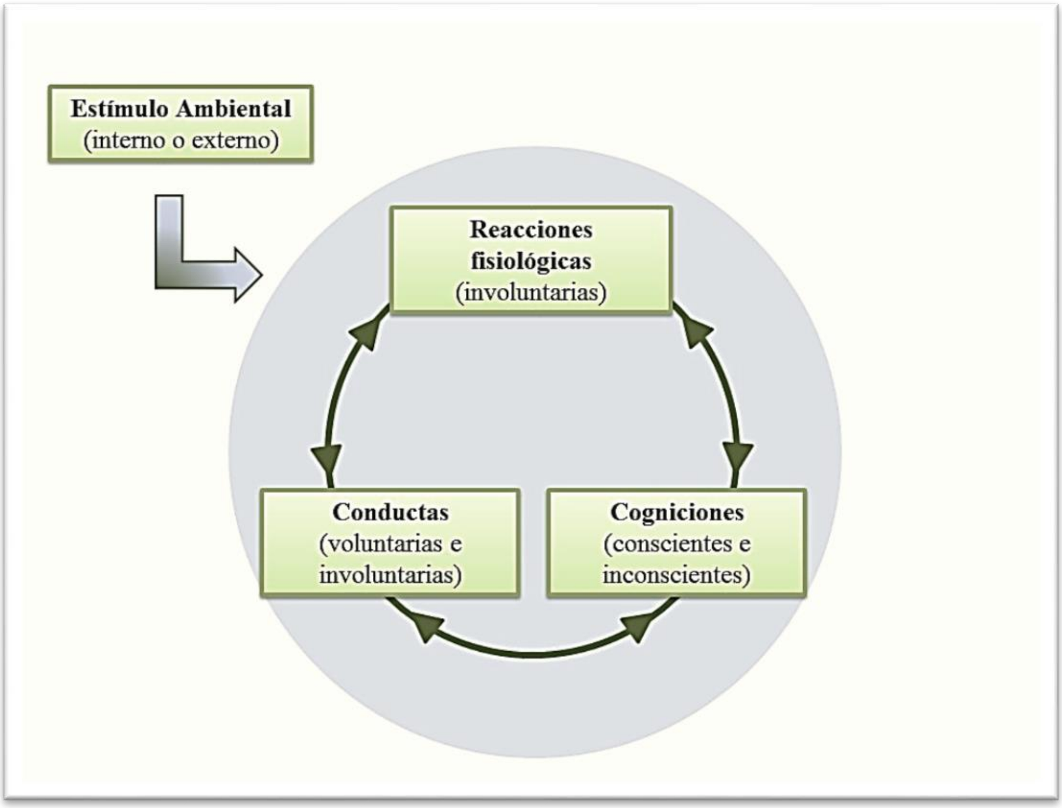

Imagen 2: Esquema del triple sistema de respuesta propuesto por Peter J. Lang (1979)

1.2.- Clasificación de las emociones

Las emociones están presentes en nuestras vidas desde que nacemos. Juegan un papel relevante en la construcción de nuestra personalidad y en nuestra interacción social. Además de ser la principal fuente de las decisiones que adoptamos diariamente, las emociones intervienen en todos los procesos evolutivos: en el desarrollo de la comunicación, en el conocimiento social, en el procesamiento de la información, en el apego, en el desarrollo moral, etc.(Aritzeta et al. 2008).

Podemos diferenciar las emociones básicas y las complejas; y, a su vez: las agradables (positivas) y desagradables (negativas).

- Las emociones básicas (también primarias o fundamentales) son las que producen, entre otras manifestaciones, una expresión facial característica y una disposición típica de afrontamiento, ya se pueden observar en un bebe. No requieren procesamiento cerebral complejo.

- Las emociones complejas (también secundarias o derivadas) son el resultado de conjugar las emociones básicas, pero no evidencian rasgos faciales universales, aunque sí tendencias particulares (de diferentes contextos) a la acción. Requieren un procesamiento cerebral más complejo.
- Las emociones positivas (o agradables) hacen referencia a las que se experimentan cuando se logra una meta o se está en disposición de hacerlo. Afrontar esta posibilidad permite disfrutar del bienestar que proporciona la propia acción. Son emociones de aproximación.
- Las emociones negativas (o desagradables) se experimentan cuando se bloquea una meta; suceden ante una amenaza o una pérdida, y requieren de energía y movilización para afrontar la situación de manera relativamente urgente. Emociones de rechazo.

Existe una gran variedad de clasificaciones y tipologías de las emociones, entre las que se dan ciertas convergencias y divergencias. (Tabla 2).

Paul Ekman & Wallence Frisen	***Robert Plutchik***	***Silvan Tomkins***	***Carroll Izard***
Miedo	Miedo	Miedo	Miedo
Ira	Ira	Ira	Ira
Disgusto	Disgusto	Disgusto	Disgusto
Sorpresa	Sorpresa	Sorpresa	Sorpresa
Felicidad	Alegría	Disfrute	Alegría
Desprecio		Desprecio	Desprecio
Tristeza	Tristeza		Tristeza
	Anticipación	Interés	Interés
	Aceptación		
		Vergüenza	Vergüenza
		Angustia	
			Culpa

Tabla 2: Emociones básicas humanas según diferentes autores

La comunidad científica está de acuerdo, en cierta medida, que para clasificar las emociones se debe utilizar un esquema dimensional y estas diferentes dimensiones se relacionan entre sí. Por ejemplo, algunos teóricos afirman que las emociones positivas y negativas están inversamente relacionados (Russell & A. 1980), pero otros apoyan la opinión de que las emociones positivas y negativas son relativamente independientes entre sí (Larsen et al. 2001). Además, hay quienes sostienen que el enfoque y la evitación son más o menos sinónimo de estados emocionales positivos y negativos respectivamente. Sin embargo, algunos estados emocionales como la ira plantean problemas de este punto de vista, en el sentido de que sugieren una disociación de valencia y de aproximación-evitación (Harmon-Jones & Allen n.d.). Por el contrario, la perspectiva de emociones discretas sostiene que cada emoción (por ejemplo, la ira, la tristeza, desprecio) corresponde a un perfil único en la experiencia, la fisiología y el comportamiento (Ekman 1992)(Panksepp 2007). Es posible conciliar perspectivas dimensionales y discretos en cierta medida mediante la propuesta de que cada emoción discreta representa una combinación de varias dimensiones (emociones primarias y secundarias) (Haidt & Keltner 1999)(Smith & Ellsworth 1985). Por ejemplo, la ira sería valencia negativa, alta excitación, y motivación enfoque, mientras que el miedo podría ser caracterizado por valencia negativa, alta excitación, y la motivación de evitación.

En este trabajo, con el fin de ser lo más robustos posibles, consideraremos las emociones divididas en dos grupos genéricos, positivas y negativas.

1.3.- Conocer las emociones.

Sería magnífico comprender científicamente las emociones. Nos aportaría una perspectiva sobre el funcionamiento de los aspectos más personales y ocultos de la mente y, al mismo tiempo, nos ayudaría a entender qué podría andar mal cuando este aspecto mental falla y aparecen ciertas enfermedades. Sin embargo, como hemos comentado en el apartado anterior, los científicos no han podido ponerse de acuerdo al definir las emociones, pese a que muchos de ellos han dedicado su trayectoria profesional a la tarea de explicarlas. Por desgracia, puede que una de las cosas más significativas que se han dicho de ellas es que todos saben qué son hasta que se les pide que las definan.

El problema de descubrir cómo funciona el cerebro ha sido acertadamente descrito por el psicólogo experimental, científico cognitivo y lingüista Steven Pinker como “ingeniería a la inversa”. Tenemos el producto y queremos saber cómo funciona. Por eso, desmenuzamos el cerebro con la esperanza de ver qué pretendía la evolución al poner en marcha este mecanismo.

Conocer el funcionamiento de las emociones en el cerebro nos serviría en infinidad de puntos, algunos de ellos serían:
-Estudiar patologías (fobias, ansiedad, depresión, etc.)
-Conseguir una interactuación cerebro-ordenador emocional. Cada día existe más tecnología a nuestro alrededor, que esta tecnología pudiese conocer nuestras emociones en tiempo real y adaptarse a nosotros, supondría un sistema inteligente similar a una relación humano-humano.
-Comunicación con personas discapacitadas. Hay personas, que se encuentran en un estado que le es muy difícil comunicar las emociones tal y como lo hacemos las demás personas sin problemas, poder interpretar estas emociones supondría una mejora en la calidad de vida tanto de enfermos como de cuidadores.
-Conseguir realizar estudios objetivos. En el contexto del neuromarketing.

1.4.- Estructuras cerebrales vinculadas a las emociones.

Tal como hemos visto en la primera parte de esta memoria, hoy día se asume que cualquier experiencia emocional posee sus propios mecanismos y correlatos cerebrales que en algunos casos pueden verse solapados. El conocimiento sobre estos procesos es cada vez más profundo y las nuevas técnicas neurofisiológicas y de neuroimagen están proporcionando nuevos indicios sobre el funcionamiento, tanto normal como patológico, de los fenómenos emocionales. Es cierto que este conocimiento es mucho mayor en el caso de emociones primarias, seguramente debido a la posibilidad que estas proporcionan de ser estudiadas comparativamente mediante experimentación animal y a la mayor robustez que les confiere su universalidad. No obstante, las nuevas herramientas de carácter no invasivo que se están desarrollando van a proporcionar valiosísima información que permitirá una mejor comprensión de los mecanismos neurobiológicos que sustentan las reacciones emocionales secundarias, más complejas y derivadas de las prácticas socioculturales.

1.4.1.- Tres cerebros en uno. Visión filogenética.

En la década de los 70, MacLean, en un intento por explicar los fenómenos emocionales y sus mecanismos cerebrales asociados, desarrolló el concepto de sistema límbico y propuso un esquema de estructuración cerebral que contemplase los distintos niveles de complejidad que poseen estos procesos: es la conocida como hipótesis del cerebro triuno (MacLean 1977). Dicha hipótesis, de carácter evolucionista, se basa en la idea de que el cerebro de los mamíferos superiores actuales (entre los que nos encontramos los humanos) ha experimentado una serie de cambios progresivos en los que se han ido englobando las configuraciones cerebrales específicas de los antepasados comunes desde los que se presupone fueron evolucionando. De esta manera, McLean propuso la existencia de una estructuración cerebral compuesta por tres superestructuras o cerebros que, organizados jerárquicamente, conformarían nuestro cerebro actual (imagen 3).

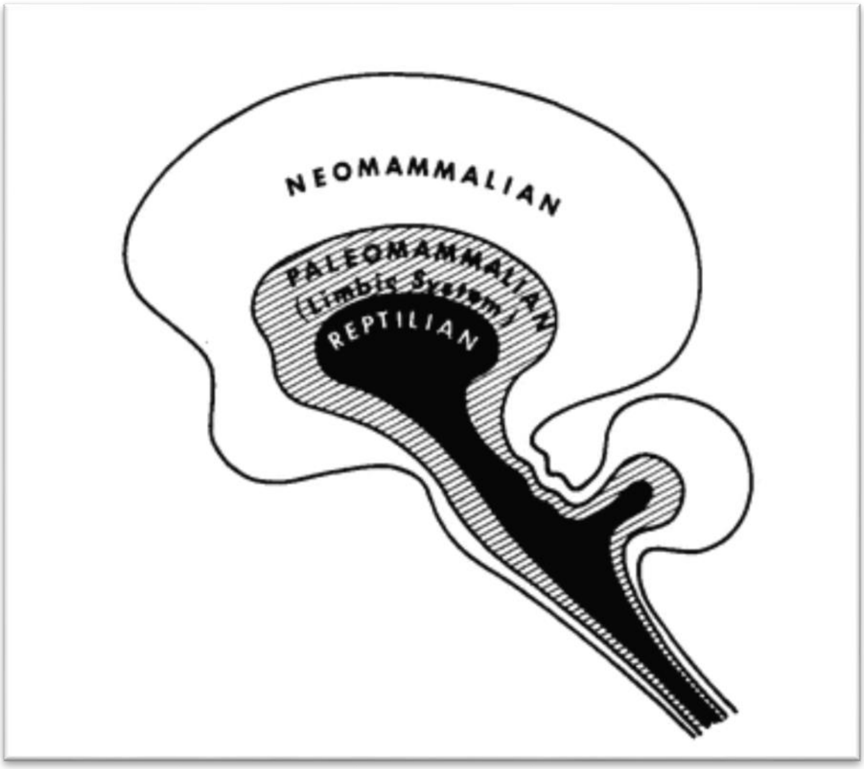

Imagen 3: Cerebro triuno propuesto por McLean (1977)

Cada uno de los tres cerebros sería:

I. Cerebro reptil (protorreptiliano u homeostático).

- Comprendería el tronco cerebral, por lo que se trataría principalmente de un cerebro homeostático e instintivo que regula funciones básicas para la supervivencia del organismo.
- Su funcionamiento sería autónomo y estereotipado, conllevando pautas de comportamiento reflejas e inflexibles.

II. Cerebro paleomamífero (emocional o límbico).

- Este cerebro comprendería el conjunto de estructuras que conocemos como sistema límbico que sustentan la mayoría de los fenómenos emocionales.
- La principal función de esta estructura, sería la integración de la experiencia actual y reciente con los instintos básicos activados por el cerebro reptil. De esta manera, se obtendría un mecanismo de supervivencia menos autónomo que, aunque seguiría siendo automático, sería activado por estímulos ambientales, liberando al organismo de la expresión estereotipada de los instintos y dotándolo de mayor capacidad de interacción con su medio.

III. Cerebro neomamífero (neocortical o racional).

- Comprendería las diferentes áreas neocorticales filogenéticamente más recientes. Estas estructuras serían capaces de regular emociones específicas creadas a partir de las percepciones e interpretaciones del ambiente en función de los objetivos del propio organismo.
- Una de sus funciones, por tanto, sería la regulación de respuestas emocionales, lo que propiciaría un comportamiento mucho más flexible, basado en interpretaciones complejas y en el uso de capacidades de planificación a largo plazo, y que implicaría la capacidad de responder de manera no contingente a determinados estímulos para resolver de forma adecuada problemas complejos (principalmente surgidos en contextos sociales).

En condiciones normales estos tres cerebros trabajan conjuntamente (también junto al resto del organismo) para generar un único comportamiento integrado que posibilite la mayor adaptación posible a las circunstancias ambientales. No obstante, en situaciones críticas para la supervivencia, los sistemas primigenios pueden “raptar” los recursos cerebrales del resto de sistemas en pro de la homeostasis del organismo. Esto es posible debido a la existencia de jerarquías neuronales (Perna et al. 2005). Estas jerarquías se sustentan en la mayor proporción de conexiones nerviosas que se proyectan desde los sistemas primitivos hacia los más recientes, que las conexiones que existen en dirección inversa. De esta manera, la capacidad de reclutamiento que poseería el cerebro reptil sobre el emocional y el neocortical sería mucho mayor que la que éstos poseerían sobre el cerebro homeostático. Este hecho explicaría cómo pueden darse los “raptos” comentados en situaciones críticas. Sin embargo, esta circunstancia no quiere decir que las estructuras recientes no tengan la capacidad de influir en el funcionamiento de las más antiguas, todo lo contrario, ya que es precisamente la capacidad de influencia y regulación del sistema emocional y neocortical lo que permite un comportamiento flexible y adaptado en la mayor parte de las situaciones cotidianas.

1.4.2.- Cerebro emocional. Visión anatómico-fisiológica.

Tradicionalmente se ha asociado el conjunto de estructuras que conforman el sistema límbico con el sustrato cerebral que posibilita la experimentación de los diferentes fenómenos emocionales, por lo que a dicho sistema se le ha llegado a denominar el cerebro emocional. El primero en describir este sistema cerebral fue Paul Broca en 1878 y lo denominó "lóbulo límbico", comprendiendo las estructuras del giro cingulado, giro subcalloso, giro parahipocámpico y la formación del hipocampo (imagen 4). Años más tarde, James Papez (1937), basándose en la experiencia clínica, propuso su conocido circuito neuronal con el que intentaba explicar cómo interactúan procesos subcorticales (principalmente hipotalámicos, que mediarían las respuestas autónomas y conductuales simples; vía del sentimiento) y corticales (principalmente cingulados, que mediarían la experiencia emocional consciente y las acciones complejas basadas en emociones; vía del pensamiento) para producir respuestas y experiencias emocionales coordinadas. además, Papez hipotetizó que este circuito poseía una elevada reverberación de la información entrante, característica que se encontraría en la base de los extensos periodos de activación autónoma y mental que las emociones pueden provocar (Papez et al. 1937) imagen 5 .

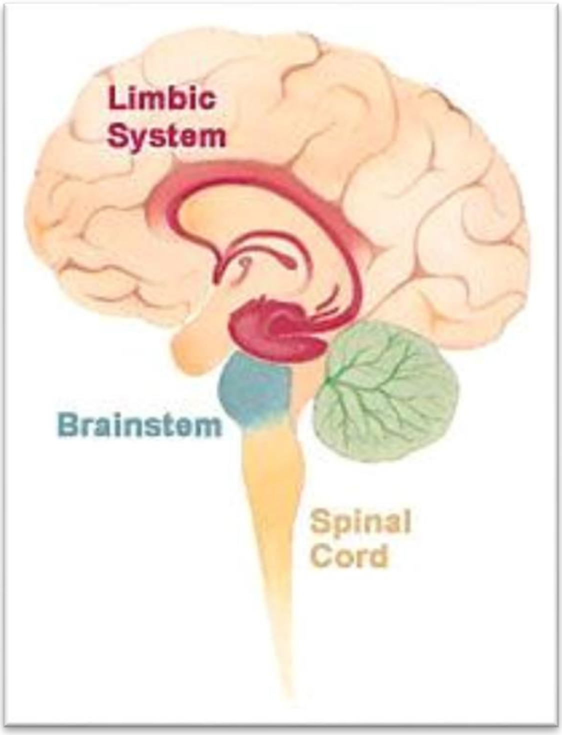

Imagen 4: Diagrama de sistema del cerebro límbico, el tronco cerebral, y la médula espinal

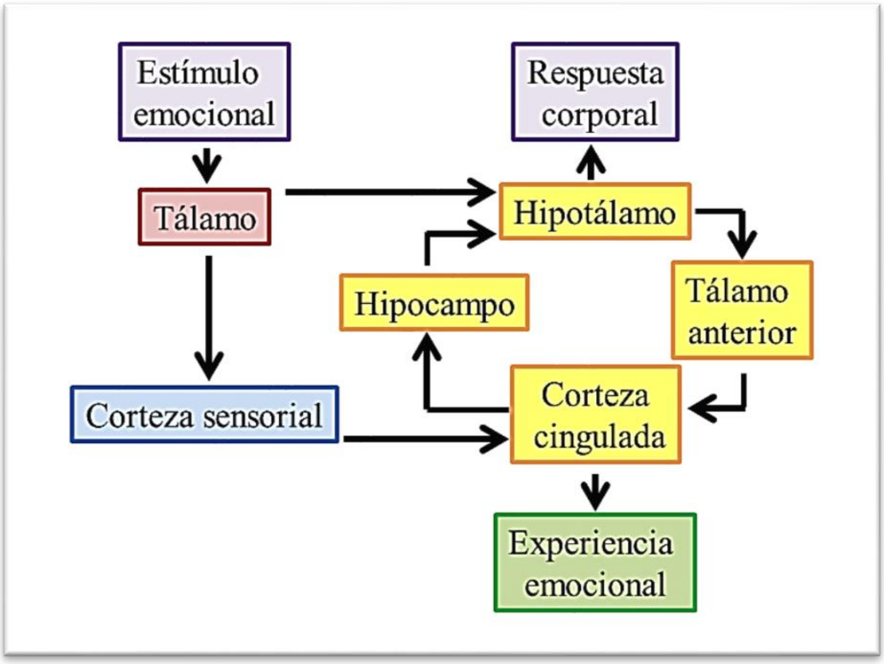

Imagen 5: Circuito neuronal propuesto por James Papez (1937)

No obstante, como hemos explicado en el capítulo anterior, el autor al que se le atribuye el acuñamiento del término “Sistema Límbico” es Paul MacLean (1952), quien describe un conjunto formado por estructuras corticales (de la zona medial) y subcorticales que se encuentran en el limbo o frontera entre telencéfalo y diencéfalo, relacionadas fundamentalmente con la expresión, regulación y control de las emociones.

Algunas de las funciones vinculadas a las reacciones emocionales de este sistema límbico serían:

- Núcleo amigdalino: regulación de la conducta emocional innata y base de las respuestas y aprendizajes emocionales.
- Hipotálamo: Rector de las expresiones motoras emocionales básicas.
- Hipocampo: asociado al aprendizaje y memoria espaciotemporal.
- Área septal: vinculada al reforzamiento de conductas de supervivencia. Motivación sexual, cuidado de la prole, etc.
- Núcleo anterior del Tálamo: principal distribuidor de la información derivada de los estímulos emocionales hacia la corteza ventromedial prefrontal (radiaciones tálamo-corticales) y hacia estructuras subcorticales como el hipocampo y la amígdala.

- Circunvolución cingulada: se propone como una de las zonas donde se realiza la integración de la información emocional con la cognoscitiva.

Este esquema del sistema límbico como organizador de las emociones puede ser especialmente atrayente (estructuras agrupadas en base a consideraciones anatómicas desde una perspectiva evolucionista), no obstante, diferentes autores (Kötter & Meyer 1992) proclaman en sus trabajos la insuficiencia de dichos argumentos y la falta de consenso sobre los criterios a tener en cuenta para la inclusión de estructuras en este sistema. Además, en la actualidad, cada vez se apoya con mayor fuerza el papel fundamental de la Corteza Prefrontal en la integración de la información sensorial y emocional crítica para la toma de decisiones y la conducta social adaptativa, así como para la interpretación, expresión y modulación de las emociones.

1.4.3.- La corteza cerebral en los fenómenos emocionales

Estructuras de la corteza cerebral cada vez han ido adquiriendo más importancia en el estudio de las emociones sobre todo en la medida que ha ido avanzando el conocimiento sobre el funcionamiento de los sistemas prefrontales. Hoy en día, sabemos que la corteza cerebral juega un papel muy importante en diversos aspectos de las emociones:

- Expresión de las emociones. Como el lenguaje afectivo o expresiones faciales.
- Interpretación. De los componentes como el lenguaje afectivo, las expresiones faciales, comprensión del humor o la comprensión de situaciones emocionales (tanto verbales como no verbales, de gran importancia para el comportamiento social).
- Regulación y monitorización de las respuestas emocionales.
- Experiencia consciente de éstas (los sentimientos).

Ambos hemisferios cerebrales están especializados en la expresión e interpretación de las emociones. De esta manera, los procesos corticales que intervienen en las reacciones emocionales forman el extremo superior de un continuo de la capacidad expresiva e interpretativa de dichas reacciones en cuya parte inferior se encuentran los condicionamientos sustentados por el sistema amigdalar.

Las estructuras prefrontales son las que mayor implicación tiene en los procesos emocionales.

1.4.4.- El papel del córtex prefrontal

En ambientes sociales complejos, como en los que el ser humano se desenvuelve en la actualidad, ocurre que determinadas reacciones emocionales si fuesen por la vía rápida tálamo-amígdala no serían adaptativas e, incluso, serían contraproducentes. A pesar de ser respuestas muy rápidas y efectivas, en contextos sociales complejos con frecuencia suelen ser necesarias acciones más deliberadas que tengan en cuenta otros factores ambientales y personales, así como la habilidad para anticipar, planear y monitorizar las conductas en marcha y las futuras. El trabajo científico apunta a que son las estructuras prefrontales (imagen 6) las principales encargadas de organizar el comportamiento y la toma de decisiones implementando dichas capacidades, convirtiéndose así en el dispositivo controlador del cerebro emotivo, fundamental en la regulación emocional, la comprensión de situaciones complejas y el comportamiento social adaptativo.

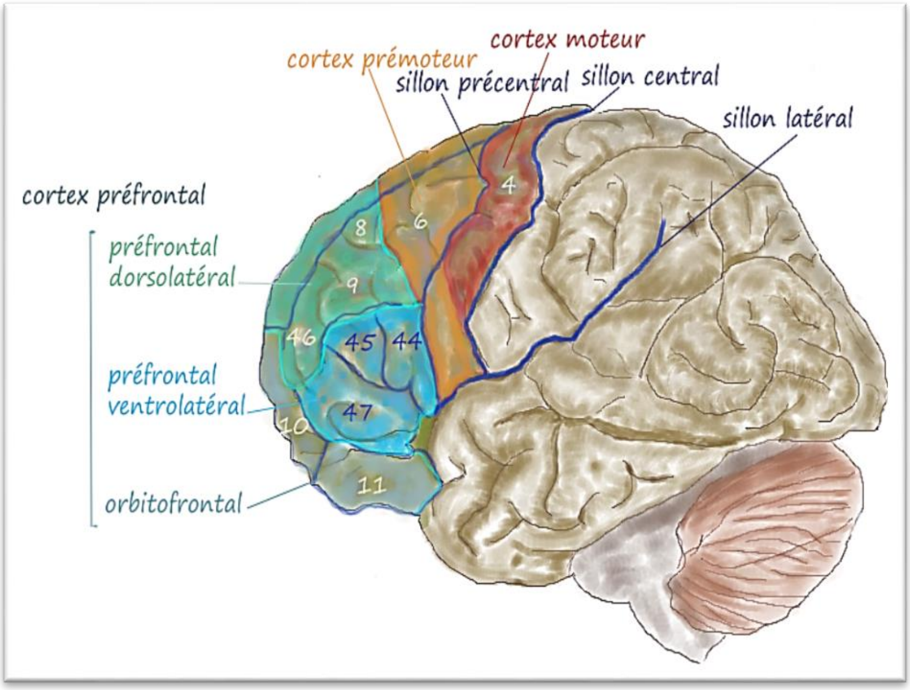

Imagen 6: Lateral córtex frontal

En condiciones normales ambos hemisferios trabajarán de manera complementaria en la regulación y control de las emociones. Sin embargo, investigaciones recientes sugieren que cada división hemisférica muestra una vinculación diferencial con las reacciones emocionales de valencia positiva y negativa (Canli et al. 1998), nuestros estudios apoyan esta teoría **(Grima Murcia et al. 2015)**, **(Artículo en**

revision: Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions).

- Hemisferio derecho: dominante en el control del tono emocional, con un mayor procesamiento de las emociones de valencia negativa, como el miedo o la ira, y mayor vinculación con aspectos automáticos relacionados con la supervivencia inmediata. Promueve conductas de alejamiento, timidez, depresión, etc. Cuando las lesiones prefrontales están focalizadas en este hemisferio es frecuente que aparezca un síndrome psicopático (hipercinesia, desinhibición conductual, actitud pueril y jocosa, agitación, impulsividad, irritabilidad, falta de juicio social, autoindulgencia), principalmente por afectación orbitaria. Asimismo, son frecuentes sentimientos de euforia injustificados y anosognosia.
- Izquierda: es dominante respecto al contenido e interpretación de las emociones positivas. Lleva a cabo un control cognitivo de los estados emocionales a través del lenguaje. Promueve conductas de aproximación, vigilancia, control y superación de estados disfóricos y media en las respuestas del sistema inmunitario. Lesiones prefrontales focalizadas en este hemisferio (preferentemente dorsolaterales) pueden generar un síndrome pseudodepresivo (hipocinesia, apatía, falta de impulso, reducción del habla, indiferencia, falta de planificación, inercia psíquica y ausencia de motivación).

1.5.- Generar emociones:

Existen diferentes maneras de poder generar emociones controladas en un laboratorio para poder monitorizar los resultados y entender las respuestas que se producen en el humano. Podemos estimular cualquiera de los cinco sentidos (gusto, tacto, olfato, oído y tacto) para obtener una respuesta afectiva o podemos realizar una combinación estimulando al mismo tiempo varios sentidos. La inmensa mayoría de estudios se centran en estímulos auditivos y/o visuales.

En este trabajo nos centramos en estímulos visuales, utilizando una base de datos internacional generada por la Universidad de Florida, International Affective Picture System (IAPS) (Lang et al. 2008) con imágenes validadas por la comunidad científica. Cada imagen viene acompañada por una puntuación que hace referencia a su valencia, aunque se debe de tener cuidado al adoptar estas valencias ya que la mayoría de estudios se han realizado en población estadounidense y puede haber alguna variación con población española tal y como comprobamos en un estudio previo.

Del mismo modo, hemos podido realizar otros estudios utilizando estímulos generados por nosotros mismos para generar emociones, comparando imágenes entre sí, **(Grima Murcia et al. 2017), (Grima Murcia et al. 2015), (Artículo en revisión: Neural representation of different architectural images: An EEG study).** En uno de nuestros trabajos comparamos espacios naturales con aerogeneradores y sin aerogeneradores, obteniendo resultados muy interesantes que apuntan al procesamiento negativo de las grandes centrales nucleares, pero no ocurriendo lo mismo con las instalaciones eólicas y/o fotovoltaicas. También hemos realizado estudios presentando imágenes de habitaciones de mayor y menor complejidad, obteniendo interesantes resultados que apuntan a la preferencia por el mayor detalle y familiaridad en el procesamiento de este tipo de imágenes.

En otro trabajo realizado en colaboración con la Universidad de Alicante comparamos imágenes de anuncios publicitarios, utilizando la misma metodología se han obtenido y publicado interesantes resultados **(Ortiz et al. 2017).**

La imagen es un potente estímulo visual, ya que somos animales visuales, y la utilización de estímulos visuales pertenecientes a diferentes áreas (arquitectura, publicidad…) nos ayuda a entender los procedimientos y respuestas cerebrales asociadas inevitablemente a una emoción.

1.6.- Técnicas de medición de los procesos emocionales

En los últimos años el estudio y conocimiento de las emociones ha avanzado considerablemente, a parte del interés que supone para la sociedad, se debe al crecimiento en tecnología y equipos que nos permiten monitorizar los procesos emocionales Las técnicas que se pueden utilizar para realizar la medición de las emociones son diversas:

1.6.1.-Electroencefalografía (EEG)

- La Electroencefalografía es el registro y evaluación de los potenciales eléctricos generados por el cerebro y obtenidos por medio de electrodos situados sobre la superficie del cuero cabelludo. Dicho registro tiene signos muy complejos que varían mucho entre individuos y con la localización de los electrodos, debido al gran número de interconexiones que presentan las neuronas y por la estructura no uniforme del encéfalo. Hemos utilizado esta técnica en nuestros trabajos **(Grima**

Murcia et al. 2017)(Lopez-Gordo et al. 2016)(Ortiz et al. 2017)(Grima Murcia et al. 2015)(Grima Murcia et al. 2015) (Trabajo en revisión: Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions) y (Trabajo en revisión: Neural representation of different architectural images: An EEG study).

1.6.1.1.- Inicios del EEG.

Es a Hans Berger (1873-1941) al que se le atribuye el invento del electroencefalograma. Nació en Alemania, en 1873, fue hijo único de un médico y nieto de un famoso poeta, Hans Berger estudió medicina en varias Universidades de su país y obtuvo un puesto de asistente en el Hospital Neuropsiquiátrico de Jena en el año 1897. En este Hospital pasó por todos los rangos de la vida académica hasta convertirse en 1927 en rector de la Universidad.,

Imagen 7: Hans Berger (1873-1941)

En su juventud Berger sirvió en el ejército. Un día se cayó del caballo y casi es arrollado por un carro. Su hermana, ese mismo día, que estaba a cientos de kilómetros, tuvo el presentimiento de que algo espantoso le había ocurrido a su hermano Hans y logró que su familia le enviara un telegrama urgente para comprobar que siguiera vivo. A partir de aquel accidente, Berger se obsesionó con la telepatía e insistió en buscar su explicación estudiando las señales que hacen funcionar el cerebro. Entendía que el encéfalo era capaz de transmitir señales somos si fuera una radio cuyas ondas pueden ser captadas por otros cerebros de otros individuos que están en la misma frecuencia

Su trabajo es un ejemplo perfecto de cómo el método científico, en manos de un investigador honesto, puede conducir a conclusiones revolucionarias partiendo de hipótesis totalmente erradas.

Después de intentar demostrar sin éxito una relación entre la temperatura cerebral y la actividad psíquica se convirtió en un neurofisiólogo autodidacta y comenzó a registrar la actividad eléctrica espontánea en cerebros de perros y gatos. Al parecer llevaba a cabo sus estudios casi en secreto, fuera del horario laboral, por lo que sus colaboradores comenzaron a temer por su salud mental. A ello contribuyeron sus conferencias sobre telepatía, que creía explicable por la propagación de las ondas cerebrales.

El 6 de julio de 1924 Hans Berger fue capaz de registrar la actividad eléctrica cerebral de su hijo Klaus. Había realizado el primer electroencefalograma de la historia. Sin embargo, la comunidad científica acogió su hallazgo con escepticismo, juzgando que las ondas cerebrales del Dr. Berger no eran más que artefactos, y ridiculizándolo en numerosas ocasiones. En los diez años siguientes publicó una quincena de artículos sobre distintos aspectos de su técnica y fue en el Congreso Internacional de Psicología de París en 1937 cuando recibió el reconocimiento de sus colegas, si bien hasta los años 50-60 del siglo XX no se generalizaría la electroencefalografía, con el perfeccionamiento tecnológico.

Poco antes del inicio de la Segunda Guerra Mundial fue candidato al Premio Nobel. Sin embargo, renunció a él para evitar su instrumentalización por el régimen nazi, con el que nunca simpatizó. En 1936 las autoridades le retiraron de su cargo y le prohibieron investigar. Sus biografías no son muy explícitas en este punto ni en los problemas que experimentó a partir de entonces. Sólo dicen que su carácter depresivo no pudo soportar aquella situación y acabó con su vida en el año 1941.

1.6.1.2.- Electrogénesis cerebral

El tejido nervioso presenta como una de sus funciones básicas la capacidad de generar potenciales eléctricos que son la base de la excitabilidad del organismo. Para comprender la forma en que se generan estos potenciales es preciso un conocimiento de la estructura y las conexiones de aquellas partes del cerebro que los originan. Histológicamente, la neocorteza está constituida por seis capas celulares: (imagen 8).

I: Capa superficial plexiforme de pequeñas células.

II: Capa de células granulares.

III: Capa de células piramidales.

IV: Capa de células granulares.

V: Capa de células piramidales.

VI: Capa profunda polimorfa.

Las células de las capas III y V son efectoras.

Las células de las capas II y IV son receptoras.

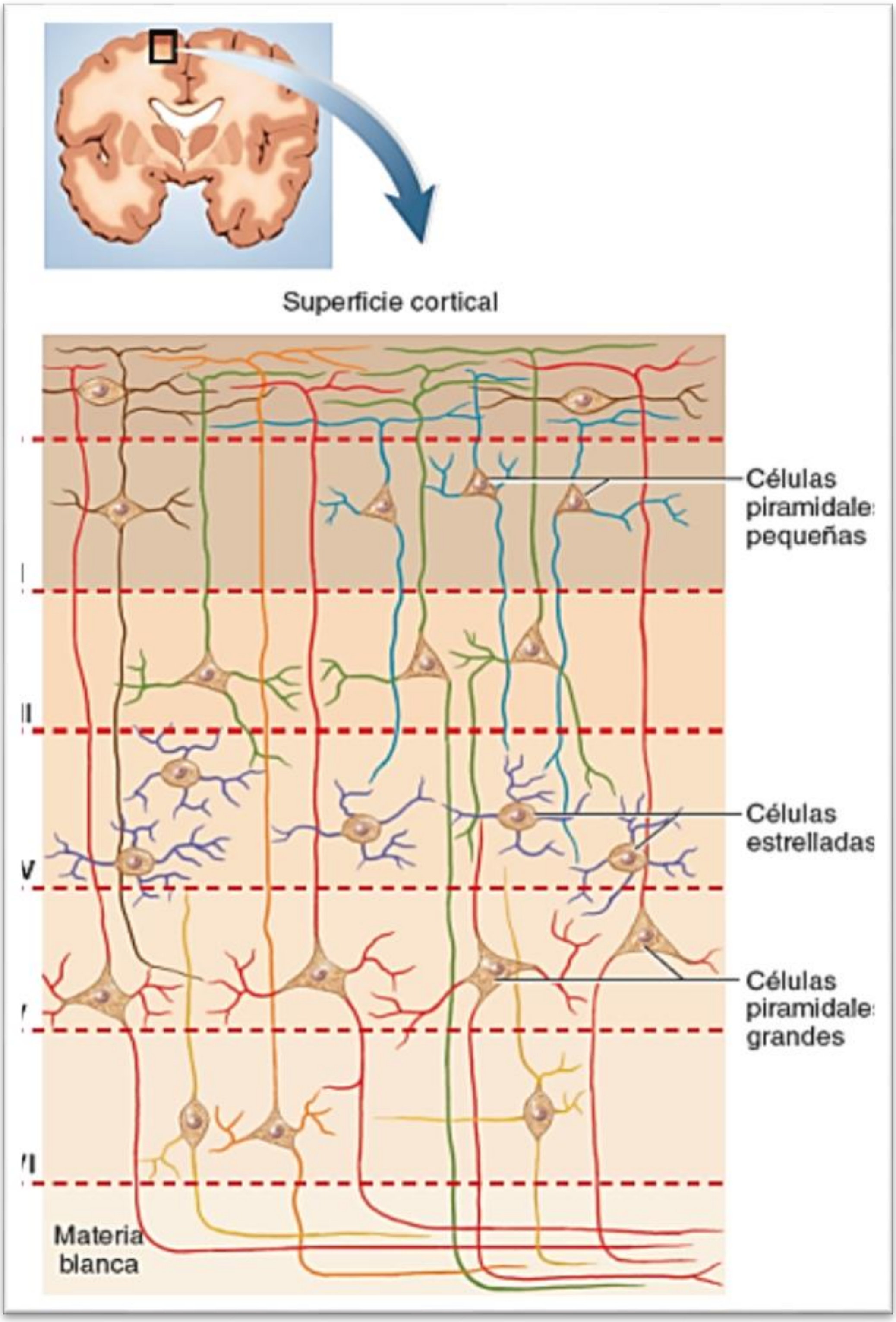

Imagen 8: Sección de la corteza mostrando las seis capas histológicas. Fuente: Kenneth S. Saladin: Anatomía y fisiología, la unidad entre forma y función 6 edición.

1.6.1.3.- Electrogénesis cortical

Una fracción de tejido cortical solitario es lugar de actividad eléctrica espontánea. Esta actividad se describe por salvas de ondas lentas sobre las que se superponen ritmos rápidos. Entre una salva y otra aparecen períodos de silencio eléctrico. Estas señales son producidas como consecuencia de la actividad sináptica general de regiones discretas de tejido: los PPSE (potenciales postsinápticos excitadores) y los PPSI (potenciales postsinápticos inhibidores) se suman entre si y dan lugar a potenciales lentos que son las ondas que se pueden registrar. Una de estas porciones de tejido capaz de producir actividad eléctrica se llama un generador. Una tensión positiva en la superficie cortical traduce una despolarización en las capas más profundas de la corteza. En cambio, una tensión negativa puede ser resultado, bien de una despolarización superficial, o de una hiperpolarización profunda.

1.6.1.4.-Sincronización de la actividad celular

De lo dicho anteriormente, las señales corticales son consecuencia de la actividad neuronal. Sin embargo, dado que en un registro normal se recoge la actividad de muchos miles de neuronas, para poder conseguir una actividad global mínima es preciso que las neuronas vecinas se encuentren sincronizadas. Cuando así ocurre, se pueden observar ondas tanto mayores y tanto más lentas, cuanta mayor sea la sincronía de los generadores. La sincronización se encuentra bajo control de estructuras subcorticales, fundamentalmente ciertos núcleos talámicos que actúan como los marcapasos sincronizadores de las actividades rítmicas corticales. Por el contrario, otras regiones más caudales que van desde el hipotálamo hasta la porción rostral del bulbo constituyen estructuras desincronizadoras.

1.6.1.5.- Captación de EEG.

La actividad bioeléctrica cerebral puede captarse por diversos procedimientos: Sobre el cuero cabelludo, en la base del cráneo, en el cerebro expuesto o en localizaciones cerebrales profundas. Para captar la señal se utilizan diferentes tipos de electrodos: electrodos superficiales, basales o quirúrgicos. El registro de la actividad bioeléctrica cerebral recibe distintos nombres según la forma de captación: Electroencefalograma (EEG) (cuando se utilizan electrodos de superficie o basales), Electrocorticograma (ECOG) (si se utilizan electrodos quirúrgicos en la superficie de la corteza), Estéreo Electroencefalograma (E-EEG) (cuando se utilizan electrodos quirúrgicos de aplicación profunda).

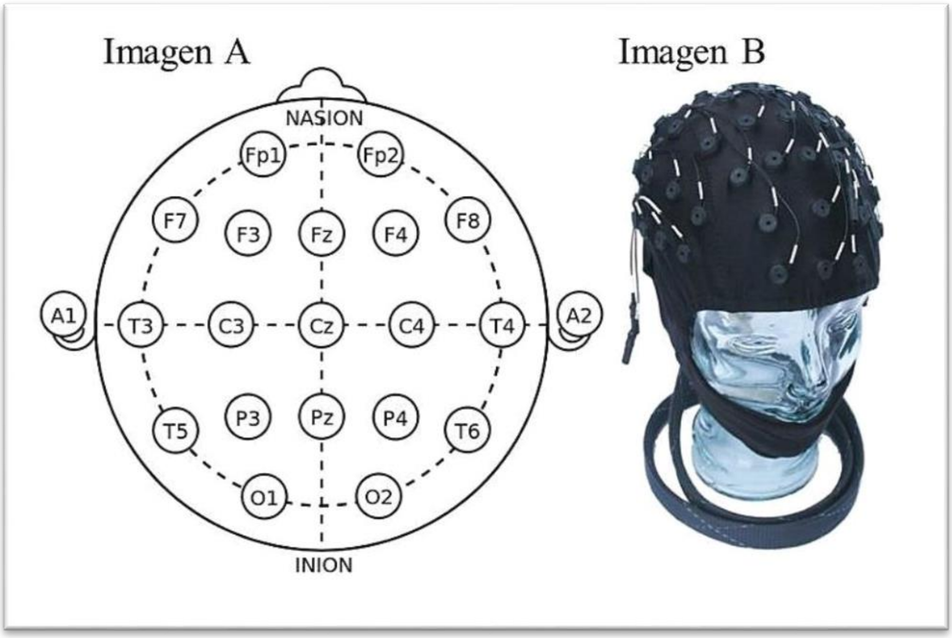

Imagen 9: Imagen A: Distribución de electrodos según el sistema internacional 10-20 Imagen B: Gorro Quik Cap 64 de compumedics utilizado en los experimentos.

En este trabajo hemos realizado el registro EEG, utilizando electrodos superficiales, de contacto. Para conseguir una mayor conducción de la señal se aplica un gel conductor entre los electrodos y el cuero cabelludo. El sistema de posicionamiento de los electrodos superficiales, aunque hay varios sistemas diferentes (Illinois, Montreal, Aird, Cohn, Lennox, Merlis, Oastaut, Schwab, Marshall, etc.), utilizamos el sistema internacional 10-20 (imagen 9) que es el más utilizado en el momento actual (Klem et al. 1999).

Estos electrodos pasan por un amplificador y la señal se registra en un equipo para su procesamiento. Las principales ventajas del EEG es que es un sistema económico, simple, no invasivo y con alta resolución temporal, del orden de milisegundos. Como desventaja, podemos señalar la pobre resolución espacial y que no se registra la actividad eléctrica en capas profundas del cerebro.

Imagen 10: Imagen laboratorio estimulación EEG del Instituto de Bioingeniería (Universidad Miguel Hernández)

1.6.1.6.- EEG portátil.

Cada vez, resulta más interesante utilizar EEG inalámbricos, para aplicaciones en BCI (brain computer interface) estos sistemas resultan indispensables, no podemos movernos con un complejo sistema como el utilizado en los estudios de este trabajo.

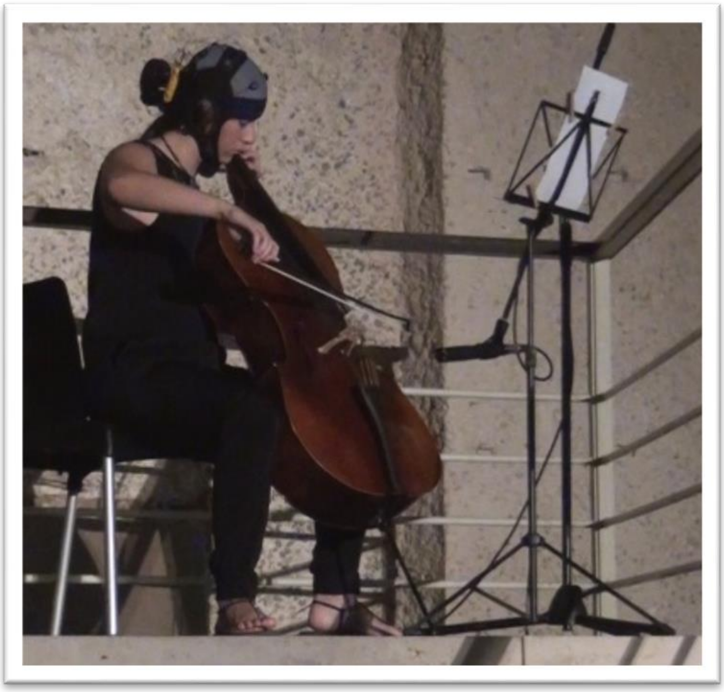

Imagen 11: Casco inalámbrico Enobio 8, en concierto música y Cerebro celebrado en Elche (4-6-2015) IWINAC 2015.

Estos sistemas portátiles (imagen 11), que suelen conectarse por bluetooth al ordenador, tienen algunos inconvenientes: la señal registrada suele tener más artefactos, la duración de la batería es limitada y uno de los problemas más importantes que es la correcta sincronización con el estímulo, al no tener un enlace físico la sincronización es compleja y un pequeño desfase puede suponer un serio problema en el análisis de la señal posterior. Hemos trabajado en la solventación de este problema, obteniéndose la publicación **(Lopez-Gordo et al. 2016).**

1.6.2.- Eye tracking

El eye-tracking o seguidor de mirada es un conjunto de tecnologías que permiten registrar y monitorizar la forma en la que una persona mira una determinada escena o imagen, en concreto en qué áreas o zonas fija su atención, durante cuánto tiempo y qué orden sigue en su exploración visual.

Las tecnologías de eye-tracking tienen un gran potencial de practica en una amplia variedad de disciplinas y áreas de estudio, desde el marketing y la publicidad hasta la investigación médica o la psicolingüística, pasando por los estudios de usabilidad. En nuestra línea de investigación, hemos podido colaborar con el Hospital Universitario de la Arritxaca en Murcia para aprovechar nuestro sistema de seguidor de mirada portátil aplicándolo en el entorno quirúrgico, obteniendo el artículo **(Sánchez-Ferrer et al. 2017)**. Del mismo modo, se ha podido utilizar esta técnica como elemento de innovación docente, obteniéndose el proyecto *"Aplicación de la tecnología de seguidor de mirada (Eye Tracker) para la preparación y mejora de resultados en el Examen Clínico Objetivo Estructurado (ECOE) de Medicina*" (2016-2017) del programa de innovación educativa universitaria UMH, y una publicación **(Trabajo en revisión: Case study: using a portable eye tracking during objective structured clinical examination (OSCE) of medical students).**

A pesar de que la precisión del eye-tracking como sistema de entrada dista de la de otros, como el teclado o el ratón, puede tener numerosas aplicaciones prácticas, tales como su uso en ambientes de realidad virtual o por usuarios con discapacidad motriz. Además, en algunas rutinas como la selección de objetos de una interfaz, la mirada puede resultar más rápida que la acción mediante el ratón, como demuestran (Sibert & Jacob 2000).

Existe una gran diversidad tecnológica de sistemas de eye-tracking, cada uno con sus propias ventajas e inconvenientes. Una de los métodos más precisos implica el contacto físico con el ojo a mediante un sistema formado por lentes de contacto, pero inevitablemente estos procedimientos resultan muy incómodos. La mayoría de métodos que existen en la actualidad son mucho menos molestos, ya que se basan en el uso de cámaras (eye-trackers) que proyectan rayos infrarrojos hacia los ojos del voluntario, sin necesidad de contacto físico.

Imagen 12; Voluntario con gafas tobii utilizadas en los experimentos. Imagen extraida de la noticia publicada en 2015 en La verdad, "Música y neurociencia, al unísono"

Podemos diferenciar dos grupos entre los sistemas que se basan en eye tracker: aquellos que directamente lleva el participante, como gafas (figura 12) y aquellos que registran la actividad ocular desde la distancia, generalmente en un monitor. Los primeros sistemas nos resultan especialmente adecuados para actividades en las que el participante debe tener total libertad para moverse y mover la cabeza.

El eye tracking se puede utilizar en el estudio de las emociones(de Lemos et al. n.d.), información como el tamaño de la pupila nos puede dar indicaciones sobre la carga emocional, además de servirnos para poder saber el objeto de interés del sujeto.

1.6.3.- Resonancia magnética funcional (fMRI)

La resonancia magnética funcional o fMRI es una técnica que proporciona imágenes de la actividad del cerebro mientras realiza una tarea concreta el voluntario. La fMRI no requiere inyección de sustancia alguna, pero requiere que el sujeto se sitúe en una máquina en forma de tubo que puede generar cierta ansiedad claustrofóbica. Su tecnología utiliza un potente imán para medir los cambios en la distribución de sangre oxigenada durante y después de que el sujeto realice determinadas tareas.

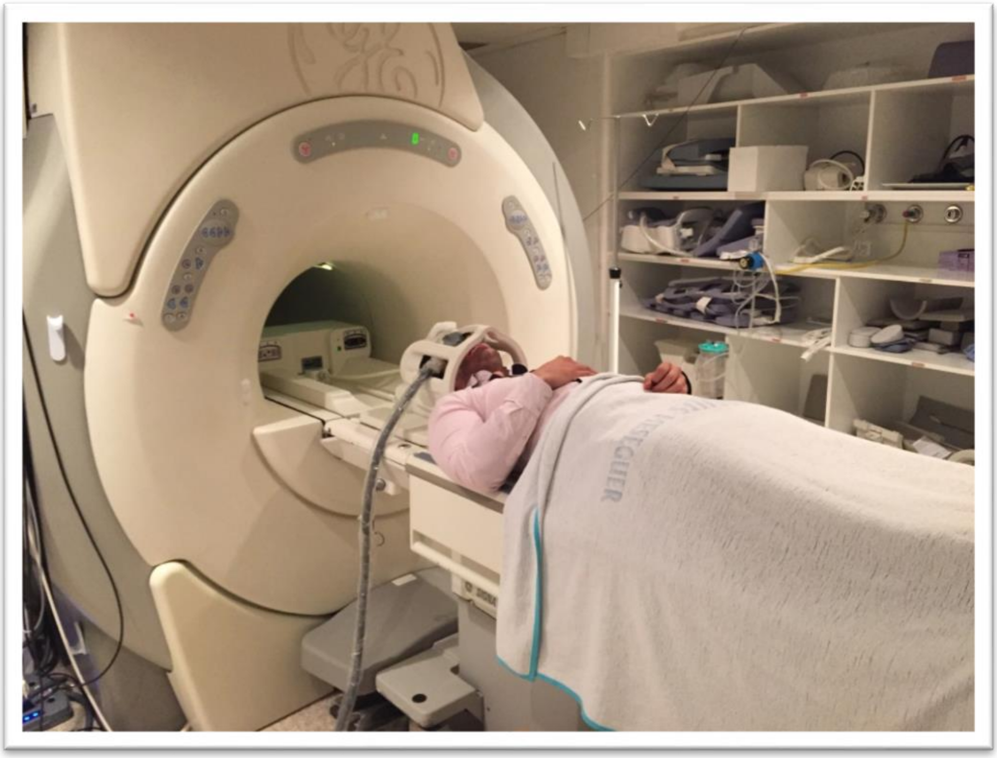

Imagen 13: Imagen de un voluntario en el experimento. Hospital General Universitario Morales Meseguer, Murcia. Noviembre 2016.

La fMRI ofrece una excelente resolución espacial, ya que identifica perfectamente (hasta 1-3 mm de resolución) la zona del cerebro con mayor actividad en función de los niveles de oxígeno en sangre (BOLD, *Blood Oxigenation Level-Dependent*), supuestamente un incremento del oxígeno está relacionado con un incremento de la actividad neuronal en esa parte determinada del cerebro. No obstante, requiere más tiempo para obtener las imágenes (unos 5-8 segundos), por lo que no ofrece la velocidad de reacción de la EEG, además es una técnica cara. Hemos utilizado esta técnica para localizar mejor espacialmente la activación de las emociones **(artículo en revisión: Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions).**

1.6.4.- Magnetoencefalografía (MEG).

Esta técnica mide los campos magnéticos que produce la actividad neuronal en el cerebro ante estímulos concretos. La señal es de mayor calidad que en el caso de la resonancia y de la electroencefalografía, pero el coste de realizar estos estudios es muy elevado, lo que convierte a esta práctica en poco habitual.

1.6.5.- Tomografía de emisión de positrones (PET).

Mide cambios en el metabolismo del cerebro, relativos a su glucosa a partir de una inyección que se administra al sujeto estudiado. Es una técnica costosa y requiere de un proceso invasivo en el voluntario como es la inyección.

1.6.6.- Mediciones de respuesta galvánica (GSR).

Esta respuesta alude a las reacciones de la piel ante estímulos recogidas a través de electrodos dispuestos en los dedos.

1.6.7.- Electromiografía (EMG).

Unos pequeños electrodos dispuestos en músculos faciales miden el movimiento de los mismos y su relación con estados emocionales. Registran microexpresiones que el individuo estudiado realiza de modo inconsciente ante ciertos estímulos. Mide básicamente la atracción o el rechazo del sujeto hacia lo que ve, ya sea una campaña publicitaria, una película, una imagen fija o un texto.

1.6.8.- Ritmo cardiaco (ECG).

Las palpitaciones del corazón son utilizadas para recoger información sobre la atención que el individuo genera hacia un estímulo y sus emociones de rechazo o interés.

1.7.- Línea de investigación.

Con todo lo expuesto en esta introducción, podríamos definir nuestra principal línea de investigación consistente en el estudio de las respuestas cerebrales tempranas ante estímulos emocionales, aplicando diferentes técnicas y aprovechando estas técnicas para la aplicación en otros ámbitos de interés científico.

1.8.- Objetivos de la tesis.

Cada día, el estudio de las emociones adquiere más relevancia, a pesar de los cientos de estudios, aún no se ha llegado a una unanimidad de resultados universal. No se tiene muy claro como la información se procesa desde la zona occipital y conexiona con la zona frontal de la corteza. La mayoría de los estudios que generan emociones utilizan rostros para inducir estados, nosotros, proponemos como objeto principal de la tesis:

- Localizar la ventana temporal que aparece en los registros de EEG relacionadas con el procesamiento de emociones primarias (positivas/negativas) ante imágenes complejas obtenidas de la IAPS, combinándolo con fMRI y sistemas de cálculo de redes que aporten más información sobre el complejo sistema emocional.

Como objetivos secundarios tenemos:

-Confirmar si es posible la utilización de técnicas de electroencefalografía para aplicación emocional en otros campos científicos. Utilizar esta técnica para realizar otro tipo de estudios y confirmar si se aporta importante información para entender los procesos cerebrales implicados en otras disciplinas.

-Trabajar con el eye tracker portátil para realizar estudios emocionales en un futuro. Combinando EEG portátil y gafas eye tracker para poder captar el estado emocional de usuario.

-Definir una nueva técnica de sincronización para sistemas EEG portátiles.

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2.-Materiales, métodos, resultados y discusión

2.1.- Materiales y métodos.

A continuación, se presentan un resumen de los materiales y métodos utilizados en los experimentos principales de los trabajos que componen esta tesis doctoral (para mayor detalle consúltese el artículo publicado):

Todos los participantes de los diferentes trabajos fueron personas sanas, sin patología de base conocida, que accedieron voluntariamente a la realización del experimento.

En los trabajos realizados con EEG, como estímulo se utilizaron diferentes tipos de imágenes complejas, algunas estandarizadas pertenecientes a la base de datos internacional IAPS, otras realizadas expresamente para el estudio (imágenes de anuncios, paisajes, habitaciones…)

Para la captación de la actividad cerebral se utilizó un electroencefalograma de 64 canales con gel transmisor. Los datos de EEG se registraron continuamente utilizando electrodos Ag-AgCl montados en un gorro comercial y conectados a un amplificador NeuroScan SynAmps EEG (Compumedics, Charlotte, NC, USA) de 64 ubicaciones según el sistema internacional 10/20 (Klem et al. 1999). La impedancia de los electrodos de registro se controló para cada sujeto antes de la recopilación de los datos y los umbrales se mantuvieron por debajo de 25 kΩ. Todas las grabaciones se realizaron a una frecuencia de muestreo de 1000 Hz en una sala de laboratorio silenciosa y con poca iluminación.
Para el análisis, las señales de EEG se filtraron utilizando filtros de paso bajo y filtros de paso alto. Los artefactos eléctricos debidos al movimiento y al parpadeo ocular fueron corregidos.
Para realizar el análisis se empleó un enfoque ampliamente utilizado en psicofisiología: el examen de los cambios topográficos eléctricos en la actividad del EEG. Este enfoque tuvo en cuenta los 64 canales de actividad simultáneamente. Utilizamos el software comercial Curry 7.

Los datos fueron analizados a través de un método no paramétrico (TANOVA). Con este análisis, obtendremos las ventanas temporales donde existen diferencias significativas en el procesamiento de diferentes imágenes. Para visualizar mejor estas diferencias se utilizaron diferentes métodos de reconstrucción.

En los trabajos realizados utilizando como herramienta de captación el seguidor de mirada, se utilizaron las gafas comerciales Tobii. Estas gafas pueden ser usadas por el voluntario como gafas normales ya que pesan sólo 45 g., el campo visual es de 160 ° (horizontalmente), con pérdida mínima de la visión durante los movimientos oculares extremos. El sistema debe ser calibrado por separado para cada voluntario pidiéndole a los participantes que miren una tarjeta de calibración colocada delante de ellos durante varios segundos. Este sistema permite al investigador ver la sesión de seguimiento ocular tanto en tiempo real (transmisión por Wi-Fi o conexión por cable), como después a partir de la grabación obtenida. Un círculo se muestra en la pantalla de vídeo de la cámara utilizada para grabar la escena con la cámara HD integrada en los lentes Tobii. Este círculo representa la visión macular del participante y nos aportan la información de los puntos de fijación del voluntario.

2.2.- Resultados y discusión.

"Y al prender su luz interior el hombre descubrió que tenía una sombra atada a él mismo. Y al perderse entre las sombras el hombre descubrió que su luz interior brillaba como ninguna otra."

Carl Gustav Jung (1875-1961)

Ante cualquier estímulo del mundo que nos rodea, nuestro cerebro responde de manera inmediata, en el rango de milisegundos ya ha decidido si debe huir o aproximarse. Estas antiguas circuiterías presentes en nuestra cabeza han asegurado la supervivencia de nuestra especie a lo largo de millones de años. En el mundo actual en el que vivimos, difícilmente podemos encontrarnos con un oso que nos ataque como les pasaría a nuestros ancestros, sin embargo, todos hemos sentido ese miedo y ese temblor en las piernas al pasar por un callejón oscuro, nuestro cerebro a partir de los sentidos es capaz de captar una amenaza "real o imaginaria" y rápidamente se prepara para huir, en esos momentos, ante cualquier ruido inesperado o figura sospechosa saldremos corriendo lo más rápido posible, nuestro cerebro será capaz en el rango de milisegundos de haber tomado la decisión y que esta prevalezca sobre todo lo demás.

Como se ha comentado en la introducción de esta tesis, una de las cosas más sorprendente de los sentimientos primarios es el profundo y completo sistema idealizado por la evolución para proteger a nuestras crías, el vínculo que se genera entre madre e hijo, con toda la comunicación no verbal que conlleva asegura que el bebé sea protegido y cuidado.

Cuando algunas emociones son sobredimensionadas aparecen enfermedades, como pueden ser las fobias, por ejemplo, dos personas pueden pasear en un tranquilo barco por el océano y una de ellas pude disfrutar de sensación de paz, libertad, incluso bañarse en la tranquilidad de un mar en calma, en cambio la otra persona puede sentirse insegura, en peligro, con un miedo irracional e incluso se puede desencadenar una serie de reacciones fisiológicas que dan lugar a un cuadro agudo de ansiedad.

Por otro lado, también tenemos en nuestra sociedad personas que son incapaces de interpretar correctamente las emociones de los demás y tienen serios problemas de comunicación, como las personas que sufren trastorno del espectro autista (TEA), estas personas, deben aprender, con ayuda, a descifrar los sentimientos de los demás, lo que el resto de personas podemos hacer de manera natural, en ellos supone una incógnita y esto imposibilita de manera grave sus relaciones sociales.

Mucho se ha estudiado y se sigue estudiando para poder entender cómo el cerebro sobredimensiona o imposibilita la interpretación de emociones y poco se sabe al respecto, algunos medicamentos mejoran estas patologías, pero no existe una receta mágica.

También en el ámbito de las relaciones sociales nos encontramos con el problema de la interacción hombre/máquina, en las últimas décadas, los robots han sufrido un importante desarrollo, cada vez es más común el interaccionar con estas máquinas, por lo que el desarrollo de interfaces hombre-máquina y cerebro ordenador ha sufrido grandes avances, uno de los retos pendientes es poder relacionarse afectivamente, que los robots sean capaces de reconocer nuestras emociones y actuar en base a ese estado tal y como ocurre de manera natural en las relaciones entre humanos.

Para acercarnos a esta interacción hombre-máquina emocional, uno de los requisitos más importantes es el desarrollo de un sistema de reconocimiento de emociones fiable, que nos garantice una precisión aceptable de reconocimiento, robustez frente a los artefactos, y capacidad de adaptación a las aplicaciones prácticas.

Según todo lo expuesto en las párrafos anteriores, nos podemos llegar a hacer una idea de la importancia y la necesidad de interpretar las emociones de manera sencilla y fiable, la presente memoria de tesis se centra en el estudio de emociones bifásicas (gusta/no gusta), ya sea para poder comunicarnos con personas incapacitadas o bien para conseguir una mejor interfaz cerebro-ordenador, cerebro-máquina.

En el trabajo se ha pretendido utilizar EEG para poder interpretar reacciones tempranas en el cerebro, también se ha empezado a utilizar seguidor de mirada con la finalidad de poder incorporarlo al EEG y ser otra medida que nos permita completar y ampliar información referente al proceso emocional.

A continuación, se describen los trabajos que conforman la presente tesis doctoral.

- En el primer trabajo presentado (Murcia, Lopez-Gordo, et al. 2015), estudiamos las dinámicas temporales y espaciales utilizando EEG ante estímulos visuales complejos. Utilizamos la base de datos de imágenes de la IAPS. En un primer paso, se realizó una validación inicial de la puntuación con la población muestra, de esta manera nos aseguramos evitar los sesgos debido a la cultura americana frente a la española. Una vez que se realizó este estudio previo, pudimos seleccionar las 80 imágenes que posteriormente fueron utilizadas en el registro con el EEG.

  Nuestros resultados sugieren una lateralidad hemisférica cerebral en los primeros milisegundos después de presentar el estímulo. Obtenemos que se produce una laterización en hemisferio derecho para imágenes negativas y en hemisferio izquierdo para imágenes positivas (imagen 14).

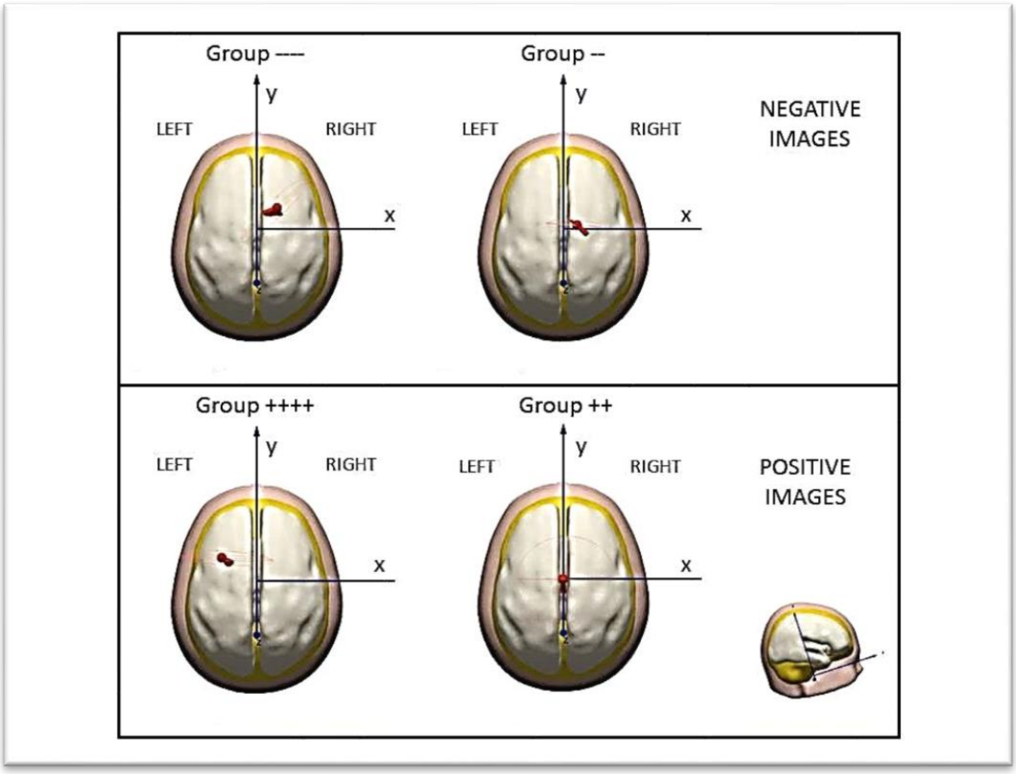

Imagen 14: Reconstrucción cabeza con dipolo rotativo para ventana de tiempo (424-474) post estímulo.

Normalmente este tipo de estudios se realizan con imágenes faciales (enfadado/alegre), que tienen menos variabilidad entre ellas y nosotros demostramos que mediante imágenes complejas de escenas de todo tipo, como cachorros, asesinatos etc. se pueden generar emociones primarias bifásicas tempranas.

Los resultados en este trabajo obtenidos, nos pueden ayudar a detectar y a predecir mediante detección de localización espacial en una determinada ventana de tiempo si la emoción que ocurre en el sujeto es positiva o negativa.

- En el segundo estudio realizado (en revisión en frontiers), siguiendo con la misma línea de investigación anterior, se presenta un artículo de perspectivas en el que se combinan EEG, fMRI y sistemas de análisis de los registros utilizando redes funcionales. Los primeros resultados obtenidos (imagen 15) utilizando estos tres sistemas, no sólo indican la lateralización de las redes funcionales durante el procesamiento cerebral de imágenes complejas, también sugieren que las emociones negativas evocan conexiones neuronales más fuertes, lo que podría ser una necesidad evolutiva (teoría del detector de humos).

Estas diferencias aparecen muy temprano, de 150 a 350 ms después de que la imagen aparece, que apoya la noción de que el cerebro asiste y procesa rápidamente las características perceptivas básicas de una escena visual.

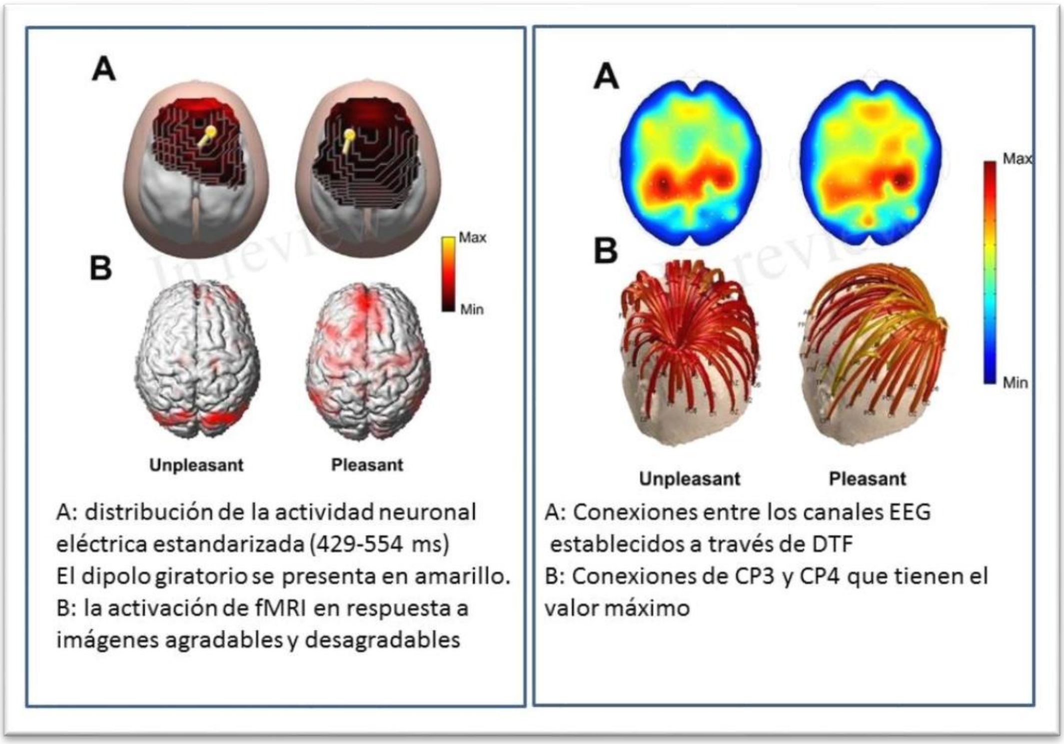

Imagen 15: Resultados artículo presentado

El progreso que nosotros aportamos en este ámbito podría estar vinculado al desarrollo de nuevas metodologías de análisis. Así, la teoría de grafos, que es un lenguaje para el análisis de redes, puede ser útil para definir los patrones de las redes cerebrales y para cuantificar las propiedades de la red en diferentes niveles.

El trabajo en este campo combinando estas tres tecnologías puede ser muy prometedor y nos va a ayudar a entender conexiones entre regiones cerebrales.

- En nuestra línea de trabajo nos encaminamos a trabajar con sistemas inalámbricos que nos permitan libertad de movimientos y comodidad para el usuario, no obstante en estos sistemas tenemos el importante problema de sincronización entre estímulo y señal de EEG, en los sistemas fijos, como en el que hemos realizado los experimentos, existe una conexión física entre ordenador estimulador y ordenador registrador que nos ofrece una perfecta sincronía, esto no ocurre en los EEG portátiles, debemos de encontrar un sistema que nos permita sincronizar perfectamente los eventos relativos con potenciales (ERPs), ya que nuestra ventana de tiempo en la que nos debemos centrar para estudiar el estado afectivo va a ser muy concreta. Existen programas comerciales que nos permitirían realizar una sincronización, pero debido a su costo y la necesidad de software específicos no lo vemos lo más apropiado. En el tercer trabajo presentado en esta memoria de tesis (Lopez-Gordo et al. 2016), se mide el rendimiento de la detección asíncrona del inicio de ensayos aplicado a un sistema de clasificación binario auditivo. El BCI se basa en utilizar un preámbulo de sincronización que nos sirve para detectar el ERPs de manera bastante eficaz, no obstante, se deben de seguir realizando ensayos.

- En el presente trabajo de tesis también hemos podido aplicar la técnica de EEG, en otros campos o ámbitos para responder a preguntas muy concretas.

  i. ¿existen diferencias en el procesamiento cerebral temprano entre anuncios que utilizan imágenes literales y anuncios que utilizan metáforas?

     En este trabajo publicado recientemente (Ortiz et al. 2017), se realiza un estudio comparando imágenes publicitarias con metáforas hibridas con imágenes literales también de anuncios (imagen 16). Hasta la fecha, el procesamiento de las metáforas ha sido estudiado con estímulos auditivos, nosotros introducimos metáforas visuales, encontrando que los resultados son comparables a la bibliografía existente respecto a metáforas auditivas.

Imagen 16: Ejemplo de imágenes literales y metáforas utilizadas en el trabajo

Por lo tanto, nuestros resultados apoyan la hipótesis presentada por otros autores de que las imágenes literales y metafóricas híbridas se procesan de manera diferente.

ii. ¿El impacto visual de las energías renovables podemos cuantificarlo con EEG a partir de ERPs?

En este estudio utilizamos diferentes tipos de imágenes retocadas con Photoshop, imágenes con grandes aerogeneradores y la misma imagen sin aerogeneradores, imágenes con placas fotovoltaicas y sin placas e imágenes con centrales nucleares y sin centrales (imagen 17).

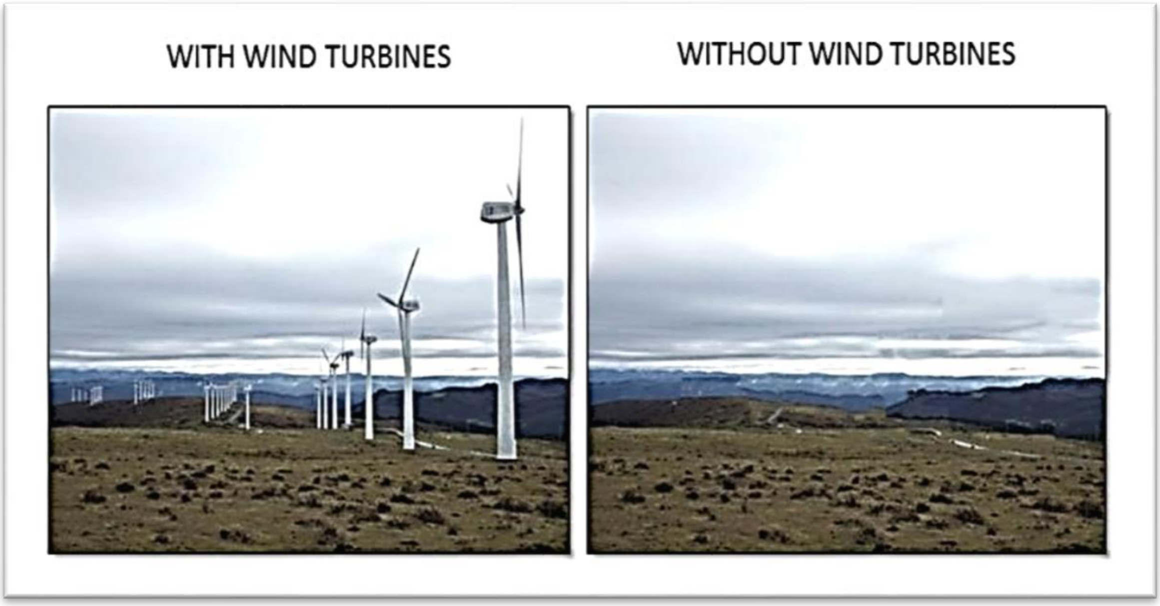

Imagen 17: Ejemplo de estímulo utilizado en el trabajo

Los resultados obtenidos indican que no existen diferencias significativas entre imágenes con energías renovables y sin energías renovables, en cambio, cuando comparamos entre imágenes con plantas nucleares y sin plantas nucleares sí se produce una clara diferencia en el procesamiento alrededor de los 400 ms pos estímulo. Nuestros resultados sugieren que no existen diferencias significativas tempranas en el procesamiento visual, no existe una predisposición innata al rechazo de la instalación en el paisaje de aerogeneradores o placas solares. Sin embargo, sí existe un rechazo en el caso de las centrales nucleares, la puntuación subjetiva es significativamente menor al resto y además se produce una activación del hemisferio derecho en el procesamiento de imágenes con plantas nucleares. Esta activación lateral derecha está relacionada, tal como otros autores y nosotros mismos hemos demostrado, con el procesamiento de emociones negativas. Puede ser debido a que innatamente las altas columnas de humo (ver imagen 18) de vapor de agua salientes de las torres de refrigeración son relacionadas con un incendio e innatamente el ser humano tiende a rechazarlo y a huir para poder sobrevivir.

Imagen 18: Ejemplo de estímulo con y sin central nuclear.

iii. ¿existe un procesamiento temprano distinto cuando se utilizan imágenes esquemáticas en 3D realizadas por ordenador frente a imágenes más complejas?

En este trabajo inicial (Murcia, Ortíz, et al. 2015) comparamos diferentes tipos de imágenes, unas son esquemas en 3D sencillos de habitaciones, frente a fotografías de habitaciones reales. Nuestro objetivo es comprobar si existe un procesamiento temprano diferente entre los dos grupos de imágenes. En los resultados, se obtiene, que efectivamente existen diferencias significativas en los procesamientos tempranos dependiendo del tipo de imagen, además de existir una clara preferencia subjetiva por las imágenes reales. En cierto modo, estos resultados pueden ser justificados dentro de la neuroestética, como la predilección del ser humano por las imágenes familiares, nos parece más familiar y acogedor una habitación con todo tipo de detalles y complementos a un frío diseño realizado por ordenador.

Posteriormente se completó este trabajo presentándolo en una revista de alto impacto y obteniendo resultados similares a los obtenidos en el estudio preliminar.

- Con la finalidad de utilizar el eye tracker portátil combinándolo con EEG portátil para ayudarnos a localizar los objetos fuente de las emociones, se han realizado diversos estudios utilizando este sistema de seguidor de mirada portátil.

  Hemos utilizado las gafas Tobii (Sánchez-Ferrer et al. 2017) como un método para aprendizaje, totalmente innovador en el ámbito de la anatomía humana, haciendo grabaciones con cadáveres tratados con la técnica Thiel, también grabaciones con cirugía laparoscópica real, siendo la herramienta del seguidor de mirada muy útil para dar instrucciones cuando se tienen las dos manos ocupadas operando.

  Por otro lado, también se ha realizado un trabajo utilizando el mismo dispositivo, eye tracker portátil, para la grabación de la primera Evaluación Clínica Objetiva Estructurada (ECOE) realizado en la Universidad Miguel Hernández en el Grado de Medicina. Se propone utilizar este sistema para realizar las grabaciones de las diferentes estaciones y servir de ayuda para saber puntos de atención e interacción. Además, puede ayudar a puntuar este tipo de pruebas de manera más objetiva.

3.-Conclusión y trabajos futuros

Durante el desarrollo de esta tesis nos hemos centrado principalmente en el estudio de las emociones. Hemos podido utilizar diferentes tecnologías disponibles en el mercado, combinándolas entre ellas y aprovechando para aplicarlas en otras disciplinas de trabajo distinta a la línea principal, obteniendo interesantes trabajos en el campo de los estudios visuales de paisaje, procesamientos de diferentes diseños de 3D o aplicaciones en innovación docente.

Las conclusiones principales así obtenidas se pueden resumir en:

- Existe una ventana temporal, después de presentado un estímulo visual emocional, en el que se produce una diferencia de activación significativa en la corteza cerebral. En esta ventana de tiempo, podemos afirmar, que los estímulos negativos producen una mayor respuesta en el hemisferio cerebral derecho, mientras que los estímulos positivos la producen en el hemisferio izquierdo. Además, las respuestas eléctricas cerebrales ante estímulos negativos son de mayor intensidad que las respuestas positivas.
- Combinar diferentes técnicas de análisis con el electroencefalograma, como cálculo de conectividad de redes y técnicas de neuroimagen como fMRI nos ayudan a profundizar en el estudio de los procesamientos de las emociones en el cerebro.
- Las técnicas de EEG son aplicables a otras áreas de conocimiento y son capaces de darnos resultados objetivos para conocer emociones humanas ante diferentes estímulos visuales.
- El seguidor de mirada proporciona una medida objetiva del recorrido de mirada, fijaciones, puntos de interés …en diferentes contextos.
- La sincronización de sistemas de EEG portátiles es posible mediante la utilización de un estímulo auditivo.

Como trabajos futuros, el primer paso será reproducir los experimentos realizados en laboratorio con electroencefalograma portátil. Para este objetivo se utilizarán videos emocionales con la finalidad de poder obtener emociones sostenidas. El siguiente paso será poder realizar un análisis en tiempo real de los registros EEG y una clasificación entre elementos positivos y negativos y unirlo todo con eye tracker. Este sistema nos va a permitir poder conocer las emociones de manera instantánea de la persona interesada y combinarlo con viviendas inteligentes, robots de servicio, etc.

Paralelamente replicaremos los estudios realizados con voluntarios adultos en este caso, con población en edad pediátrica (beca nacional 2017 Asociación Española de Pediatría).

Del mismo modo, seguiremos realizando estudios utilizando estas técnicas en otras áreas, ayudándonos a entender diferentes procesos cognitivos.

4.-Publicaciones

- **Publicaciones en el estudio de las emociones.**

Artículo: "Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions"

M.D. Grima-Murcia, F.D. Farfán, V. Caruana, M.J. Ortiz, M.A. Lopez-Gordo, A. Bernabeu, J.M. Ferrández, E. Fernández.

Artículo actualmente en revisión en Frontiers in Computational Neuroscience.

Factor de impacto: 1.821

Q2 en Mathematical & computational biology 20/57

Q4 en Neurosciences 199/258.

- *Se adjunta transcripción literal del trabajo presentado, todos los derechos serán cedidos a la revista Frontiers in Computational Neuroscience una vez se acepte al trabajo definitivamente.*

Capítulo de libro: Spatio-temporal dynamics of images with emotional bivalence.

Murcia, M. D. G., López-Gordo, M. A., Ortiz, M. J., Ferrández, J. M. & Fernández, E. in Artificial Computation in Biology and Medicine (eds. Ferrández Vicente, J. M., Álvarez-Sánchez, J. R., de la Paz López, F., Toledo-Moreo, F. J. & Adeli, H.) 9107, 203–212 (Springer International Publishing, 2015).

- *Se adjunta transcripción literal del trabajo presentado, todos los derechos han sido cedidos a Springer International Publishing, para consultar el artículo impreso visitese http://link.springer.com/10.1007/978-3-319-18914-7_21.*

Functional networks for the processing of complex images: Towards a better understanding of spatio-temporal dynamics of basic emotions

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Abstract

An unresolved issue in the study of emotions concerns their underlying spatial and temporal dynamics. However, although in recent years there have been many progresses in neuroimaging studies, little is known about the temporal dynamics and the brain networks involved in the perception of basic emotions. Here we propose that one way to get insight into this question is to establish simple models and technologies that help to better understand the neural signatures of basic emotions. We emphasize the relevance of combining different techniques such as functional magnetic resonance imaging (fMRI) and electroencephalograph (EEG) to get good spatial and temporal resolution (with millisecond-range resolution). Furthermore, we propose to include specific measures of connectivity to quantify brain networks at different levels.

Keywords: Emotions, EEG, fMRI, Graph theory, IAPS

Measurement of human feelings and emotions

Feelings and emotions play an important role in human communication and interaction, but emotional expressions are highly diverse. Some theorists have compiled categorical lists including as many as seven (Ekman, Friesen, and Ellsworth 1972), eight (Plutchik 1962), nine (Tomkins and S. 1962) or ten (Izard 1977) primary affective states, which can be combined to end up with various blends (see table I). However, as people express their emotions differently, it is not an easy task to judge and model human emotions.

Before emotions and feelings become accessible, they have to be detected, identified and classified. Researchers from different branches of science are working on this subject. Natural scientists, such as physiologists, neurologists, biologists, biochemists etc., have speculated on the origins, evolution and functions of emotions (Nesse 1990, Frijda 2016). Theories about emotions and their significance to the individual and society have proliferated through psychologists, anthropologists and sociologists (Weiner and Bernard 1985, Barbalet 2002, Leach 2016). Moreover philosophers have offered many proposals concerning emotions (Gordon 1987, Zhu and Thagard 2002); whereas creative artists have proposed explanations for emotions, their meaning and impact, and ways to portray them in sculptures and paintings (Freedberg and Gallese 2007, Boccia et al. 2016). In addition, other disciplines also have their views on emotions, including political sciences, economics and performing arts, (Camurri, Lagerlöf, and Volpe 2003, Havas and Chapp 2016, Elster 1998). Consequently, when it comes to define emotions, there is no shortage of ideas and theories and the objective measurement of human emotions still remains difficult.

One way to get insight into this problem is to establish simple models allowing a better understanding of basic feelings and emotions. In this framework, since contemporary dimensional models of emotion regard the positive to negative valence dimension as an important organising principle (Harmon-Jones and Gable 2008), we can consider this biphasic approach for the analysis of basic emotions. Thus, although emotional events have varying strength, speed, and vigor, they can be generally differentiated on the basic of whether they are good or bad (Arnold M.B. 1960), agreeable or disagreeable (MacLean PD 1993), positive or negative (Cacioppo and Berntson 1994), pleasant or unpleasant (Lang, Bradley, and Cuthbert 1990). This basic approach can be used for the study of emotional responses to visual information (Fanselow 1994) and specifically for the analysis of the specific spatio-temporal responses that occur in the brain following the view of complex scenes (Christian E. Waugh and Schirillo 2012, Linden et al. 2012, Costa et al. 2014).

General overview of procedures to study emotions

Numerous techniques can be used to study brain processes associated with basic emotions. For example, several authors have shown that it is possible to record simultaneously different brain regions in animal models to characterize their main neural patterns (Kalin 2004, LeDoux 2000). However, we should be aware that although many animal studies can be extended to humans, it is often not possible to learn about human emotions using only animal models. Other researchers are using changes in vital parameters such as blood pressure, skin conductance or pulse respiration (Butler, Lee, and Gross 2009, Nava et al. 2016, Poppendieck et al. 2009) as well as changes in facial expressions (Ekman and Paul 1993, Minakshee Sarma 2016). Anyway one key aspect in the study of emotions is to characterize the neural signature that defines and differentiates univocally each emotion and the temporal and spatial dynamic underlying these processes (Costa et al. 2014).

The overwhelming majority of studies related to emotions use functional magnetic resonance imaging (fMRI), which have a good spatial resolution but very poor temporal resolution, in the order of several seconds (Iordan et al. 2013, Kragel and LaBar 2016, Song et al. 2016). Other researchers are using electroencephalography (EEG) and magnetoencephalography (MEG), which have the advantage of their high temporal resolution, but the spatial resolution is low (Costa et al. 2014, Thiruchselvam et al. 2011, Soleymani et al. 2016, de Borst and de Gelder 2016). Thus, since the strengths and weaknesses of EEG and fMRI are complementary, simultaneous EEG-fMRI may be able to achieve something which seems rather difficult: namely the noninvasive recording of human brain activity containing both high spatial and high temporal resolution.

Brain connectivity

Another different approach that has been less used in this field is to consider the structural and functional connectivity of the brain while processing emotions. This methodology also allows us to investigate the spatial location of sources and their interconnections in the brain as well as to investigate how different brain processes and their outputs change over time (C. E. Waugh, Shing, and Avery 2015).

The basic idea of this approach is to consider the brain as a complex network that involves structurally and functionally connected regions (Sporns 2011). Therefore we can use the powerful combinatorial methods found in graph theory, where the node is the fundamental unit of which graphs are formed and network topology can be quantitatively described by a wide variety of measures (Bullmore and Sporns 2009, Rubinov and Sporns 2009). One of these measures is the clustering coefficient, which quantifies the number of existing connections between the nearest neighbors of a node as a proportion of the maximum number of possible connections (Watts 1998). This coefficient describes somehow the ability for specialized processing that occurs within densely interconnected groups of brain regions and is a measure of segregation Furthermore, this parameter has straightforward interpretations in the framework of anatomical and functional networks. Figure 1 shows a representative example. Thus the presence of clusters in anatomical networks suggests the potential for functional segregation in these structural networks, while the presence of clusters in functional networks suggests an organization of statistical indicative dependencies of segregated neural processing.

This methodology can be also applied to the analysis of how the brain processes the main perceptual features (e.g. spatial location, color, shape, and spatial orientation) and the two fundamental emotions (pleasant or unpleasant), which are always linked to the view of any complex image. However, to implement this functional measure, it is necessary to establish an association between nodes. One way to address this question is to use the Granger causality (Sporns 2011). The notion of Granger causality is pretty simple and basically states that a variable X causes Y if Y can be better predicted using the histories of both X and Y than using the history of only Y. Thus if some series Y(t) contain information in past terms that helps in the prediction of series X(t), then Y(t) is said to cause X(t) (Granger 1969).

The formulation of Granger causality is compatible with a two-channel autoregressive model (Brzezicka et al. 2011), which can be useful to get insight into the sources and interconnections in the brain when processing, for instance, complex pleasant and unpleasant pictures. Furthermore Kaminski and Blinowska proposed a full multivariate autoregressive (MVAR) models spectral measure, called the directed transfer function (DTF), which can be used to determine the directional influences between any given pair of channels in a multivariate data set (Kaminski and Blinowska 1991, Kamiński et al. 2001). This idea can be straightforward applied to investigate brain dynamics. Thus DTF describes the causal influence of channel *j* on channel *i* at frequency *f* and it can be calculated through eq. 1.

$$\gamma_{ij}^2(f) = \frac{|H_{ij}(f)|^2}{\sum_{m=1}^{k}|H_{im}(f)|^2} \qquad \text{(eq. 1)}$$

Where, $H(f)$ is the transfer matrix of the MVAR model, whose element H_{ij} represents the important information about the connection between inputs and outputs of the modeled system. The above equation defines a normalized version of DTF, which takes values from 0 to 1 producing a ratio between the inflow from *j-th* channel to *i-th* channel and all the inflows to *i-th* channel. This method has been applied to a number of neurobiological systems (Blinowska 2011) and we propose here that, along with other approaches, it could be helpful for the study of brain processes related to basic emotions.

Temporal and spatial analysis of basic emotions

To test that the above-mentioned ideas and procedures can be applied to investigate the neural activity associated with the processing of basic emotions we used both EEG recordings and fMRI techniques. The same set of complex pictures from the International Affective Picture System (IAPS), which is a large database that contains standardized, emotionally evocative, internationally accessible photographs (Lang, Bradley, and Cuthbert 2008) was presented to several subjects. The pictures included pleasant (e.g. babies and beautiful animals) and unpleasant (e.g. scenes of violence and injuries) images and all were presented in color, with equal luminance and contrast.

For the EEG recordings we used a 64-channel NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA) and a sampling rate of 1000 Hz. Each image was presented randomly, and only once, for 500 ms and followed by a black screen for 3500 ms. The subjects observed the images and then were asked to rate the arousal and valence of their own emotional experience from 1 (very unpleasant) to 9 (very pleasant) according to the procedures used in our previous studies (Grima Murcia et al. 2015; Murcia et al. 2017; Ortiz, Grima Murcia and Fernandez 2017). For the fMRI paradigm we used a clinical 1.5 T MR scanner (GE Healthcare). Each image was also presented for 500 ms and followed by a 1000 ms grey image. The subjects were instructed to keep their gaze fixed on the screen and no oral output was required to avoid potential artifacts. Each full cycle lasted 15 secs with a total of 4 cycles per scanning run.

The functional connectivity was established by using the above-described DTF function. EEG segments of 200 ms with overlap 150 ms of all recording channels were fitted to a 3th-order MVAR model and a normalized version of DTF (Brzezicka et al. 2011). Figure 2A shows the average of clustering coefficient values for pleasant and unpleasant images for a representative subject at 150-350 ms time interval. Specific clustering, as well as a significant lateralization is revealed. Maximum clustering values are observed in CP3 (left parietal area) for unpleasant images and CP4 (right parietal area) for pleasant images. The analysis of the information flows also shows that a large number of strong connections leave from CP3 channel for unpleasant images, whereas for pleasant images the connections leave CP4 channel and have less intensity (Fig 2B).

Figure 3A shows the standardized electric neural activity distribution as well as the dipole source location that best explain the observed scalp potentials (in yellow) for a time window of 429-554 ms. This time frame was chosen to investigate the flow of information at later stages. The two halves of the brain seem to contribute again in a different way to the processing of pleasant and unpleasant images. This apparent asymmetrical representation of positive (in the left prefrontal cortex) and negative emotions (in the right prefrontal cortex), can also be observed in the fMRI activations (Fig 3B). Therefore, emotional information could start to be processed in parietal areas and then it goes to prefrontal areas for decision making.

Future challenges

Despite the obvious importance of the time component in understanding how emotions are represented in the brain, little is relatively known about the neural temporal dynamics of emotion processing. The preliminary results showed here not only reveal the lateralization of functional networks during the brain processing of complex images, but also suggest that negative emotions evoke stronger neural connections, which could be related to the greater impact of negative cues for survival (Baumeister et al. 2001). Furthermore these differences start very early, 150-350 ms after imaging onset, what supports the notion that the brain processes and catalog very quickly the basic perceptual features of any visual scene (Hillyard, Teder-Sälejärvi, and Münte 1998).

Progress in this area could be linked to the development of new methodologies able to explore the dynamics of the spatiotemporal brain networks with a millisecond-range resolution. Thus, graph theory, which is a language for the analysis of networks, can be useful to define patterns of brain networks and to quantify network properties at all different levels. This quantification is likely to improve further, since new graph measures are described regularly, but the real challenge is to come up with models that are able to combine the spatial (fMRI) and temporal (EEG) characteristics of brain responses simultaneously. Furthermore, we need new methodologies that are able to reveal functional networks at the single trial level. All these methods could be applied to whole brain analysis and help to address many relevant research questions.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

We are very grateful to all our volunteers for their time and their help to support this study. This work has been supported in part by grant MAT2015-69967-C03-1-R, by the Bidons Egara Research Chair of the University Miguel Hernández and by a research grant of the Spanish Blind Organization (ONCE).

Figure Legends

Figure 1. Examples of clustering for a single central node and its nine (high) and ten neighbors (low).

Figure 2. Clustering coefficients at 150 – 350 ms time interval for pleasant and unpleasant images. A, Connections among EEG channels established via DTF of EEG segments of 200 ms with the overlap of 150 ms. B, Connections from CP3 and CP4 that exceed 75% of the maximum value.

Figure 3. A, Standardized electric neural activity distribution for a time window of 429-554 ms. The rotating dipole that best explain the observed scalp potentials is shown in yellow. B, fMRI activation in response to pleasant and unpleasant pictures.

Figure 1.

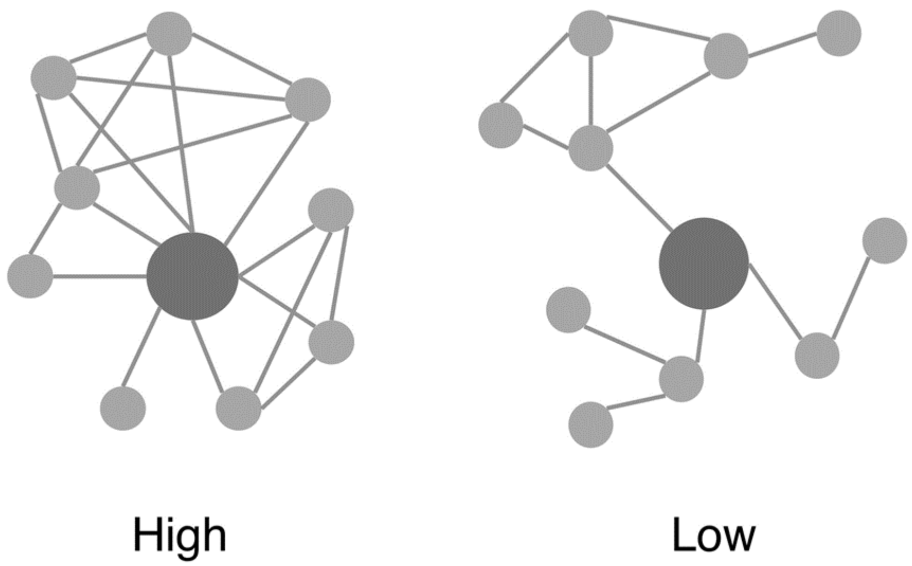

Figure 2.JPEG

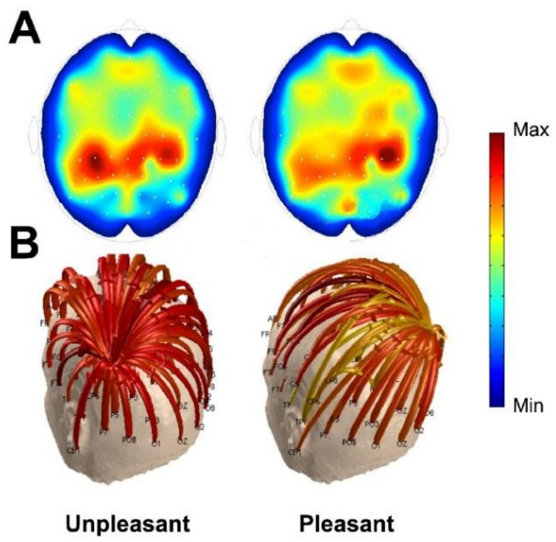

Figure 3.JPEG

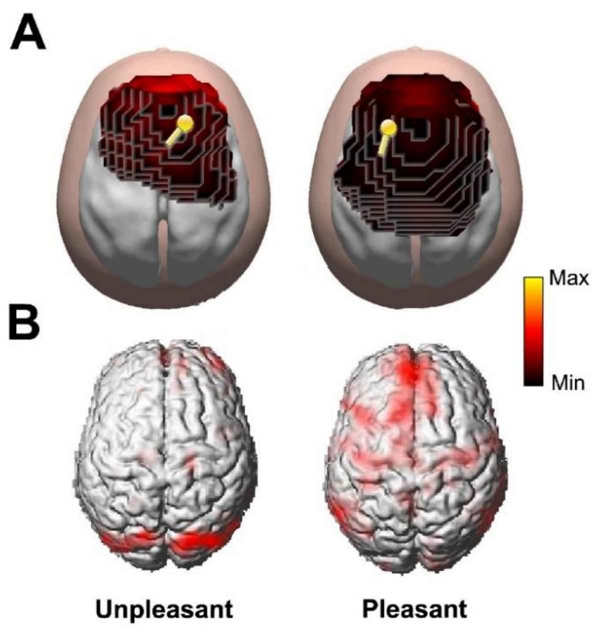

Table 1. Basic human emotions

Paul Ekman & Wallence Frisen (1972)	***Robert Plutchik (1962)***	***Silvan Tomkins (1962)***	***Carroll Izard (1977)***
Fear	Fear	Fear	Fear
Anger	Anger	Anger	Anger
Disgust	Disgust	Disgust	Disgust
Surprise	Surprise	Surprise	Surprise
Happiness	Joy	Enjoyment	Joy
Contempt		Contempt	Contempt
Sadness	Sadness		Sadness
	Anticipation	Interest	Interest
	Acceptance		
		Shame	Shame
		Distress	
			Guilt

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Spatio-temporal dynamics of images with emotional bivalence

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Abstract.
At present there is a growing interest in studying emotions in the brain. However, although in the latest years there have been numerous studies, little is known about their temporal dynamics. Techniques such as fMRI or PET have very good spatial resolution but poor temporal resolution and vice-versa in the case of EEG. In this study we propose to use EEG to gain insight into the spatio-temporal dynamics of emotions processing with a better time resolution. We conducted an experiment in which binary classification (like / dislike) of standardized images was performed. Topographic changes in EEG activity were examined in the time domain. In the spatial dimension, we used a rotating dipole for the spatial location and determination of Cartesian coordinates (x, y and z). Our results showed a temporal window (424-474msec) with a significant difference which involved a lateralization (left to very positive stimuli and right to very negative stimuli) even for neutral stimuli. These results support the lateralization of brain activity during processing of emotions.

Keywords: EEG Teleservices, Brain-computer interface, Brain area networks

Introduction

The ability to recognize the emotional states is an important part of natural communication. Emotion plays an important role in human–human communication and interaction. Considering that, in normal live, we all are surrounded by machines; the emotional interaction between humans and machines is one of the most important challenges in advanced human–machine interaction and brain–computer interface [1]. For a robust analysis of the affective human–machine interaction, one of the most important requisites is to develop a reliable emotion recognition system capable to guarantee high recognition accuracy, robustness against artifacts and adaptability to applications.

Some researchers support the notion of biphasic emotion, which states that emotion fundamentally stems from varying activation in centrally organized appetitive and defensive motivational systems that have evolved to mediate the wide range of adaptive behaviors necessary for an organism struggling to survive in the physical world [2]. In this framework, neuroscientists have made efforts to determine how the relationship between stimulus input and behavioral output is mediated though specific, neural circuits that have evolved to organize and direct adaptive actions [3].

Relatively little is known about the neural temporal dynamics of emotion processing [4]. The majority of neuroimaging studies are based on methods such as functional Magnetic Resonance Imaging (fMRI) [5] or Positron Emission Tomography (PET) [6] with excellent spatial resolution but a very poor temporal one (in the range of seconds). Conversely, Electroencephalography (EEG) offers excellent temporal resolution (in the range of milliseconds), thus offering a better choice to solve the temporal problem.

Among neuroimaging techniques, EEG has demonstrated it can provide informative characteristics in responses to the emotional states [7]. Since Davidson et al [8] suggested that frontal brain electrical activity was associated with the experience of positive and negative emotions, the studies of associations between EEG asymmetry and emotions has received much attention [9]. In other studies, EEG asymmetry and event-related potentials (indexing a relatively small proportion of mean EEG activity) were also used to study the association with emotion [10].

In this study we investigated the temporal dynamics of neural activity associated to emotions (like/dislike) generated by complex pictures derived from the International Affective Picture System (IAPS) [11]. First, we used EEG to solve the problem of temporal resolution. We evaluated the correspondence between subjective emotional experience induced by the pictures and then the neural signature derived from the temporal profiles associated with their perception. Finally, we estimated with rotating dipole and head reconstruction the underlying neural places in which event-related potentials (ERPs) were generated. The tridimensional location was used for the assessment of changes in the activation of cortical networks involved in emotion processing. We completed the study by analysis of lateralization during emotion identification task in the tridimensional space.

Our results i) provide valuable information to understand the temporal dynamics of emotions, ii) are coherent with other works [12] about hemispheric lateralization and iii) introduce locations in the tridimensional space. Therefore, we suggest that the findings of this study could be useful for the development of effective and reliable neural interfaces.

Method

Participants

Twenty-two participants participated in the study (mean age: 24.7; range: 19.7–33; eleven men, eleven women). All participants had no personal history of neurological or psychiatric illness, drug or alcohol abuse, or current medication, and they had normal or corrected to normal vision. All of them were right handed with a laterality quotient of at least + 0.4 (mean 0.8, SD: 0.2) on the Edinburgh Inventory [13]. All subjects were informed about the aim and design of the study and gave their written consent for participation.

Stimuli and validation

A subset of standardized stimuli (144 pictures in total) was preselected from the IAPS dataset [11]. This is a database that contains a set of normalized emotional stimuli for experimental investigations of emotion and attention. It contains a large set of standardized, emotionally-evocative, internationally accessible, color photographs including contents across a wide range of semantic categories, from pleasant images (e.g. babies and beautiful animals) to unpleasant images (e.g. scenes of violence and injuries). Each image was presented with a score (9-1) concerning their affective valence. Stimuli were presented in color, with equal luminance and contrast.

The preselected IAPS stimuli were categorized into four groups according to punctuation IAPS, namely very nice pictures (7<punctuation≤9), nice pictures (5<punctuation ≤7), unpleasant images (2<punctuation ≤5) and very unpleasant images (1<punctuation ≤2). Each group was composed of 36 images.

IAPS pictures were previously scored with American population. In order to avoid artifacts due to the cultural issue (the participants were Spanish), we executed a previous study to calibrate the valence of the images with our participants. Stimulus categorization was validated in a study including 30 participants who did not participate in the main experiment (mean age: 23.3; range: 20.6–31.3; seventeen men, thirteen women). The stimuli were presented one by one during 1 second followed by a black screen for 3 secs on a 21 inches' screen in random order. Subjects were instructed to give each stimulus a score from 1 to 9 avoiding 5 depending on subjective taste (1: dislike; 9: like). Their verbal response was recorded. Eighty out of the 144 images were selected for the main EEG experiment based on their new subjective score. Half of them (40) corresponded to positive images (score> 5, CI = 95%) and the other half were negative images (punctuation <5; CI = 95%).

Procedure

Figure 1 summarizes the serial structure of the study. Each image was presented for 500msec and followed by a black screen for 3500msec. The participants task was to view the images and to rate the arousal and valence of their own emotional experience. Pictures score ranged from 1 (very unpleasant) to 9 (very pleasant). The images appeared randomly and only once.

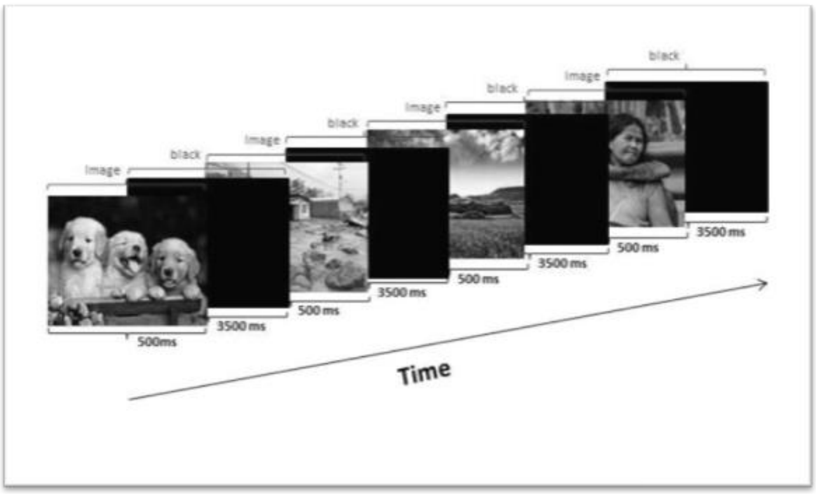

Fig. 1. Experimental design. The sequence of stimuli was presented in continuous mode by using a commercial stimulus presentation software (STIM2, Compumedics, Charlotter, NC, USA).

Data acquisition

We instructed subjects to remain as immobile as possible, avoiding blinking during image exposure and trying to keep the gaze toward the monitor center. EEG data was continuously recorded at a sampling rate of 1000 Hz from 64 locations (FP1, FPZ, FP2, AF3, GND, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, REF, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, CB2) using the international 10/20 system [14]. EEG was recorded via cap-mounted Ag-AgCl electrodes. A 64-channel NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA). The impedance of recording electrodes was monitored for each subject prior to data collection and the threshold were kept below 25 kΩ. All the recordings were performed in a silent room with soft lighting.

Signal processing was performed with the help of Curry 7 (Compumedics, Charlotte, NC, USA). Data were re-referenced to a Common Average Reference (CAR) because the statistical and analysis methods required CAR. EEG signals were filtered using a 45 Hz low-pass and a high-pass 0.5 Hz filters.

Electrical artifacts due to motion, eye blinking, etc. were corrected. They were identified as signal levels above 75µV in the 5 frontal electrodes (FP1, FPZ, FP2, AF3 and AF4). These electrodes were chosen because they are the most affected by potential involuntary movements. The time interval for artifact detection was from (-200msec, +500msec) from stimulus onset. The detected artifacts were corrected using Principal Component Analysis (PCA). PCA is a classical technique in statistical data analysis, feature extraction and data reduction [15].

EEG data in the interval (-100, 1000) msec from stimulus onset were analyzed in this study. For each person, records were separated into 8 subgroups according to their given score (9, 8, 7, 6, 4, 3, 2, and 1). In turns, subgroups for dipole analysis were grouped into 4 groups as shown in Table 1.

	Dislike				*like*			
	Group ----		Group --		Group ++		Group ++++	
opinion punctuation	1	2	3	4	6	7	8	9

Table 1. Separation of subjective scores into 4 groups for all people. Dipole separation performed for reconstruction using the mean of all people.

Statistical analyses

To constrain our analysis, we used an approach that has been widely used in psychophysiology: the examination of topographic changes in EEG activity (see [16] for an overview and [17]). This approach considers whole-scalp EEG activity elicited by a stimulus as a finite set of alternating spatially stable activation patterns, which reflect a succession of information processing stages. Differences in topographic patterns of activity between conditions were assessed using the Curry 7 software.

There are two main reasons why we used this analysis rather than the more traditional which is based on the assessment of amplitudes and latencies of a set of pre-defined ERP components. First, it takes into consideration the entire time course of activity and the entire pattern of activation across the scalp by testing the global field power from all electrodes (see for further explanation [18]). Second, this approach is able to detect not only differences in amplitude, but also differences in underlying sources of activity. The latter is based on the fact that maps that are confirmed to be both spatially and temporally different must necessarily be the product of a different set of generators. However, we emphasize that the analysis of topography changes is not incompatible with the analysis of traditional ERPs.

As recommended, topographical differences were tested through a non-parametric randomization test known as TANOVA (Topographic ANOVA). TANOVA tests for differences in global dissimilarity of EEG activity between two conditions by assessing whether the topographies are significantly different from each other on a time point-by-time point basis. TANOVA were performed to assess differences in activation patterns between different groups of images by subjective scoring. TANOVA is sufficient to indicate the time windows of interest for further analysis dipole. In this study, the significance level is $\alpha=0.01$. As suggested by [19], the corresponding required number of repetitions was chosen to be $p> 1000$. Map normalization was used for the difference tests, such that the MGFP per map was equal to 1.

The dipole source localization (DSL) solves the EEG inverse problem by using a nonlinear multidimensional minimization procedure that estimates the dipole parameters that best explain the observed scalp potentials in a least-square sense. In this process, we assume that EEG is generated by one or no more than few focal sources. The dipole source model can be further classified as moving, fixing or rotating dipoles depending on the degree of freedom of parameters. In our study we used a rotating dipole, that may be viewed as two independent dipoles whose orientation is allowed to vary with time [20].

Boundary Element Method (BEM) was used in the head reconstruction since it permits to locate the source dipoles. Thus BEM models are superior in non-spherical parts of the head like temporal and frontal lobe or basal parts of the head, where spherical models exhibit systematic localizations of up to 30 mm [21].

Results

Participant rankings compression

The participants responded correctly to 1758 images (99.98%) following the instructions before starting the experiment. In only two images volunteer answered incorrectly (score 5) or did not respond. The images followed by incorrect answers were not excluded in the analysis below. The distribution of the new scores (or valences) was 49.4% and 50.6% greater and less than 5 respectively.

EEG

Differences in stimulus-elicited activity are depicted in Figure 2. There were significant differences between pictures with different scores ($p<0.01$). These differences started approximately 276 msec after stimulus onset. All subgroups were significant different to each other in two time windows, namely [276 - 294] msec and [424 - 474] msec.

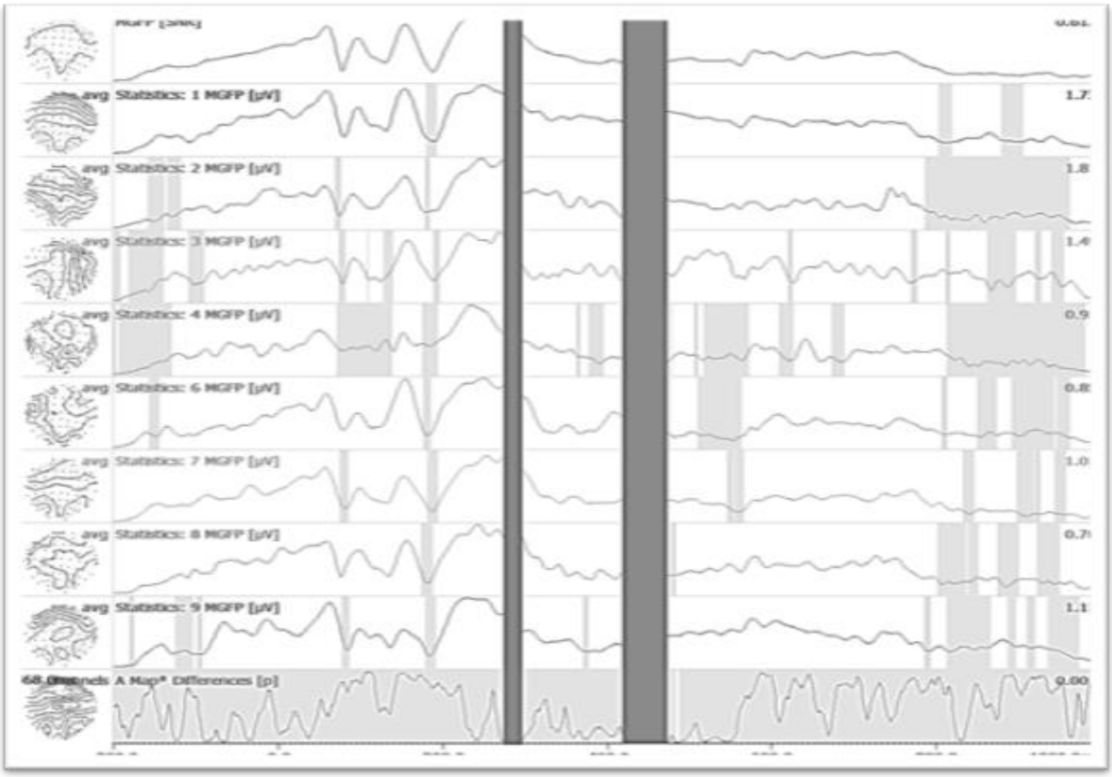

Fig. 2. Time points of significant differences in EEG activity for the 8 contrasts (9, 8, 7, 6, 4, 3, 2 and 1). It is as indicated by the T ANOVA analysis, depicting 1 minus p-value across time. Significant p values are plotted (p<0.01). The two vertical rectangles contain interval with significant differences.

Dipoles

One rotating dipole source model was used in the two time windows with significant differences indicated by the TANOVA (see Figure 2). When we focused in the larger time window (424-474msec, duration 50msec) we found significant differences in the dipoles for the different types of images (see Figure 3).

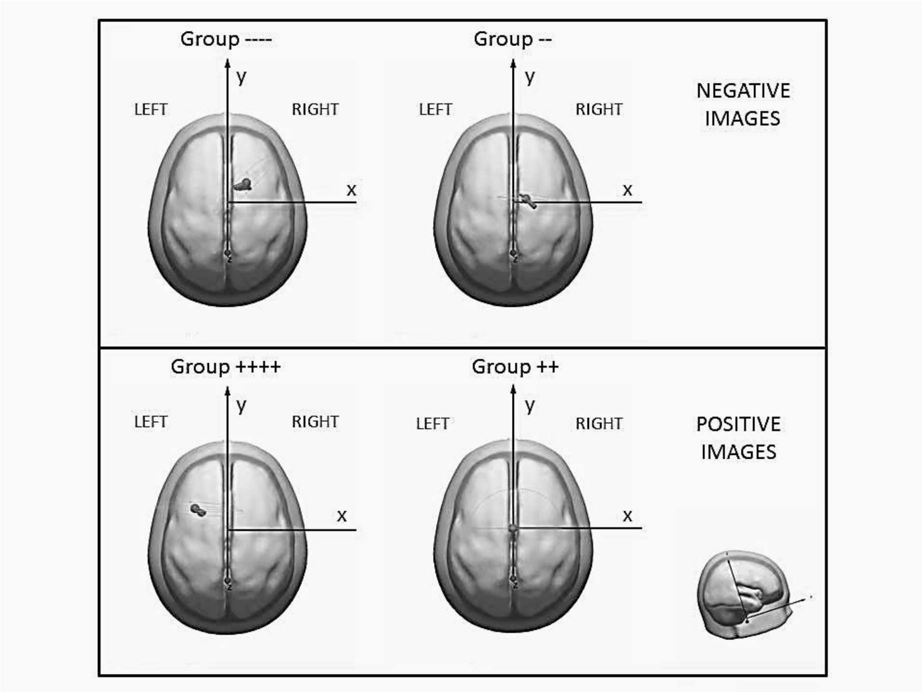

Fig. 3. Head reconstruction by rotating dipole in time window [424-474] msec. Rating was grouped into four groups according to subjective punctuation (see Table 2).

The Cartesian coordinates of the rotating dipole for each group are shown in table 2.

window 424-474ms											
Dislike (coordinates in mm)						like (coordinates in mm)					
Group ----			Group --			Group ++			Group ++++		
x	y	z	x	y	z	x	y	z	x	y	z
20,7	25,4	8,3	13,9	10,5	20	-0,6	5,3	16,8	-35,8	27,4	7,5

Table 2. Coordinates of dipole in head for window significant [424-474] msec.

Discussion and conclusion

Our results suggest a strong lateralization in the processing of images with emotive content. Thus, we found an increased activity in the left hemisphere for emotions with a positive valence. In contrast, there was an increased activity in the right hemisphere for emotions with a negative valence. These results are in line with the valence hypothesis in the hemispheric lateralization of emotion processing, which postulates a preferential engagement of the left hemisphere for positive emotions and of the right hemisphere for negative emotions[22][23]. Furthermore, the z coordinate of the resulting rotating dipoles, provide valuable information for further studies in this field. In this framework our results support the point of view that in extreme emotions (groups ++++ and ----), z is smaller or more intermediate than in neutral images (groups ++ and --).

On the other hand, the broad range of stimulus types adds an important dimension of universal validity to the results. The same valence can be induced by either pictures displaying facial, bodily expressions, or complex events and landscape. Therefore, we extend generalizability beyond facial expressions, which are the stimuli most commonly used in emotion research.

In future work, we plan to perform a deeper study of the dipoles for each group, which would allow us to get higher levels of accuracy in the definition of the location of the dipoles. Thus, the spatial location observed in emotional processing of different visual stimuli can help to provide a comprehensive account of the role of each hemisphere in this processing, which could help in understanding deficits seen in psychiatric or developmental disorders. Furthermore, this could be helpful for the development of new paradigms of brain-computer interfaces.

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• Publicación en técnicas de sincronización de registros EEG

Artículo: Asynchronous Detection of Trials Onset from Raw EEG Signals

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Asynchronous Detection of Trials Onset from Raw EEG Signals

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Clinical processing of event-related potentials (ERPs) requires a precise synchrony between the stimulation and the acquisition units that are guaranteed by means of a physical link between them. This precise synchrony is needed since temporal misalignments during trial averaging can lead to high deviations of peak times, thus causing error in diagnosis or inefficiency in classification in brain–computer interfaces (BCIs). Out of the laboratory, mobile EEG systems and BCI headsets are not provided with the physical link, thus being inadequate for acquisition of ERPs. In this study, we propose a method for the asynchronous detection of trials onset from raw EEG without physical links. We validate it with a BCI application based on the dichotic listening task. The user goal was to attend the cued auditory message and to report three keywords contained in it while ignoring the other message. The BCI goal was to detect the attended message from the analysis of auditory ERPs. The rate of successful onset detection in both synchronous (using the real onset) and asynchronous (blind detection of trial onset from raw EEG) was 73% with a synchronization error of less than 1 ms. The level of synchronization provided by this proposal would allow home-based acquisition of ERPs with low cost BCI headsets and any media player unit without physical links between them.

Keywords: Event-related potentials; brain-computer interface; brain area network; EEG teleservices; e-health.

1. Introduction

Event-related potentials (ERPs) and evoked potentials are positive or negative deflections (peaks) of the EEG signal elicited as a response to a stimulus. They are extensively used in clinical practice because the peak times (i.e. latencies) point out physiological impairment along the whole pathway from the periphery up to the cortex. For instance, visual evoked potentials (VEP) are used for clinical diagnosis of optic neuropathy, multiple sclerosis, glaucoma, brain injury1 or for people with poor vision, poor cooperation, or poor optics (media opacities).2

ERP acquisition is performed in labs and hospitals because it requires an isolated room, personnel with expertise in EEG setup and because of the costs of the acquisition and the stimulation units. Currently, modern wireless brain–computer interface (BCI) headsets with dry EEG electrodes are capable of ubiquitous acquisition.3,4 They are able to register EEG signals and implement diverse paradigms and applications with a simple setup that could be described as nearly plug-and-play. However, cur-rent BCI devices do not incorporate synchronization mechanisms with the stimulus unit (e.g. a media player).

In recent years, the study of synchronization methodologies5–7 and ERPs8–10 is a frequent topic in BCI literature (see Ref. 11). ERPs acquisition requires both stimulation and EEG acquisition units to be synchronized at hardware level by means of a trigger connection, e.g. a parallel port. Conversely, mobile and BCI EEG headsets do not integrate a stimulation unit, thus not being adequate to execute event-related paradigms. This explains why most of the home-based EEG services are not meant for ERPs. Some examples in literature of home-based
and mobile EEG teleservice combined with acquisition of other bio-signals are in video-EEG,12–14

polysomnography,15 epilepsy16 or breathing detec-tion.17 These examples did not require stimulation because they registered epileptic seizures or sleep apnea that manifest for long time (from seconds up to minutes). Therefore, they do not need synchrony. In summary, current mobile EEG acquisitions are not meant for the acquisition of ERPs.

Modern BCIs3,18 are wireless, wearable and dry EEG headsets meant for personal uses19–21 that can be considered in the context of wireless body area networks.

Mobile BCIs do not provide physical connection between the stimulation unit or media player and the EEG headset, thus they lack synchronization mechanisms. Furthermore, the use of a physical link to wire mobile devices is an unfeasible and questionable approach from the point of view of the user experience. As a result, applications for mobile BCIs do not work with ERP paradigms but with brain-rhythms and steady-state responses.22

There are commercial devices and workarounds that provide synchronization, but we believe that they are not fully adequate for the context of the ubiquitous acquisition of ERPs with off-the-shelf wireless EEG headsets and any low-cost multimedia player. As far as we know, commercial wire-less EEG headsets provide synchrony by means of another device (base-station) wired to a USB port in a PC/Laptop. This and other workarounds (e.g. microphone) are not fully adequate for users since they require a PC with specific software and/or they limit their usability and mobility every-where. In our proposal, stimulus can be played with any media player without adaptations in the EEG headset. We have introduced this discussion in Sec. 1.

In this paper, we propose a procedure for the asynchronous detection of trials onset based on an auditory preamble. It evokes a brain response that can be detected from raw EEG with millisecond precision. The preamble embeds a synchronization mechanism that virtually generates the wired connection between the stimulation unit and the mobile BCI. This work is based on the findings of a preliminary study.23

2. Methodology

In this experiment, we evaluate the performance of our proposal in the asynchronous detection of trials onset. Also, we apply the detected onset to the binary classification of an auditory BCI. The BCI is based on a binary phase-shift keying (BPSK) receiver and it is designed in such a way that a small error in synchrony causes high degradation of performance in terms of classification accuracy. Then we compare classification performance of synchronous (using the real trial onset) and asynchronous onset detections.

2.1. Subjects and recordings

A total of 14 volunteers (5/9 male/female, aged between 19 and 43) participated in this study. They were collaborators and researchers of the Institute of Bioengineering, University of Miguel Hernández of Elche, Spain. Only three of them had previous experience with auditory BCIs. The study was fully auditory without any type of visual stimulation or feed-back. The volume of the auditory stimulation was manually adjusted to the comfort level of each participant. Audio files were generated with MATLAB (R2010b) and were presented by means of earphones. All participants were previously instructed with the procedure, methodology, purpose of this study and signed the informed consent.

We acquired signals from just one active EEG channel located at the frontal midline site (Fz, of the International 10–20 system) and referenced to the left mastoid (M1). These positions were chosen because they match reports of successful studies of auditory event-related potentials.24 The ground electrode was placed between Fpz and Fz. The recordings were acquired on a Synamps 2, by Compumedics Neuroscan, were band-pass filtered between 1 Hz and 100 Hz and were sampled at a rate of 1 kHz. A notch filter was applied at 50 Hz.

2.2. Auditory message

The auditory message consisted of two parts, namely the preamble and the sentence (see Fig. 1). The preamble is used for synchronization purposes. The sentence is part of a dichotic listening task in forced-attention modality. In this modality, the participant is told to pay attention to one auditory message and to ignore the other. Each auditory message of the dichotic stimulation was normalized. Then, assuming independent and uncorrelated messages the total energy presented to participants was constant across trials.

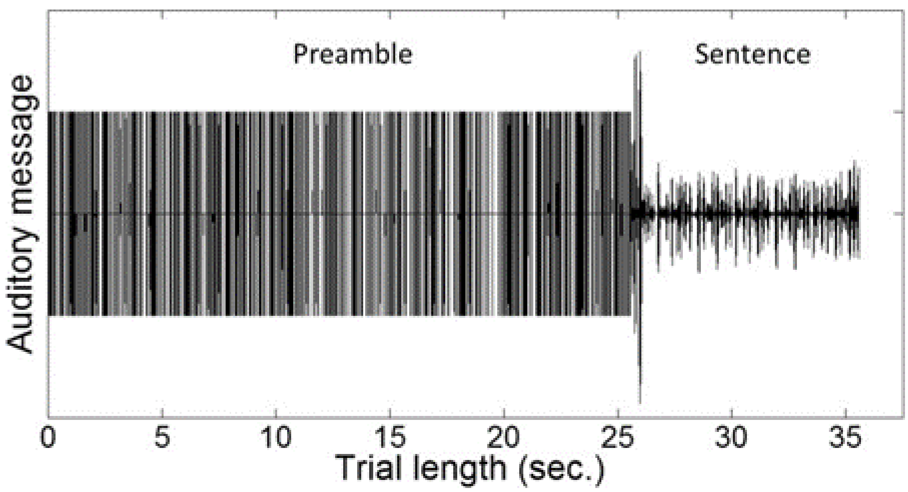

Fig. 1. Auditory message structure. The auditory message is composed of the synchronization preamble and a sentence chosen at random from the Coordinate Response Measure speech corpus.

2.2.1. Preamble

The preamble p(t) was generated by means of a pseudo-random code m(t) convoluted with a tone-pip g(t). See (1).

$p(t) = m(t) \otimes g(t)$.   (1)

The tone-pip length was 6 ms (2/2/2 of rising/plateau/falling flank) as depicted in Fig. 2.
The m(t) consisted of a binary pseudo random sequence (m-seq) generated with 10 taps with a length of 1023 bits. Each binary value was spaced out at 25 ms before convolution with the tone-pip. Then, the preamble length was 25.575 s circa (1023 bits spaced out at 25 ms).

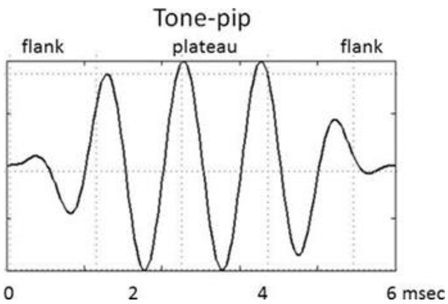

Fig. 2. The figure shows the shape of a tone-pip used for the evocation of auditory ERPs. Each vertical line of the preamble in Fig. 1 corresponds to one tone-pip.

Table 1. Target words of coordinate response measure.

Call-sign	"arrow", "baron", "charlie", "eagle", "hopper", "laker", "ringo", "tiger"
Color	"blue", "green", "red", "white"
Number	"one", "two", "three", "four", "five", "six", "seven","eight"

2.2.2. Sentences design

Auditory sentences were chosen from the Coordinate Response Measure speech corpus.25 The corpus is commonly used in selective attention experiments.26 The sentences consisted of seven words containing three target words. They follow the structure "Ready call-sign go to color number now". Table 1 shows all possible target words.

Each sentence si(t) (i equals 0 for left and 1 for right) was tagged to elicit a BPSK constellation of symbols. It was achieved by modulating the amplitude of two carriers by the two sentences. The two carriers were of the same frequency (5 Hz) and counter-phased (πi/2). Signals si(t) represent the tagged messages (2).

$$s_i'(t) = \frac{1}{2}\left[1 + \sin\left(2\pi 5t + \frac{\pi i}{2}\right)\right] s_i(t). \qquad (2)$$

This procedure gave rise to two auditory messages si(t) that were delivered one to the left and the other to the right ear. There are previous papers that used this principle to elicit a reliable constellation of BPSK (or m-PSK) signals in BCI applica-tions.27–29 The duration of the sentences was 10 s. Please refer to Ref. 28 for further details about the psycho-physiological principles that justify this sentence design.

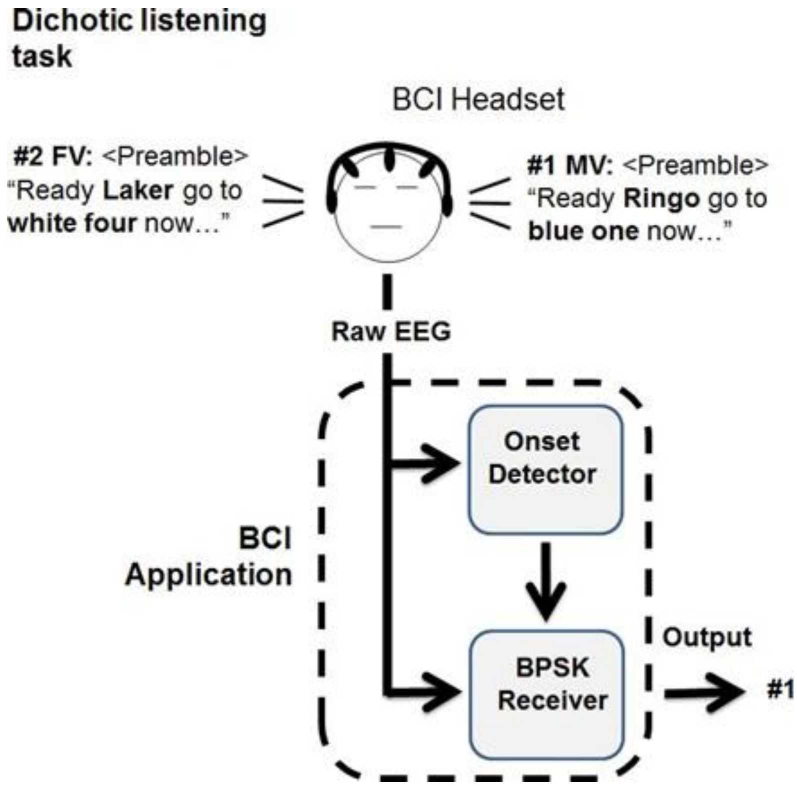

Fig. 3. Asynchronous onset detection. The figure shows a dichotic listening task in which two auditory messages are concurrently delivered to a participant. The participant must attend the cued message (in this example male voice #1) and ignore the other. Each message includes the synchronization preamble. "Preamble": auditory preamble; MV: male voice; FM: female voice. A BCI headset acquires raw EEG data and asynchronously transmits it to the BCI application. The onset detector block estimates the trial onset directly from the physio-logical response. The BPSK receiver uses this

estimation together with the raw EEG to extract features and map onto a BPSK constellation. Then, it performs detection of the attended message (in our example output #1).

2.3. Procedure

The experiment consisted of a session that, in turn, consisted of 24 trials. In each trial, an auditory instruction invited the participant to press a key. Afterwards, a tone-beep indicated the beginning of the auditory message. Finally, a beep sounded and another auditory instruction signaled the end of the trial and the preparation for the next one. During the inter-trial time, the participant had to complete a task. See Sec. 2.4 for further details

In each trial, an algorithm randomly selected two sentences formed with combinations of the target words of Table 1. In each trial, the two sentences were from a male and a female voice. Each sentence
was encapsulated with the same auditory preamble, thus forming the auditory message presented in each trial (see Figs. 1 and 3).

We formed two auditory messages per trial, one was the target and the other was considered a distracter. The auditory messages were concurrently delivered. The first auditory message was delivered to the left ear and the second to the right. The participants were randomly cued to attend to one of them and ignore the other. The order of delivery was the cue of the dichotic listening task. Cues to the left (first auditory message) and right (second one) were counterbalanced, as well as the male and female voices of speakers (always male and female voices to left and right ear, respectively).

2.4. Participants' task

At the end of each trial, participants had to report the three target words of the attended message (see Table 1). Once the target words were reported, the system scored the accuracy of the responses (per cent of correctly reported target words). The purpose of this behavioral task was to keep the motivation and attention of the participants high, thus resulting in a challenging task. Participants used to ask for scores of previous participants and colleagues before beginning their sessions.

2.5. Preamble detection

We detect the preamble by means of a replica-correlator detector, which is equivalent to a matched filter. A matched filter is implemented by a simple correlation of a replica of the preamble p(t) with the EEG signal. The replica was obtained by convoluting the m-seq used to generate the preamble (see Sec. 2.2) with four cycles of sinusoidal wave of 40 Hz. In general terms, we synthesized the auditory 40 Hz phenomenon30 as the response to the preamble. The condition for a true positive (TP) detection is that the synchrony error (error between the real onset and the detected onset) must be less than 100 ms. The reason for that is because ±100 ms corresponds to four cycles of 40 Hz. This solution is not optimal since the literature says that the number of cycles of the 40 Hz phenomenon may vary from 3-430 depending on the participant. However, our generalized method avoids previous sessions of calibration and is designed to work without priors of the physiological response of any participant.

2.6. Attention classification

Once the asynchronous trial onset was detected, we performed an asynchronous classification of the attended auditory message. Since we performed the experiment in a laboratory with the physical link between the stimulation and the acquisition unit we knew the real trial onset. This will be considered as the gold standard.

2.6.1. Feature extraction

The raw EEG was detrended and normalized. Then, the discrete Fourier transform (DFT) was computed. In this study, the stimuli design caused a constellation of BPSK signals at the frequency of EEG modulation, namely 5 Hz. Only the DFT coefficient corresponding to 5 Hz (C5) was extracted for classification.

2.6.2. Training

Training is needed since we cannot know a priori the position of symbols of the constellation. In a BPSK the amplitude of symbols is not relevant, but only their phases. Thus, the goal of the training was to establish the phase of the symbols of the BPSK constellation. A BPSK constellation is composed of two counter-phased symbols. This means that both symbols are separated by 180◦ or the equivalent in time 100 ms (half period of C5 is 100 ms). This is a critical aspect since minor errors in the asynchronous detection of the trials onset could cause important errors in performance of the classification of the attended source. For instance, at 5 Hz, an onset error of just 20 ms in the trial onset could cause a constellation error of 36◦.

We used leave-one-out cross-validation to train the constellation and evaluate the performance of the system. We performed 24 evaluations for each participant. In each one, 23 features were used for training and 1 for classification. The trained constellation was defined as the one that maximized the accuracy of the classification of the attended auditory message.

2.6.3. Classification

In BCI literature, there are many different approaches for extraction and classification31 of EEG features applied to clinical diagnosis32–34 or BCI applications,35–37 etc. Since the auditory messages in this experiment elicited a constellation of BPSK signals, we simply used a BPSK receiver to detect the attended source.

Detection of the attended auditory message was performed by the BPSK receiver block (see Fig. 3). Once the trial onset was detected, the feature (C5) was extracted from the raw EEG (see Sec. 2.6.1) and mapped onto the trained BPSK constellation (see Sec 2.6.2). That is, the two counter-phased symbols of the trained BPSK constellation respectively rep-resent attention to the left and right auditory messages. Then, classification (attention to the left or right auditory message) was performed by means of a minimum Euclidean distance classifier from C5 to the symbols of the trained BPSK constellation. This classifier, under some general assumptions, is the optimal Bayesian classifier.38

1. Results

The total number of participants was 14. Based on the criterion hereafter explained we excluded three of them, namely P03, P09 and P10, because they did not elicit reliable EEG responses in terms of carrier-to-noise ratio (CNR). We know that users of well-known technologies such as EEG-BCIs suffer from a certain (or even severe) illiteracy. For this reason, authors did not expect 100% success in this novel approach.

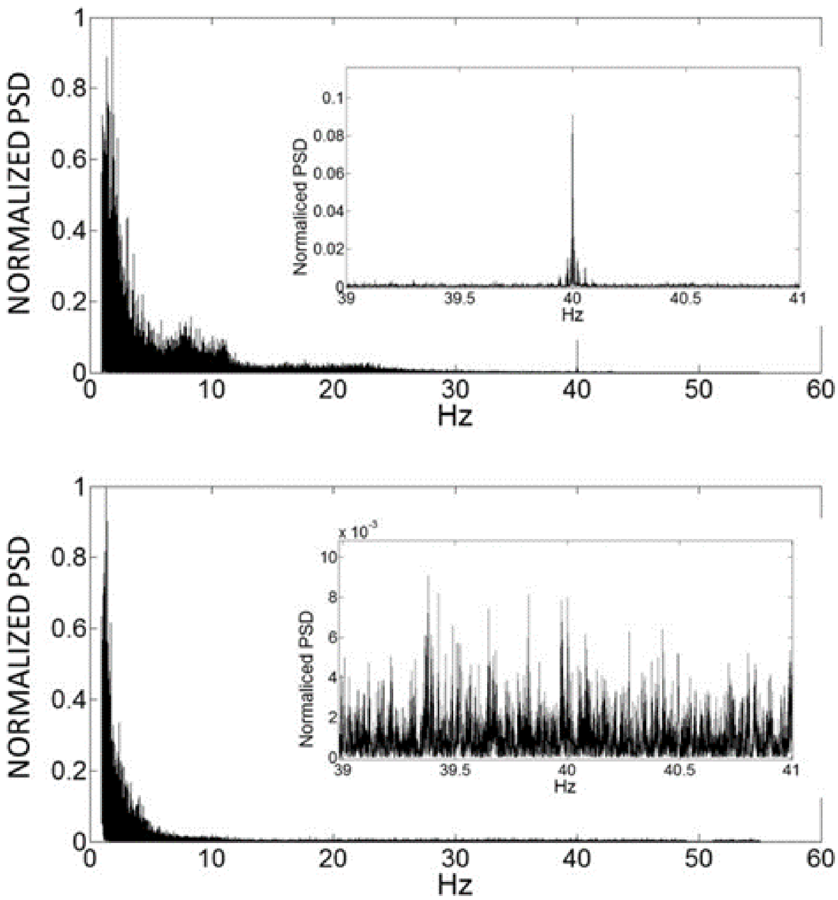

Fig. 4. Illustrative examples of PSD of participants with good (upper plot) and bad (bottom) CNR (P04 and P10, respectively).

The exclusion criterion was defined as participants with the parameter CNR below 0 dB. We defined CNR as the participant's ability to elicit the 40 Hz phenomenon. This CNR was measured as the mean power spectral density (PSD) at 40 Hz (C) divided by the mean PSD in the interval 35–45 Hz excluding 40 Hz (N). For illustrative purposes, Fig. 4 shows an example of two participants with good and bad CNR, respectively. In the plot corresponding to the good CNR, we can clearly appreciate the peak at 40 Hz. In the plot corresponding to the participant with bad CNR we cannot appreciate the 40 Hz phenomenon, thus making the asynchronous detection of the stimulus onset unfeasible.

Table 2 shows the CNR of all participants (including those excluded). It is well established that a percentage of the population cannot control a BCI effectively (it may be 20% (Ref. 39) or even more depending on the paradigm). Thus, the exclusion of some participants was not surprising. In the case of participant P01, only 19 trials were performed due to an unexpected incident during his EEG session.

3.1. Detection performance

The third column of Table 3 shows the number of TP detections as well as the rate (fourth column) relative to the total of trials (second column). The last two columns show mean and standard deviation of the synchrony error, that is the time difference between the asynchronous detection of the trial onset and the real one.

The suitability of CNR as a parameter to dis-criminate participants with high, medium and low rates of asynchronous detection was estimated. We fitted a linear regression of the rate of detected trials (fourth column in Table 3) on CNR values (Table 2) for all participants. At a significance level of $\alpha = 0.05$, we obtained a significant value of r2 = 0.40 (F-statistic versus constant model: 7.84, p-value = 0.016). We also tested the goodness of fit of CNR to the error in the synchronization

Table 2. CNR values in dB units. Participants with gray background were excluded from statistical analysis due to unreliable EEG signals.

P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14
4.2	2.7	−0.8	12.3	1.0	0.1	4.0	0.5	−1.3	−0.7	0.2	4.4	2.2	13.0

Table 3. Detection performance. Participants with gray background were excluded from statistical analysis.

Detection performance					
	Trials			Syn error (ms)	
Partic.	Total	Detected	Rate	Mean	Std
P01	19	18	0.95	4.8	9.6
P02	24	19	0.79	−3.5	20.8
P03	24	9	0.38	10.6	25.7
P04	24	24	1.00	−5.3	6.2
P05	24	18	0.75	15.8	8.4
P06	24	24	1.00	1.5	8.6
P07	24	10	0.42	−2.3	21.4
P08	24	17	0.71	1.9	13.3
P09	24	2	0.08	−11.0	17.0
P10	24	2	0.08	−11.5	3.5
P11	24	7	0.29	−18.4	34.3
P12	24	21	0.88	−2.7	14.6
P13	24	8	0.33	−16.8	22.6
P14	24	24	1.00	−2.9	5.0
Mean			0.73	−0.9	14.3

(fifth and sixth columns in Table 3). However, we obtained an insignificant explanatory power for the mean of r2 = 0.10 (F-statistic versus constant model: 1.04, p-value = 0.334) and for the standard deviation r2 = 0.26 (F-statistic versus constant model: 3.24, p-value = 0.106). The variable that best fitted the synchronization error was the rate of detected trials (fourth column in Table 2). We obtained significant values for mean r2 = 0.41 (F-statistic versus constant model: 6.14, p-value = 0.0351) and standard deviation r2 = 0.74 (F-statistic versus constant model: 25.2, p-value = 0.000715).

Bars in Fig. 5 represent the histogram of synchronization errors in the temporal window [−100 . . . 100] ms. It plots frequencies of 190 detected trials (the sum of values under the third column in Table 3) in bins of 4 ms each bar.

3.2. Classification performance

Table 4 shows the classification accuracy using the real onset (third column) and the detected one (last column).

It is important to clarify that the performance of the synchronous classification is not being studied in this paper (third column in Table 4). The method-ology based on a BPSK receiver to detect attention in dichotic listening tasks is well-established in other

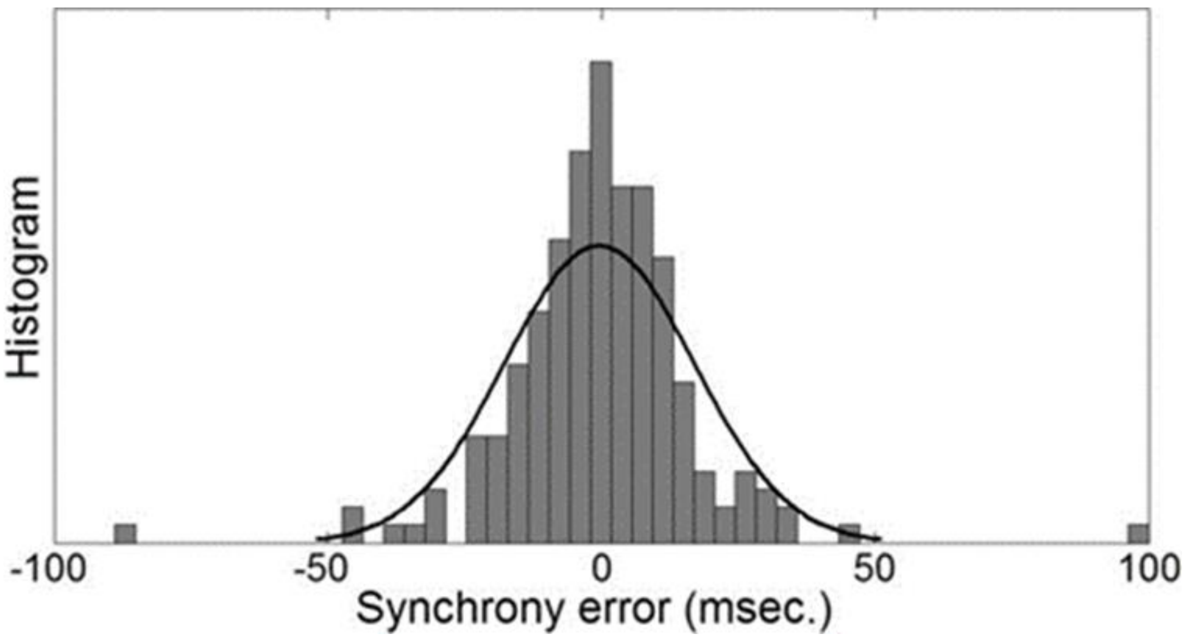

Fig. 5. Distribution of synchronization error. The histogram (gray bars) corresponds to frequencies of synchronization errors in the temporal window [−100 . . . 100] ms. Each bar represents a bin of 4 ms. The figure shows that the distribution of the error is not uniformly distributed in the range [−100 . . . 100] ms.

Table 4. Classification performance. Participants with gray background were excluded from statistical analysis.

Classification performance							
	Syn onset				Asyn onset		
Partic	Trials	Acc.	C.I.		Trials	Same Cla.	Rate
P01	19	0.84	0.68	1.00	18	16.00	0.89
P02	24	0.50	0.30	0.70	19	17.00	0.89
P03	24	0.54	0.34	0.74	9	7.00	0.78
P04	24	0.83	0.68	0.98	24	19.00	0.79
P05	24	0.88	0.74	1.00	18	12.00	0.67
P06	24	0.75	0.58	0.92	24	21.00	0.88
P07	24	0.63	0.43	0.82	10	5.00	0.50
P08	24	0.79	0.63	0.95	17	11.00	0.65
P09	24	0.54	0.34	0.74	2	2.00	1.00
P10	24	0.63	0.43	0.82	2	1.00	0.50
P11	24	0.54	0.34	0.74	7	5.00	0.71
P12	24	0.54	0.34	0.74	21	9.00	0.43
P13	24	0.75	0.58	0.92	8	1.00	0.13
P14	24	0.79	0.63	0.95	24	22.00	0.92
	Mean	0.71	0.66	0.77			0.73

contributions.23,27,28,40 However, it is important to show its results to check whether the preamble can be used with a real BCI application in an effective way. On the right side of Table 4, we show trials with asynchronous detection (sixth column) and how many of them classify equally as with synchronous detection (seventh column).

Differences between the sixth and seventh columns are due to error in synchrony. The mean accuracy was 73% with peaks of 92% (last column in Table 4).

4. Discussion

The results set out in the previous section reveal the strength of our proposal for the asynchronous detection of trials onset of EEG signals. The detection was performed completely asynchronously on raw EEG data and the absolute synchronization error aver-aged across subjects was only 0.9 ms. (see Table 3). Furthermore, the detection was performed with no priors about the beginning of the trial and the specific electrophysiological characteristics of the 40 Hz phenomenon of each participant. No calibration session was performed or data analyzed previously. In essence we could describe it as the blind detection of the trial onset.

Three participants, namely P03, P09 and P10 were excluded from statistical analysis. We arbitrarily decided to establish the participant exclusion threshold at a CNR of 0 dB (the same level of carrier at 40 Hz and surrounding noise). There is a trade-off between the synchronization error and the number of participants that depends on the CNR threshold. For example, for a CNR threshold of 3 dB the standard deviation of the synchronization error would be only 9.9 ms, but the number of participants excluded would be 11 (with CNR threshold at 0 dB, the standard deviation of the synchronization error was 14.3 but only three participants were excluded). Since we deliberately opted for a plug-and-play design, free of calibration and suitable for most of the population without priors about their electro-physiological response, we decided to keep this threshold low.

4.1. Detection performance

The mean error in synchrony is −0.9 ms. This is an extraordinary value taking into consideration that we performed a blind detection. However, the mean value is not what challenges our proposal, but the deviation in the measures. The standard deviation is 14.3 ms, which is approximately half period of 40 Hz (12.5 ms). It is coherent with what was expected, since detection was performed on the maximum absolute value of the output of the replica-correlator. That means that either positive or negative cycles of the 40 Hz phenomenon could yield detection.

From the regression analysis performed in Sec. 3.1, we found that CNR explains 40% of variance of the rate of detected trials. The importance of this finding is that we can use CNR to give an online
estimation of the performance of the asynchronous detection. Depending on CNR we can decide to extract trials from a session, decline or request more trials before processing. This could be used for clinical diagnosis. For instance, in VEP assessment, denoising is achieved by averaging many ERPs (at least two independent sweeps of 64 each). Obviously CNR does not perfectly explain the variance of the rate of detected

trials and can hardly explain the synchronization error. However, in this first study in which CNR is defined, its explanatory power and utility are satisfactory enough and its own definition will be improved in future.

The rate of detected onsets (fourth column in Table 3) is the variable that best explains the variance in the synchronization error (up to 41% and 74% in mean and standard deviation, respectively). We defined a temporal window of ±100 ms for TP detections (see justification in Sec. 2.5). Thus, we expected the replica-correlator to yield values with a maximum at zero lag. If the detection had been random, the error would have been uniformly distributed within the range ±100 ms, with a standard deviation of 57 ms. However, the global standard deviation was 14.3 and the envelope of histogram of Fig. 5 clearly shows that the distribution is not uniform. In summary, we can conclude that our proposal for asynchronous onset detection works, although its efficiency may vary across participants.

4.2. Applicability in clinical acquisition of ERPs

Table 3 shows that the asynchronous detection pro-posed in this study did not function in all trials. False positives give rise to an inefficient ERP denoising. In this case, averaging trials would contain a certain number of trials constituted only by independent and uncorrelated-with-the-ERP EEG noise. The net effect is an ERP with suboptimal SNR but with unaltered peak times since the mean synchronization error was nearly 0 ms. In clinical practice, the most relevant contribution of ERPs is the peak times, and then our proposal could be efficiently used in this scenario.

In the scenario of the previous paragraph, we assumed that a nearly zero error could be achieved by any participant. The latter was not proved. The mean synchronization error across participants was nearly zero (−0.9 ms) when a larger number of trials were averaged (190 detected trials). However, each participant averaged no more than 24 detected trials and large mean synchronization errors (e.g. 15.8, −18.4 and −16.8 ms of P05, P011 and P13, respectively) could be just a statistical effect. Large mean synchronization errors come together with large standard deviations (8.4, 34.3 and 22.6 ms, respectively), and then we cannot rule out that they are caused by the small number of trials.

In our study the goal was to check whether this bio-synchronized procedure was able to offer a high level of synchronization, but not to design an efficient paradigm in terms of information transfer rate (ITR). Obviously a real implementation for clinical acquisition would have been designed in a completely different way, for instance, by means of only one longer preamble for a run of trials, thus reducing drastically the amount of overheads.

4.3. Classification performance

Table 4 shows the performance of the attention classification with synchronous and asynchronous onset detection. As shown in the table, the mean accuracy of the synchronous classification, taking into consideration the confidence intervals (C.I.), is better than chance level (mean = 0.71, CI [0.66, 0.77] at significance level $\alpha = 0.05$). Our proposal based on a BPSK receiver for detection of attention in dichotic listening tasks was demonstrated in previous stud-ies27,28,40 and is not the focus of discussion in this study.

In this study, the primary objective is to check whether the asynchronous detection of trials onset could yield similar results to that of the synchronous detection in a dichotic listening task. In this regard, Table 4 shows that the influence of the synchrony error resulted in 73% of trials with asynchronous onset yielded the same classification as those with the synchronous onset. This is strong evidence of the validity of our proposal.

5. Conclusion

In this paper we propose a procedure for the asynchronous detection of trials onset based on an auditory preamble that can be used in acquisition of ERPs.

Our synchronization preamble evokes a brain response that can be detected with precision of a few milliseconds. The preamble embeds a synchronization mechanism that virtually generates the wired link between the stimulation and acquisition units. The level of synchronization provided by our proposal would allow assessment of ERPs by means of a low cost BCI headset and any stimulation unit (e.g. a media player).

Our proposal can be improved in future studies. For instance, the 40 Hz phenomenon was assumed to elicit four cycles of 40 Hz. It could be tailored for each participant by means of a calibration session, although at the cost of the plug-and-play design. The results with a plug-and-play approach suggest that there is much space for future improvement.

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- **<u>Publicaciones de trabajos con registros EEG para valoración de procesos cognitivos complejos.</u>**

Artículo: Brain processing of visual metaphors: an electrophysiological study

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Brain processing of visual metaphors: An electrophysiological study

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1 Introduction

Metaphors are pervasive in everyday language and often used in advertisements to draw attention and persuade consumers to purchase products or services. Despite it, there are many open questions regarding how metaphors are processed in the brain. In general, there are three possible models: the standard model, the parallel hypothesis, and the context-dependent hypothesis. According to the first model, metaphors take longer to process than literal statements because metaphoric interpretation should be sought only when literal interpretations are defective. The parallel hypothesis model argues that both metaphoric and literal meanings are processed concurrently and involve the same mechanisms. Finally, the context-dependent hypothesis postulates that the metaphorical meaning is directly accessed when this is made obligatory by the context.

Several researches have used Event-Related Brain Potentials (ERPs) to study the cognitive processes that underlie metaphor comprehension because they provide an on-line index of brain activity (Coulson, 2008). The ERP component most widely studied in metaphor processing research is the N400, which has been correlated with processing difficulty. The standard model would predict an initial N400, reflecting the literal incongruity, followed by a later ERP effect, reflecting the access of the metaphoric meaning. In contrast, the parallel hypothesis would expect N400 in literal and metaphoric sentences but with different amplitudes reflecting comprehension difficulty. The context-dependent hypothesis would assume that the context should modulate the N400 amplitude.

Coulson & van Petten (2002) compare literal sentences ("He knows that whiskey is a strong intoxicant"), literal mappings ("He has used cough syrup as an intoxicant") and metaphors ("He knows that power is a strong intoxicant"). Metaphors elicit larger N400s than literal sentences, with literal mapping falling between metaphors and literals. These authors interpret such findings as being indicative of a gradient of difficulty in sentence comprehension across the three conditions consistent with the parallel model and the claim that literal and metaphoric language share some processing mechanisms but that metaphoric language requires more processing effort than literal language.

Arzouan, Goldstein & Faust (2007a) investigate the processing differences between novel metaphors, conventional metaphors, literal sentences and meaningless expressions. Consistent with Coulson & van Petten's conclusions mentioned above, the results show a grading in N400 amplitudes, the lowest for literal sentences, increasing slightly in negativity for conventional metaphors, then for novel metaphors and the most negative for non-semantic relation. It seems, therefore, that literal expressions are the easiest to process, whereas unrelated pairs are the most difficult are require the most effort. Other experiments replicate these results (cf. (De Grauwe, Swain, Holcomb, Ditman, & Kuperberg, 2010; Lai, Curran, & Menn, 2009; Schneider et al., 2014; Tartter, Gomes, Dubrovsk, & Molholm, 2002) so this graded N400 metaphor effect seems to be further confirmed.

Although the metaphor is seen as an essential mechanism in all thought processes, most electrophysiological recording experiments have used only verbal stimuli and little is known about how visual metaphors are processed, in part because this field of study is more recent and complex than the study of verbal metaphor.

Researchers who have tried to enumerate the formal structures of visual metaphors in pictorial advertising distinguish three basic types. The first type involves the fusion of different objects in a hybrid image; in the second type only one object actually appears but the other is somehow suggested through the context; and in the third type at least two objects appear simultaneously. These three visual structure-types have received different names. For example, “hybrid metaphor”, “contextual metaphor” and “simile” (Forceville, 2007) or “fusion”, “replacement” and “juxtaposition” (Maes & Schilperoord, 2008). The three types of visual metaphor elicit different responses (van Mulken, le Pair, & Forceville, 2010) and can be differentiated with regard to their perceived complexity and deviation from expectation. Hybrids are considered more deviant than similes and contextual metaphors because participants might consider unlikely the fusion of two elements into a single ‘gestalt’.

In this study, we measured brain electrical activity when subjects are looking at literal images and hybrid metaphors in several advertisements. We consider literal images those that show the product directly. That is, just images of the advertised objects. They are, in other words, images of the object advertised in which there is no transference of qualities between objects, as happens with visual metaphors. On the other hand, we have chosen hybrid metaphors as our stimuli because they are the most deviant and could be regarded as most similar to novel verbal metaphors. Our main aims are: (a) to determine whether visual and verbal metaphors share processing patterns, and (b) to get insights into electrophysiological processing of visual metaphors. Following procedures carried out in the most recent verbal metaphor publications, we hypothesize the existence of greater negative amplitude at 400 ms time-windows for hybrid metaphors contrasted with literal images.

2 Material and methods

2.1 Participants

Twenty-two subjects participated in the study (eleven men, eleven women; average age: 24.7; range: 19.7–33). None of the participants had any personal history of neurological or psychiatric illness, drug or alcohol abuse, or current medication, and they had normal or corrected-to-normal vision. All of them were right-handed with a laterality quotient of at least + 0.4 (mean 0.8, SD: 0.2) on the Edinburgh Inventory (Oldfield, 1971). All subjects were informed about the aim and design of the study and gave their written consent for participation.

2.2 Materials, procedure and acquisition

Twelve pictorial advertisements collected from Internet databases were used as stimuli. Six were hybrid metaphors and six were literal images (Figure 1 and 2 show representative examples). The advertisements were chosen because they belonged to the class of monomodal metaphor, that is, the metaphor occurred in only one (visual) mode. Logos, slogans and brand names (if present) were removed from the original advertisements to avoid reading influence. In order to contextualize the image and ensure that it was understood, a text about the product advertised was included before each picture.

To ensure that there was no luminance difference across the images in the two categories, we measured the luminance of each image. An ANOVA showed no significant differences in luminance between literal and metaphoric images ($\alpha > 0.05$), consequently we rule out the possibility that differences in the brain processing could be due to luminance differences in the stimuli.

The subjects were comfortably seated at a distance of 0.9 m from the screen. Participants were informed that they were about to see a series of advertising images devoid of text, that some of the images were more complex than others, and that they had to think about what the advertiser was trying to suggest. Figure 3 summarizes the serial structure of the study. Each image was presented for 2 seconds, preceded by the contextualizing slide for 2 seconds, and followed by a black screen for 3 seconds. Then the participants were asked to indicate the answer they believed correct (1 or 2) for each picture. The images appeared randomly and only once.

2.3 Data acquisition

We instructed the subjects to remain as immobile as possible, to avoid blinking during image exposure and to try to concentrate their gaze towards the centre of the monitor screen. EEG data were continuously recorded at a sampling rate of 1000 Hz from 64 locations using the international 10/20 system (Klem, Lüders, Jasper, & Elger, 1999). The EEG data were recorded via cap-mounted Ag-AgCl electrodes. A 64-channel NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA) was used. The impedance of the recording electrodes was monitored for each subject prior to data collection and the thresholds were kept below 25 kΩ. The subjects were seated at a distance of 0.9 m from the screen. All the recordings were performed in a silent room with soft lighting.

Signal processing was performed with the help of Curry 7 (Compumedics, Charlotte, NC, USA). The data were re-referenced to a Common Average Reference (CAR) because this was required by the statistical and analysis methods later applied. The EEG signals were filtered using a 45 Hz low-pass and a 1 Hz high-pass filters. Eye blink effects were reduced using a regression analysis in combination with artifact averaging.

EEG data in the interval (-100, 2000) msec from stimulus onset were analyzed in this study. Epochs with signals exceeding ±75 µV were excluded, since a visual inspection of the common average referenced epochs showed that signals of this magnitude were probably due to artifact. Averages for both stimulus types (literal images, metaphoric images) were computed for each person.

2.4 Statistical analyses

Differences in topographic patterns of activity between literal and metaphoric images were assessed using Curry 7 software (Compumedics, Charlotte, NC USA). We focused our analysis on an approach that has been widely used in psychophysiology: the examination of topographic changes in EEG activity (cf. Brunet, Murray, & Michel, 2011; Laganaro, Valente, & Perret, 2012; Martinovic et al., 2014; Murray, Brunet, & Michel, 2008). This approach considers whole-scalp EEG activity elicited by a stimulus as a finite set of alternating spatially stable activation patterns, which reflect a succession of information processing stages. There are two main reasons why we used this type of analysis rather than the more traditional type based on the assessment of amplitudes and latencies of a set of predefined ERP components. First, it takes into consideration the entire time course of activity and the entire pattern of activation across the scalp by testing the global field power from all electrodes (Skrandies, 1990). Secondly, this approach is able to detect not only differences in amplitude, but also differences in underlying sources of activity. The latter is based on the fact that maps that are confirmed to be both spatially and temporally different must necessarily be the product of a different set of generators. However, we emphasize that the analysis of topography changes is compatible with the analysis of traditional ERP.

Topographical differences were tested through a non-parametric randomization test known as TANOVA (Topographic ANOVA), which allows investigating significant differences in global dissimilarity of EEG activity between two conditions by assessing whether the topographies are significantly different from each other on a temporal point-by-point basis. This approach was used to indicate the time windows of interest for further ERP analysis and analysis with sLORETA methodology. The significance level was $\alpha \leq 0.01$ an according with Rosenblad (2009) the required number of repetitions was chosen to be $p > 1000$. Map normalization was used for the difference tests, such that the MGFP per map was equal to 1.

ERP positivity and negativity were calculated from nine sets of electrode sites (see Figure 4): anterior, central and posterior; left, midline and right. Differences in peaks were contrasted during the time-period windows indicated by the TANOVA to be significantly different.

On significant time windows, we performed sLORETA calculations for the localization of the activity in the brain (Pascual-Marqui, 2002). The Boundary Element Method (BEM) was used in the head reconstruction since it permits the localization of the source dipoles. Furthermore, BEM models are superior in non-spherical parts of the head like the temporal and frontal lobes or basal parts of the head, where spherical models exhibit systematic localizations of up to 30 mm (Vatta, Meneghini, Esposito, Mininel, & Di Salle, 2010).

3 Results

3.1 Participant comprehension

On average, participants responded correctly to the questions, with a mean of 89.4% correct (SD 12.1%).

3.2 EEG

Significant differences in stimulus-elicited activity (literal versus metaphoric images) are showed in Figure 5 ($p<0.01$). These differences started approximately 157 ms after image onset an appeared in all samples. The test for differences between literal a metaphoric images yielded significant latencies in three time windows: 157-196 msec, 406-430 msec, and 580-587 msec.

3.3 Event-related potentials (ERPs)

ERPs were derived by averaging correctly classified trials on each condition for each participant. Figure 6 shows the ERPs generated by the two conditions (literal images and metaphoric hybrids in the frontal (Fz, F3, F4), central (Cz, C3, C4) and parietal (Pz, P3, P4) areas. Differences can be easily observed between the processing of hybrid metaphors and that of literal images, especially in the frontal and parietal areas. In particular, more negative waves can be seen for metaphors in earlier time windows (between 200 and 400 ms) in the frontal area, while literal images produce more positive waves. In the posterior region, however, there is a significant positive wave in the metaphoric condition, at around 300 ms.

ANOVA was performed in the time windows of significant differences indicated by the TANOVA. We compared peak maxima or minima in order to find the location of the highest positivity in 200, 400 and 600 ms time windows (see Table 1).

Our results showed that in the first time interval (157-196ms), metaphoric images generated more positivity (P200) in the posterior areas. In the 406-430 ms time interval, literal images generated more negativity (N400) in the anterior right area, while metaphoric images did so in the posterior area. In the least significant interval (580-587ms), literal images generated positivity (P600) in the left posterior area, whereas metaphorical images did so in the right central area. Topographic maps are showed in Figure 7.

3.4 Source analysis (sLORETA)

A standardized Low Resolution Electromagnetic Tomography (sLORETA) analysis showed different activation patterns for the three representative time windows (figure 8). Table 2 shows the maximum current density results with sLORETA for 9579 sources. Coordinates and brain areas (Talairach coordinates) are indicated.

4 Discussion

The results of this study reveal two fundamental findings. Firstly, there are processing differences between literal images and hybrid metaphors, as regards both the event-related potentials and the current density of the cerebral activity. And secondly, parallels can be observed between the processing of hybrid metaphors and that of novel verbal metaphors.

In the case of hybrid metaphors, there appears to be an N300-N400 pattern similar to that described by Barrett & Rugg (1990), who in their analysis of how incongruent images are processed observed a frontal-distribution, negative-polarity component at around 300ms, followed by a second negative spike in the 400-ms window. According to West & Holcomb (2002), this N300 might indicate a specific process for the representation of objects, since this component is not observed in studies of verbal-stimuli processing. These findings may mean that the semantic processing of pictorial stimuli takes place within a neuronal system separate from that involved in the processing of words and utterances. In our study, however, the N300 value only occurs with hybrid metaphors and is absent with literal images, therefore it cannot be considered to reflect specific pictorial-stimuli processing. In this framework, we believe it is much more likely to be the same pattern described by Barrett & Rugg (1990) in response to incongruent images. In other words: The N300-N400 pattern occurs with hybrid metaphors and not with literal images because the former are incongruent and the latter are not.

On the other hand, the results of the analysis of brain topographies and source distributions also show that there are specific differences in the processing of literal and metaphorical images, especially at early stages. Thus, greater frontal activity is observed with metaphors at a time window of 157-196 ms, while later, in the 406-430 ms time window, there is bilateral activity in the frontal lobes and the right temporal region. Furthermore, in the time window of 580-587 ms, metaphorical images elicit noticeable activity only in the right temporal area. By contrast, literal images induce, in general, less activity.

These results support the hypothesis that literal images and hybrid metaphors are processed differently. While literal images tend to stimulate general activity in both hemispheres leading to activity exclusively located in the left hemisphere in the final time-window, greater relative activity is observed in the right hemisphere in the case of hybrid metaphors. These finding coincide with those of Arzouan, Goldstein, & Faust (2007b), Pobric, Mashal, Faust, & Lavidor, (2008), Schimdt & Seger (2009) and Lai et al (2015). In the first of these, novel verbal metaphors produced asymmetric activity-volume and current-density between the hemispheres, with greater relative activity in the right hemisphere in comparison with effects produced by literal utterances. The study carried out by Pobric, Mashal, Faust, & Lavidor (2008) using transcranial magnetic simulation suggests that the right hemisphere might play a vital role in the comprehension of novel metaphors. Schimdt & Seger (2009) and Lai et al (2015) with fMRI conclude that the relative contribution of the right hemisphere was greater for metaphors.

The specific areas of maximum activity are, in the case of metaphors, the Medial Frontal Gyrus (at a time window of 200 ms), the Gyrus Rectus (at a time window of 400 ms) and the Right Superior Temporal Gyrus (at a time window of 600 ms). These results coincide with those of Arzouan, Goldstein & Faust (2007b) who found that novel metaphors produced greater activity in the Superior Frontal Gyri within the 350-450 ms time-window. Though their time-window was not exactly the same as ours (406-430 ms), the localization of this greater activity is very similar, since the Gyrus Rectus and the Superior Frontal Gyri are neighbouring areas.

5 Conclusions

The first conclusion to be drawn from this study is that there are striking differences in the way literal and metaphoric advertising images are processed. Metaphoric images induce more negative amplitudes than literal ones do in early time-windows, as well as greater frontal and bilateral activity. The data may be interpreted to suggest that hybrid metaphors, in contrast to literal images, initially appear to be incongruent, requiring more activation in order to process them.

One of the main aims of our study was to determine whether visual metaphors follow the same processing-pattern as that already described for verbal metaphors. Our data show coincidences between hybrid metaphors and novel verbal metaphors in the N400 effect, in which greater relative activity is detected in the right hemisphere than in the left, with maximum activity being localized in closely-linked areas (the gyrus rectus and the superior frontal gyri).

The results of our research open up possibilities for further studies, since they support the idea that metaphor, either verbal or visual, might be processed by activating a common neuronal substrate. More data are required to confirm this hypothesis; it will be necessary, for instance, to plan research using both visual and verbal metaphors based on a common metaphorical concept or presenting two types of fused objects, nonsensical and metaphorical. Furthermore, future studies should determine whether processing differences exist between the three types of visual metaphor described here (hybrid, contextual and simile), or whether such differences are only apparent. Deeper, more complete knowledge of the processing of visual metaphors is required, in order to understand more precisely the workings of the brain and also to determine to what extent metaphor is not simply a verbal device but also has a cognitive origin as Conceptual Metaphor Theory suggests.

Acknowledgements:

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Figure captions

Figure 1. Literal images.

Figure 2. Hybrid metaphors.

Figure 3. Experimental design. The sequence of stimuli was presented in continuous mode by using commercial stimulus presentation software (STIM2, Compumedics, Charlotte, NC, USA).

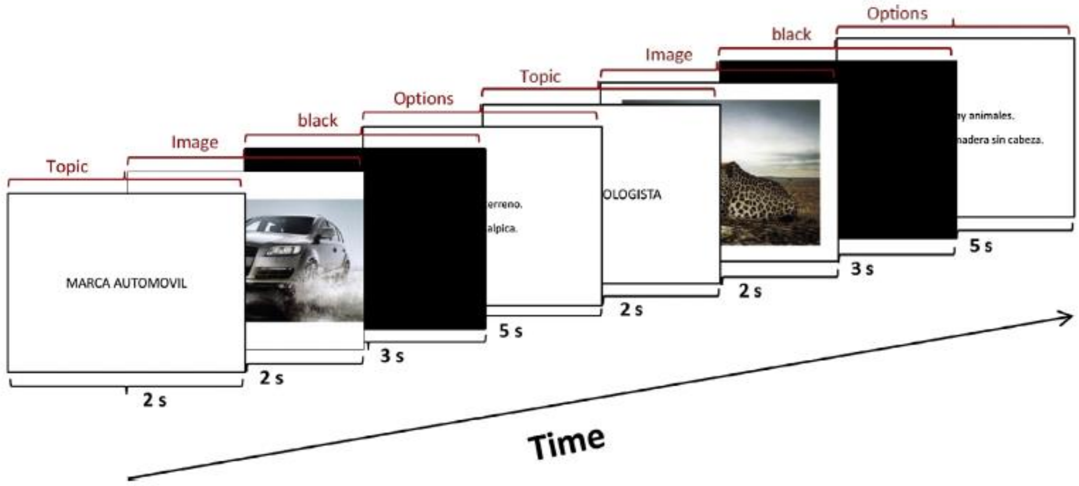

Figure 4. Electrode sites of interest: anterior, central and posterior on the left, midline and the right side of the head. The two active electrodes that are shown are REF (reference) which acts as a recording reference and GND which serves as a ground.

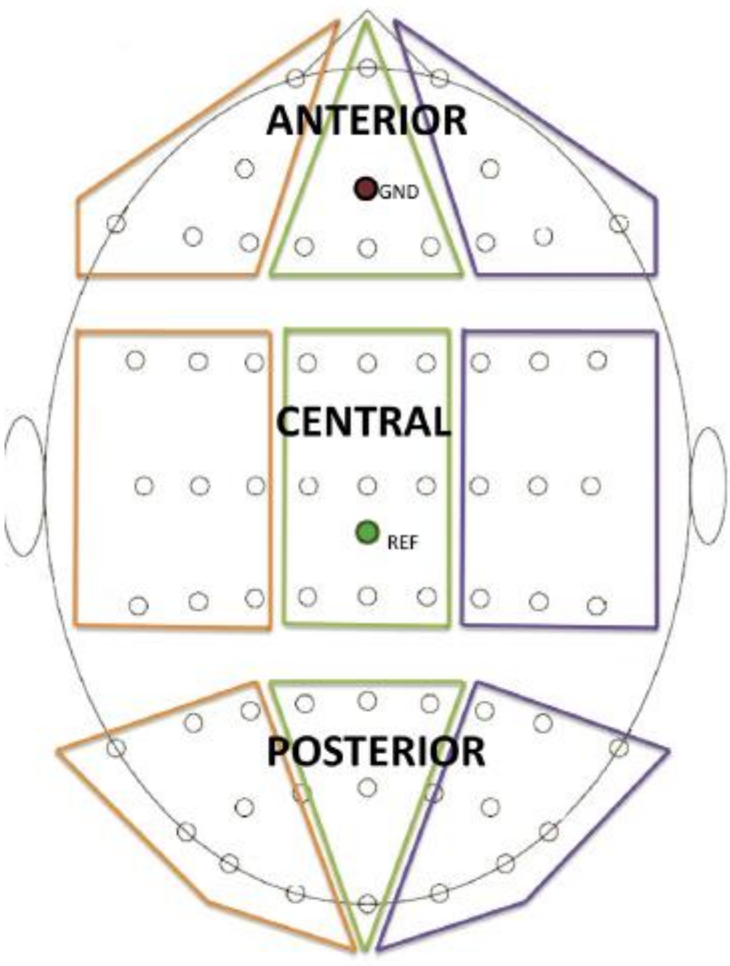

Figure 5. Time points of significant differences in EEG activity for the 2 contrasts (literal versus metaphor), as indicated by the TANOVA analysis, depicting 1 minus p-value across time. Significant p values are plotted (α≤0.01). The three vertical rectangles contain intervals with significant differences.

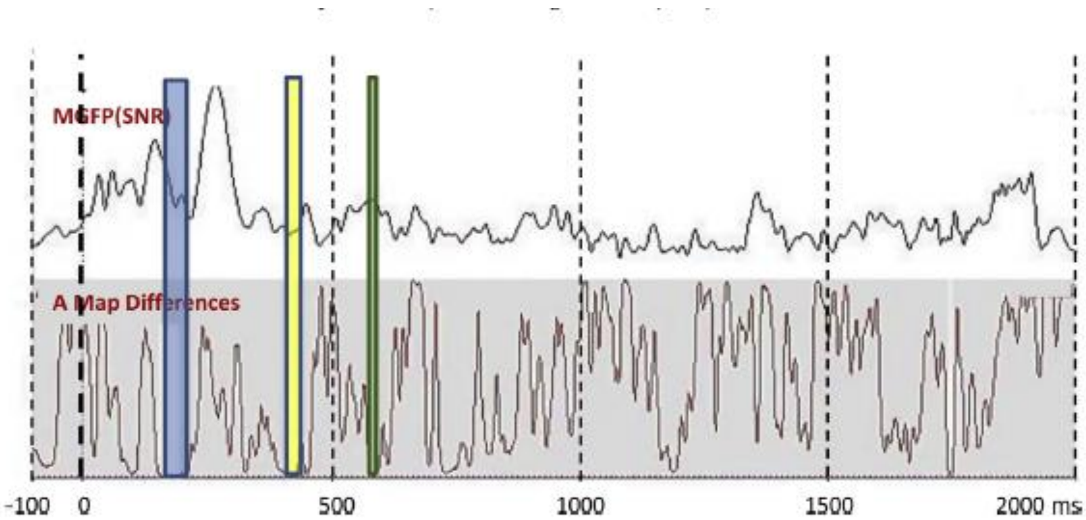

Figure 6. Grand average ERP waveforms elicited by literal images (blue) and hybrid metaphors (green) from frontal scalps (Fz, F3, F4), central scalps (Cz, C3, C4) and parietal scalps (Pz, P3, P4). Negative voltage is plotted downwards.

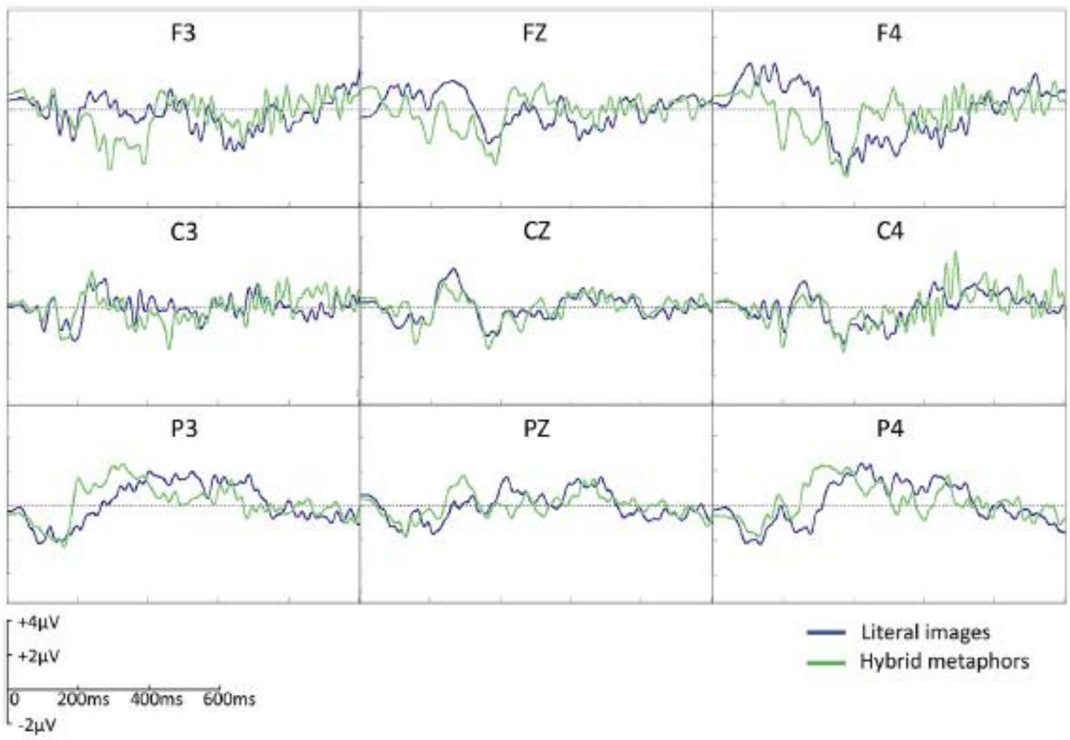

Figure 7. Topographic maps at significant intervals.

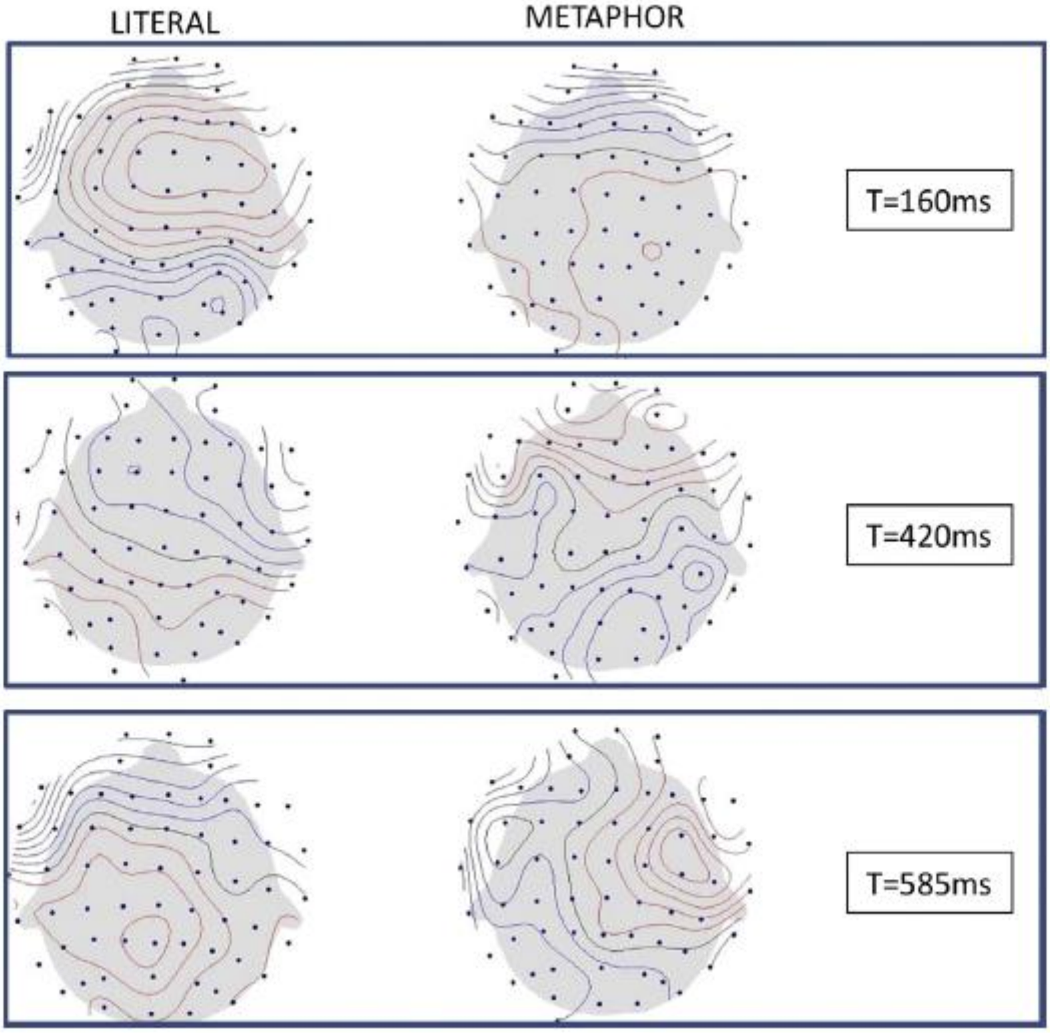

Figure 8. Activation maps for sLORETA.

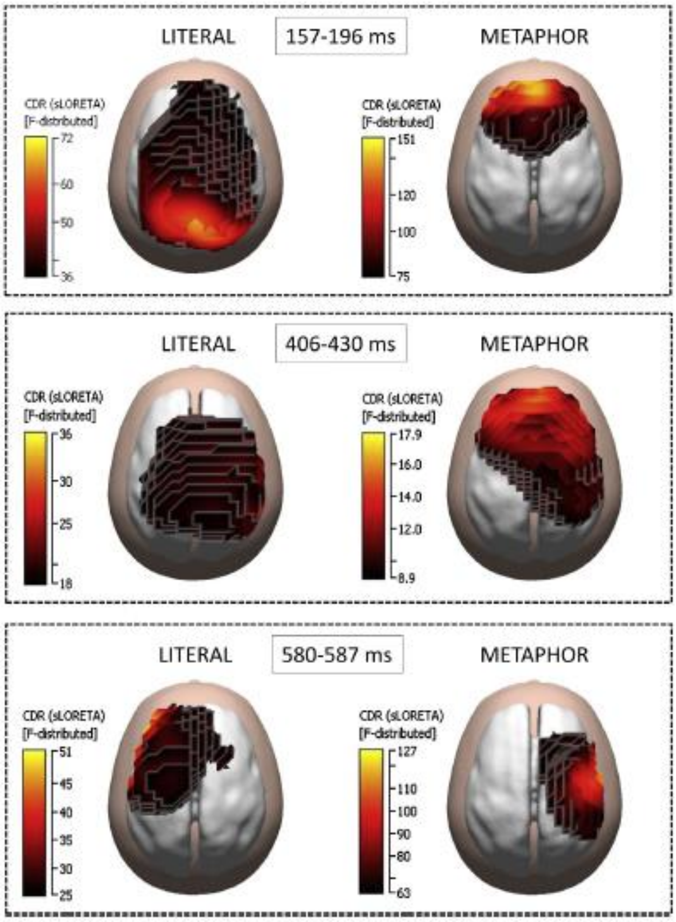

Table 1. Results of ANOVA averages (metaphoric versus literal comparison).

	Literal vs metaphor								
	Positivity (157–196 ms) P200			Negativity (406–430 ms) N400			Positivity (580–587 ms) P600		
	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right
Anterior	*Not significant*	*Not significant*	*Not significant*	*Not significant*	*Not significant*	F(1,8) > 50.7 p < 0.0001	*Not significant*	*Not significant*	*Not significant*
Central	*Not significant*	*Not significant*	*Not significant*	*Not significant*	*Not significant*	*Not significant*	*Not significant*	*Not significant*	F(1,16) > 26.4 p < 0.0001
Posterior	F(1,14) > 28.8 p < 0.0001	F(1,8) > 50.7 p < 0.0001	F(1,14) > 28.8 p < 0.0001	F(1,14) > 28.8 p < 0.0001	*Not significant*	F(1,14) > 28.8 p < 0.0001	F(1,14) > 28.8 p < 0.0001	*Not significant*	*Not significant*

Table 2. Compared Cartesian areas between literal images and metaphors.

	Literal	Metaphor
(157–196)	(4′5–19′4, 98,5)mm Cingulate Gyrus	(−9,6, 79′4, 26′6)mm Medial Frontal Gyrus
(406–430)	(47′1, 5′7, 22′1)mm Inferior Temporal Gyrus	(8′2, 55′3, 26)mm Rectal Gyrus
(580–587)	(−51′4, 32, 36′2)mm Superior Temporal Gyrus	(62′2, 14′1, 57′5)mm Superior Temporal Gyrus

Application of electroencephalographic techniques to the study of visual impact of renewable energies

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Abstract.

Much is currently being studied on the negative visual effects of the installation of large wind turbines or photovoltaic farms. However, methodologies for quantitatively assessing the landscape impact are scarce. In this work electroencephalographic (EEG) recordings are used to research for the neural activity involving 14 human volunteers when looking at the same landscapes with and without wind turbines, solar panels and nuclear power plants. According to our results no important differences can be observed for landscapes with or without solar power systems and wind turbines, what was in agreement with their subjective scores. However, there were clear and significant differences when looking at landscapes with and without nuclear power plants. These differences were more pronounced around a time window of 376-407 msec and showed a clear right lateralization for the pictures containing nuclear power plants. Although more studies are still needed, these results suggest that EEG recordings can be a useful procedure for measuring visual impact.

Keywords: visual impact, EEG, human emotions, environmental studies, renewable energies, landscape studies.

1 Introduction

Due to climate change, nuclear and renewable (wind, solar…) energy sources are increasingly being encouraged to be used in place of to fossil fuels (a policy framework for climate and energy in the period from 2020 to 2030, Brussels, COM, 2014). Consequently they can be considered as a solution to the problems of energy security and climate change (Mbarek et al., 2015). Thus, according to the US Department of Energy (DOE), renewable energy are clean, inexhaustible, and affordable (Yan et al., 2016). Furthermore, unlike most electric power plants, they do not require water. However the installation of these renewable energies on large farms inevitably involves a change in the landscape and many complain that renewable energy farms are unsightly (Klæboe and Sundfør, 2016; Larson and Krannich, 2016; Rogers et al., 2008).

Although there are numerous calculation and study techniques to minimize visual effects when building a new renewable energy station (Rodrigues et al., 2010; Wróżyński et al., 2016), it will always be visible in some areas since it is not possible to completely hide it. In addition, some renewable energies such us nuclear power plants have little social acceptance and their visual impact is generally more negative. We make these decisions in our subconscious. Furthermore. the first impression is crucial (Harris and Garris, 2008; Kim and Fesenmaier, 2008), what emphasizes the importance of unconscious processing in the perception of visual impact.

The human brain tries to classify all kind of events into categories or classes: positive or negative, friend or enemy, attractive or not attractive. That occurs, very fast, in a matter of milliseconds. Theoretically, rational thinking could be implemented. However all each stimuli are provided with an emotional ground which is tackled rationally at a later time (Damasio, 2010, 1994). Consequently, this process is caused by varying activation in centrally organized defensive and appetitive motivational structures, whose evolution has made it possible to cover the wide variety of adaptive behaviors necessary for an organism to subsist in the physical world (Cacioppo and Berntson, 1994; Davidson et al., 1990), (Fanselow, 1994).

In this context photographs can be considered valid substitutes for real landscapes (Coeterier, 1983) and neuroscientists have worked on finding out how some specific neural circuits play an important role on mediating the relationship between stimulus input and behavioral output (Fanselow, 1994). However, we know relatively little about the neural temporal dynamics of emotion processing (Linden et al., 2012; Waugh and Schirillo, 2012).

Most of research in this area are based on techniques like Positron Emission Tomography (PET) (Royet et al., n.d.) or functional Magnetic Resonance Imaging (fMRI) (Vink et al., 2014) which have an exceptional spatial resolution. However, the temporal resolution is very poor (seconds). An alternative, which provides an excellent temporal resolution (in the range of milliseconds), is Electroencephalography (EEG). This technology can be easily applied to the analysis of perception responses to different emotional states (Petrantonakis and Hadjileontiadis, 2011), (Davidson and Fox, 1982), (Harmon-Jones and Allen, 1998),(Schupp et al., 2000), but to the best of our knowledge it has not been yet applied to the study of visual impact of renewable energies although interest about the environmental and landscape impact by local communities and governments is increasing rapidly.

In this research we studied differences in temporal dynamics of neural activity associated with biphasic emotions (like/dislike) produced by the view of complex pictures of landscapes with and without renewable energies (solar, wind and nuclear). We used EEG to capture the unconscious brain activity and then analyzed the correspondences between different groups of images and the neural signatures coming from the temporal profiles related to each perception. Furthermore, we correlated the subjective scores and the test results with the generic knowledge of solar, wind and nuclear energy. Our results, which give us valuable data to better understand the temporal dynamics involved in emotions, are consistent with other research about hemispheric lateralization (Davidson, 1998), and allowing us to quantify objectively the visual impact, what could contribute to the improvement of the information that is required to prepare the documentation related with the landscape integration reports. Although more studies are still needed, our results suggest that EEG studies can be a useful technique, in addition to standard procedures, to analyze emotional processing related to visual impact of different types of power generation.

2 Method

2.1 Participants

Fourteen volunteered peoples took part in the research (mean age: 24; range: 18.9–34.2; six men, eight women). None of participants had personal history of psychiatric or neurological disorder, alcohol or drug or abuse, or current medication, and their vision were normal or corrected to normal. They were all right handed and their laterality quotient was at least + 0.4 (mean 0.7, SD: 0.2) on the Edinburgh Inventory (Oldfield, 1971). All of them were comprehensively provided with information about the details and the aim of the research and gave their written agreement for participation.

2.2 Visual stimuli and questionnaire

60 images were used as stimuli. These images were divided into three groups: images with wind turbines and the same pictures without wind turbines, images with and without photovoltaic plates and images with and without nuclear power plants (Fig 1 shows a representative sample of the same picture with and without wind turbines). We presented stimuli in color, with the same contrast and luminance.

Images with aerogenerators, photovoltaic plates or nuclear plants had more qualitative complexity (Papadimitriou, 2012, 2010) than those images with nothing.

Figure 1: Example of a representative landscape with and without wind turbines.

When the experiment was over, a similar survey to the study by Kaldellis et al (Kaldellis et al., 2012) was filled by all the participants. The questionnaire employed is given in complementary material. The first three questions dealt with how aware people are on the researched renewable energies, and the others were related with the feeling and potential involvement of the participants regarding wind turbines and photovoltaic systems. Specifically, question 4 dealt with the opinion related to renewable energy projects (photovoltaic and wind), and the questions 5 and 6 tried to identify how people react and how willing they are to take part in these kind of projects.

2.3 Procedure

In figure 2 we can see the summarized sequence of images related to the research. Each picture was displayed for 500 msec and next a black screen lasting 3500 msec. The pictures were presented only once and in a random way. The participants had to look the pictures and rate the arousal and valence of its emotional experience. The range of pictures score was from 9 (very pleasant) to 1 (very unpleasant).

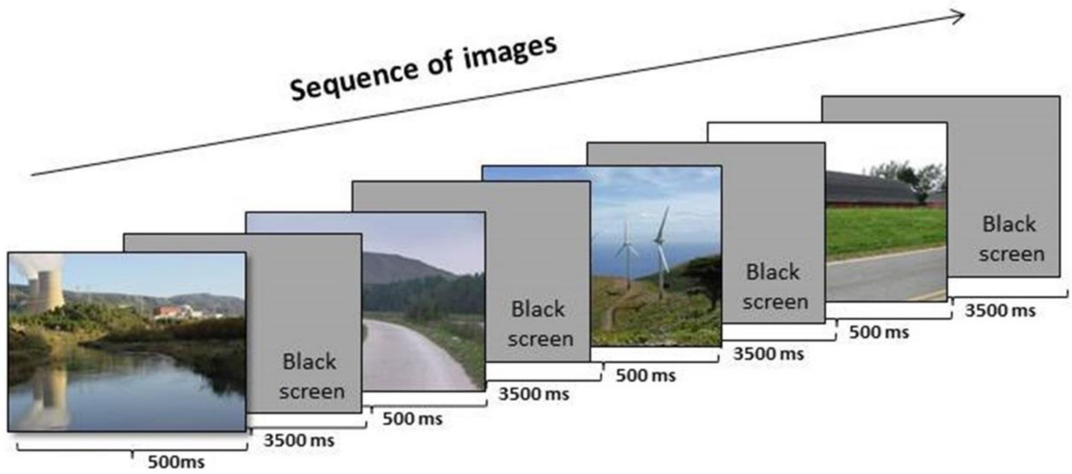

Fig. 2. Design of experiment. The stimuli were displayed randomly and continuously by means of using a commercial stimulus presentation software (STIM2, Compumedics, Charlotter, NC, USA).

2.4 Data acquisition

What we did first was to ask the volunteers to remain as immobile as they could. They were also told to avoid blinking while the images were displayed and attempt to look at the center of the screen. We used cap-mounted Ag-AgCl electrodes and a NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA) to record EEG data continuously from 64 locations according to the international 10/20 system (Klem et al., 1999). We displayed the impedance of recording electrodes for each subject and before collecting data. We kept the thresholds below 25 kΩ. All the recordings were carried out at a sampling rate of 1000 Hz in a quiet room with dim lighting.

A Common Average Reference (CAR) were used to re-reference data. We filtered EEG signals by means of a 0.5 Hz high-pass and low-pass 45 Hz filters. We corrected electrical devices because of motion and eye blinking by means of Principal Component Analysis (PCA). This is a very known method for feature extraction and data reduction (Meghdadi et al., 2006). These data appear as signals with values above 75μV in the 5 frontal electrodes (FP1, FPZ, FP2, AF3 and AF4). We chose these kind of electrodes because of their large sensitivity to potential involuntary movements. The detection was within the time interval (-200msec, +500msec) from stimulus onset.

The landscapes were separated into 3 groups according to the type of energy (wind, solar, nuclear) and in 2 subgroups according to whether they had a real image of the energy generator or not (with and without).

2.5 Statistical analyses

We studied topographic changes in EEG activity (Brunet et al., 2011; Murray et al., 2008), (Laganaro et al., 2012; Martinovic et al., 2014) by means of Curry 7 (Compumedics, Charlotte, NC, USA). The total time course and the whole pattern of activation across the scalp were considerated. To do so, we checked the total field power from all electrodes (see for additional description (Skrandies, 1990)) as with this approach, it is possible to find differences in the underlying sources of activity as well as in amplitude. When checked the topographical differences in terms of EEG activity between different images using a non-parametric randomization test (Topographic ANOVA or TANOVA) and a significance level of 0.01 as described elsewhere (Murcia et al., 2015), (Rosenblad, 2009). In addition, TANOVA was also used to show the best windows representing time for further analysis of dipoles.

The dipole source localization (DSL) is a technique that uses a nonlinear multidimensional minimization method to estimate the dipole parameters that best modelize the scalp potentials, previously detected, in a least-square sense. We assumed that EEG was produced by only one or a few focal sources using a rotating dipole, which can be considered to be composed by two dipoles working independently whose orientation may be modified with time (Fuchs et al., 1998). We made use of Boundary Element Method (BEM) for the head reconstruction as it allows us to locate the source dipoles. Furthermore, BEM models are better in non-spherical parts of the head such as temporal and frontal lobe or in the basal parts of the head, where spherical models show only systematic localizations of up to 30 mm (Vatta et al., 2010). On significant windows we performed standardized low resolution brain electromagnetic tomography (sLORETA) calculations (Pascual-Marqui, n.d.). This method is an advanced low resolution distributed imaging technique for brain source localization that makes us locate deep sources in a better and smooth mode. In addition, it has less errors in terms of localization although the spatial resolution is low.

3 Results

3.1 Subjective score

In general, the participants identified correctly the renewable energies showed in each of the images (99.76%). Figure 3 represents the mean of the total scores. We only found significant differences for the case of nuclear energy ($p<0.05$). Thus lower scores were always present when nuclear power plants were present in the images.

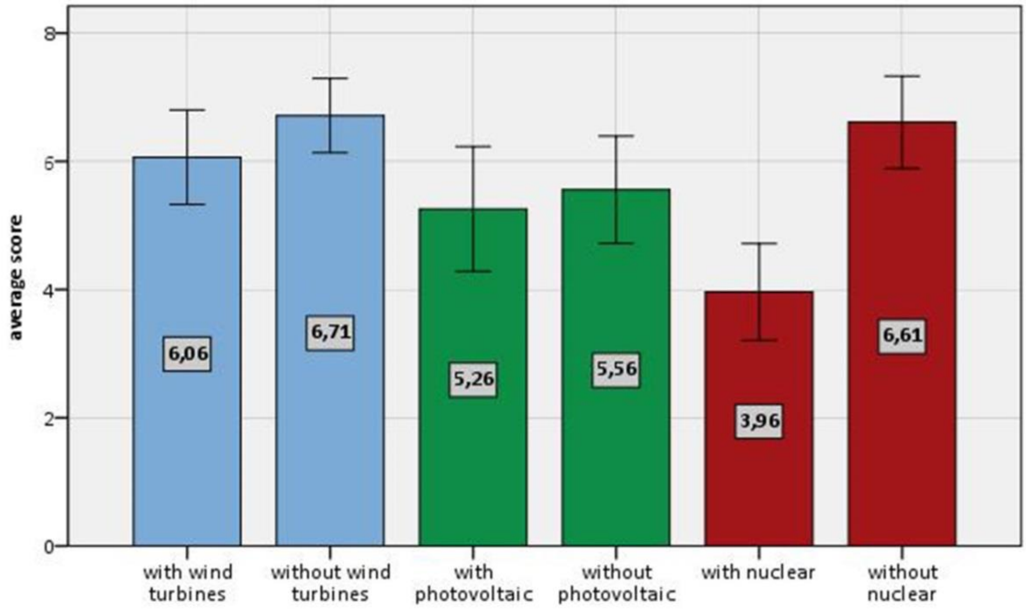

Fig. 3. Average score for all volunteers. Interval CI: 95%

3.2 Questionnaire results

Questions 1 and 2 reflected the basic knowledge of the technologies studied, whereas question 3 was more related with the role for the environment of wind turbines and photovoltaic systems. Interestingly 21.42% answered that wind and solar energy were harmful to the environment, but this was not reflected in the mean total scores.

The answers of questions 5 and 6, showed that most participants were in favour of renewable energies. Furthermore, they were willing to become involved if a new wind farm/photovoltaic system was set up in their territory, and only 14.29% were not interested (see figure 4).

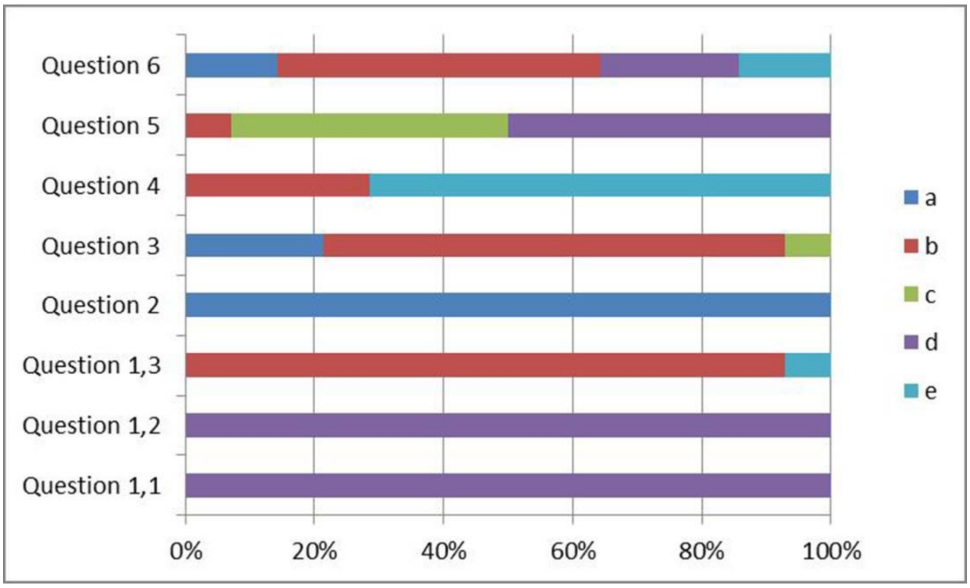

Fig. 4. Results as a percentage of questionnaire responses.

3.3 EEG

The main results of EEG recordings agreed with subjective scores. Thereby, when we compared the EEG recordings of the different groups of images, we only found significant differences for images with and without nuclear power plants (ρ≤0.01). These differences began about 376 msec after stimulus onset and the time window with bigger significant differences was between 376-407 msec (Figure 5).

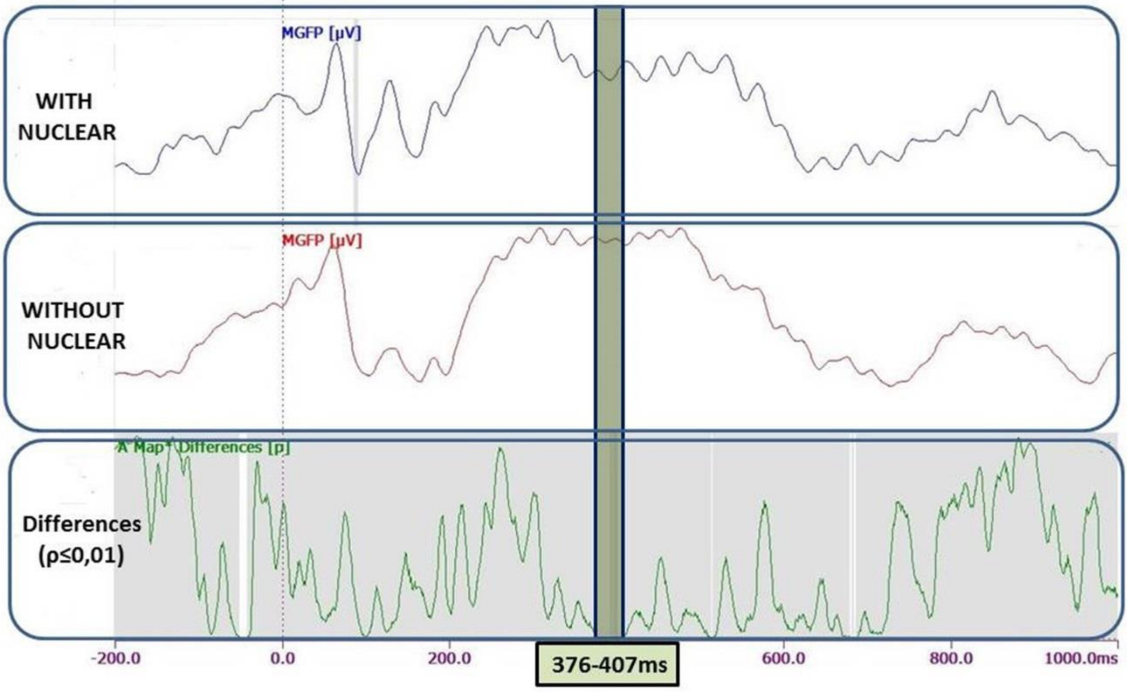

Fig. 5. Significant differences in EEG activity for images with and without nuclear energy. The vertical rectangle contains the interval with significant differences (p<0.01).

3.4 Dipoles

A common approach in the analysis of EEG recordings is to assume a priori that evoked potentials are generated by one or more intracranial dipole sources. We did not found significant differences in the distribution of dipoles when looking images with and without wind turbines and photovoltaic systems. However, the distribution of dipole sources was clearly different when looking at images with and without nuclear power plants, especially when we focused our analysis in the time window where TANOVA indicated significant differences (376-407msec, duration 31 msec). A representative example is showed in Figure 6.

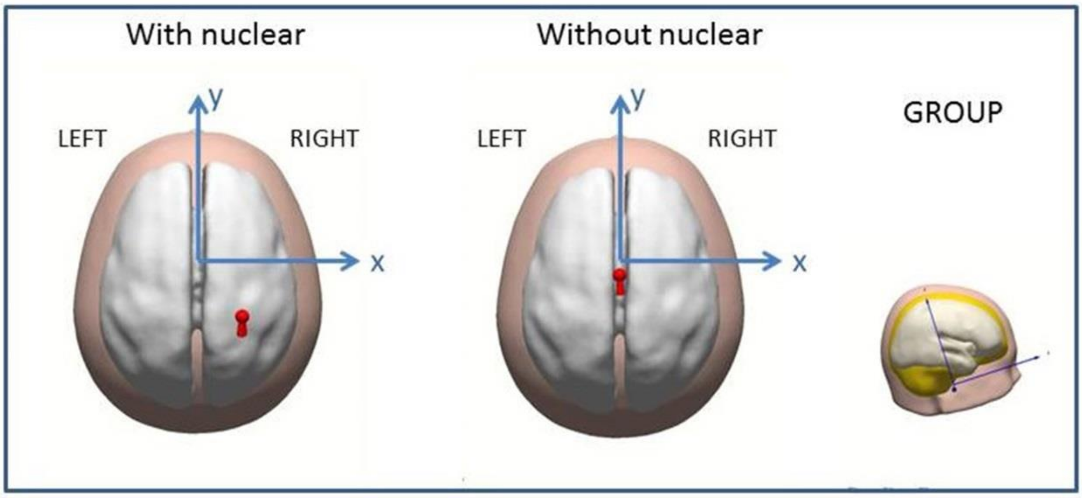

Fig. 6. Representative distribution of dipole sources (rotating red dipole) over the head reconstruction of a particular participant when looking at images with and without nuclear power plants. Corresponding time window= 376-407 msec.

3.5 solera

When we considered all possible source locations simultaneously applying the standardized LORETA, the results were very similar. We found out no significant differences when looking at images with and without wind turbines and photovoltaic systems, but the location maps were clearly different when looking at images with and without nuclear power plants. Thus, there was a significant right lateralization when looking at landscapes with nuclear power plants (Figure 7).

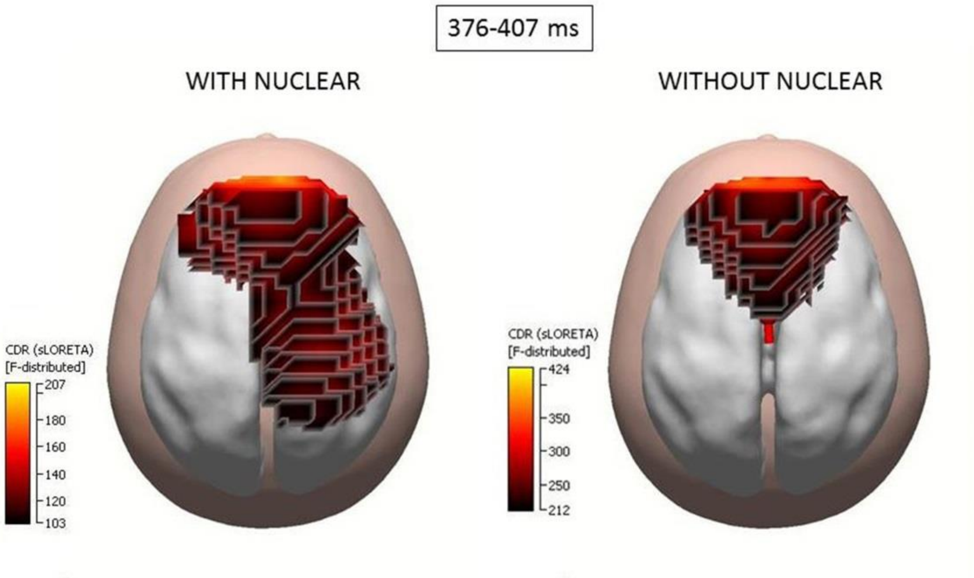

Figure 7: Activation maps for solera corresponding to a time window of 376-407 msec, when looking at images with and without nuclear power plants (significant right lateralization when looking at landscapes with nuclear power plants).

4 Discussion and conclusion

The installation of renewable power plants is being promoted by many countries, which is leading to a relevant transformation of the territories (visual impact on the landscape, etc.). Therefore, the investigations performed to assess the territorial landscape impact of this type of systems are remarkably being developed. However, although EEG is a powerful technique to analyze the brain processing of complex images it is not being applied to the study of visual impact of renewable energies.

Our results provide valuable information regarding the brain processing of landscapes with and without different renewable energies. Besides emotional expressions in humans are highly varied, show that at least in our sample, there are no significant differences regarding early brain processing when looking at landscapes with and without solar power systems or wind turbines, what was in agreement with subjective scores. These findings support the point of view that there is no innate predisposition for rejecting, a priori, the installation of solar or photovoltaic farms, not being significantly affected by the qualitative complexity of the presented landscape. On the other hand, the analysis of EEG recordings showed clear and significant differences when looking at landscapes with and without nuclear power plants. These differences were more pronounced around 400 msec and showed a clear right lateralization for the pictures containing nuclear power plants. These results are coherent with the valence hypothesis in the hemispheric lateralization of emotion processing, which suggests a preferential engagement of the right hemisphere for negative emotions (Costa et al., 2014; Fusar-Poli et al., 2009).

These results globally suggest the EEG studies can be a useful technique, in addition to standard procedures, to quantitatively assess the visual impact of different types of power generators. However, more studies are still needed in this field. In further works, we are to perform a similar investigation with volunteers of different nationalities, and involve people with professional interest in renewable energies.

Acknowledgement

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Neural representation of different architectural images: An EEG study

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Abstract: Neuro-architecture seeks to define and better understand the relationships between our psychological state and the artificial structures in which we spend most of our time, and incorporate that insight into the design. However, little is known about the subjective judgment of real architectural models and the cognitive processes involved in aesthetic appreciation of architecture. In the present study, we used both, real and computer-designed architectural images to address the underlying neural representations of each image type. Participants were asked to judge the arousal and valence of their own emotional experience after viewing each image. Furthermore, we used EEG recordings to gain a better understanding of the regions of the brain involved in the processing of both types of images. Our results show that there are significant differences in the brain processing of both types of images, especially at early stages. These results emphasize the importance of generating familiar, realistic and recognizable images for a better people's acceptance.

Keywords: Neuro-architecture, EEG, aesthetic appreciation, 3D modeling.

1. Introduction

Three-dimensional computer graphics (3D computer graphics, in contrast to 2D computer graphics) are illustrations that use a three-dimensional representation of geometric data (often Cartesian) that are stored in the computer for rendering and presentation purposes [1].In the last decades, 3D models are used in a wide variety of fields. For example, the movie industry uses them as characters and objects for animated and real-life motion pictures [2], and the video game industry uses this 3D images as assets for computer and video games [3]. They can be also useful in science and engineering and have been used for highly detailed models of chemical compounds [4] and for the design of new devices, vehicles and structures [5]. Furthermore they can be used for the construction of 3D models of internal organs, that can be built from clinical devices such as Magnetic Resonance imaging (MRI) or Computed Tomography (CT) scans and in recent years the earth science community has started to construct 3D geological models as a standard practice [6]. In addition, all these 3D models can be transformed into physical objects that are built from different materials with the help of 3D printers.

In this framework, architects have been using 3D modeling instead of hand crafted designs and drawings since 1962 [7][8]. This procedure is normally employed to create 3D interior and 3D exterior models [9][10]. Furthermore, different business firms are taking interest in the creation of 3D product models, which demonstrate the significance of 3D architectural modeling.

By applying architectural 3D models, it is possible to envision the final results on a computer screen, which, in general, generates positive effects on potential customers [11][12]. Thus, we can visualize the entire building, or a given room, using 3D rendering before the building is complete. This saves time and helps us to modify details that require being changed before the actual construction is made, which is extremely cost-effective and saves a long time. However, little is known about the relation between subjective judgment of real photographs and 3D architectural models and the cognitive processes involved in aesthetic appreciation of architecture [13].

In the present study, we used real and computed-designated architectural images of bedrooms ,to address aesthetic judgments and the underlying neural representations of each image type [14][15][16]. Our main goal was to investigate the processing characteristics and temporal time courses associated with each type of images [17]. Our results show that there are significant differences in the early stages of processing of both types of images and provide some insights regarding the emotional response to a given image and how aesthetic judgments are made [18].

2. Methods

2.1 Participants

Thirteen participants (mean age: 24.2; range: 18.9–34.2; five men, eight women) participated in the study. All participants had no personal history of psychiatric illness or neurological, drug or alcohol abuse, or current medication, and they had normal or “corrected to normal” vision and good visual acuity. All were right-handed with a laterality quotient of at least + 0.4 (mean 0.7, SD: 0.2) on the Edinburgh Inventory [19]. All subjects were informed about the aim and design of the study and gave their written consent for participation.

2.2 Stimuli

We used fifty different images that were divided into five different sets of images with ten images in each group. Groups were composed by real images (photographs), 3D computer generated images with details (pictures, curtains, carpets, common objects, etc.), 3D computer-generated images with no details, 3D computer generated images in gray (black and white image) and images sketches (only lines). Figure 1 shows a representative sample. The computer designed images were performed with the help of 3D modeling software (Sweet Home 3D, freely available at http://www.sweethome3d.com). The photographs represented real rooms, with different decoration and arrangements of furniture, windows etc. The computer designed rooms were similar and involved several room types with different arrangements of the door, windows and bed. All images were presented randomly, equated for luminance and contrast using a commercial stimulus presentation and experimental design system (STIM2, Compumedics, Charlotte, NC, USA)

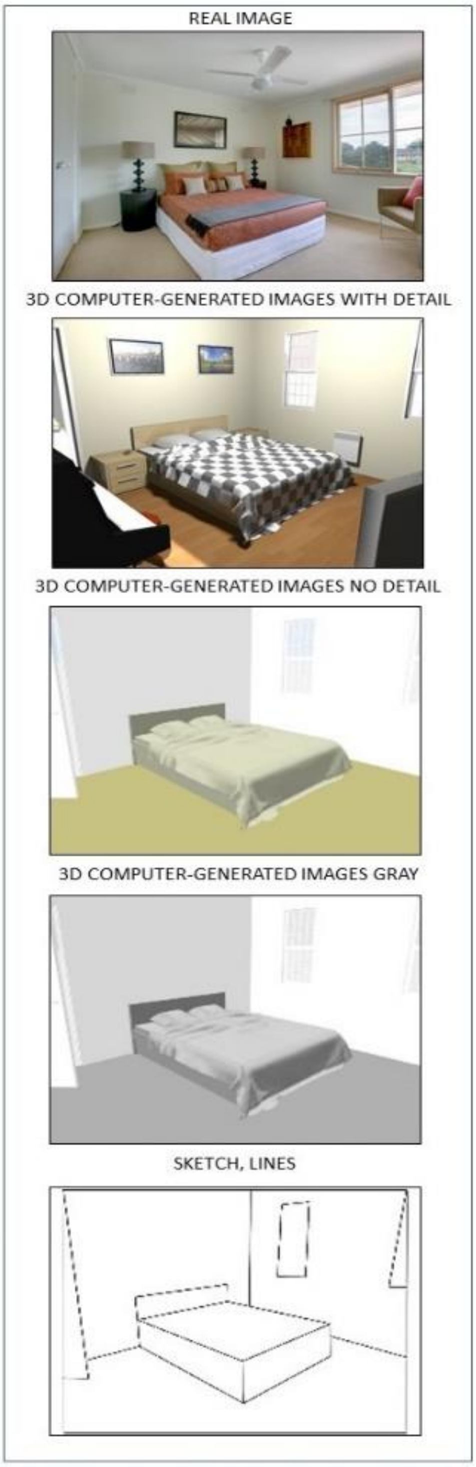

Fig 1: Representative stimulus examples.

2.3 Main experiment

Figure 2 summarizes the experimental design. Each image was presented for 500 ms and followed by a black screen for 3500 ms. The rooms images appeared in randomized order and only once. The participants were told that they would be asked to judge the arousal and valence of their own emotional experience after viewing each image (during the black period). Scales ranged from 1 (very unpleasant) to 9 (very pleasant).

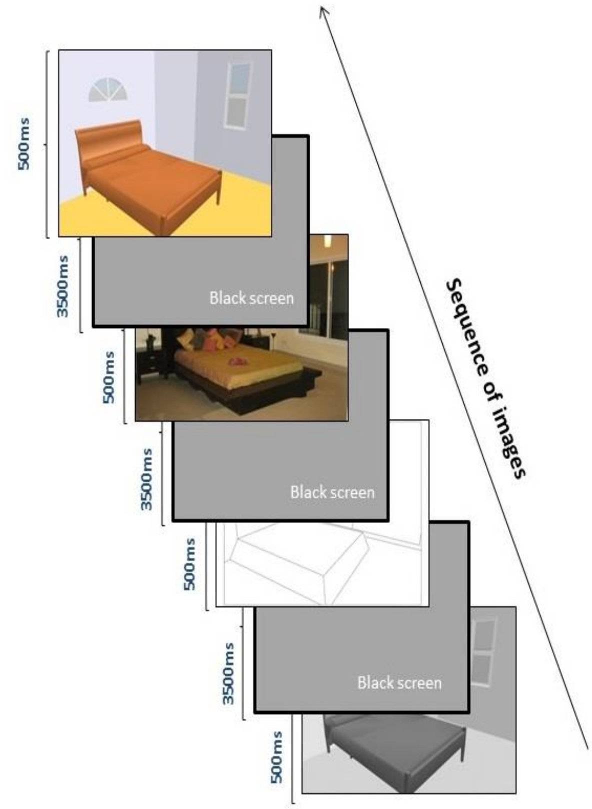

Fig 2: Experimental scheme. The sequence of stimuli was presentation software (STIM2, Compumedics, Charlotte, NC, USA)

2.4 EEG Recordings

We inculcated subjects to remain as immobile as possible, avoiding blinking during image exposure and trying to keep the gaze toward the monitor center. EEG data was continuously recorded at a sampling rate of 1000 Hz from 64 locations (FP1, FPZ, FP2, AF3, GND, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, REF, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, CB2) using the international 10/20 system [20]. EEG was recorded via cap-mounted Ag-AgCl electrodes. A 64-channel NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA) was used for EEG signal amplification and digitizing. The electrodes were filtered using a 45 Hz low-pass filter and a 0.5 Hz high-pass filter. All recordings were performed in a dimly lit and silent room.

2.5 Data analysis

To study the event-related EEG dynamics, we extracted data in a time interval lasting 1200 ms (200 ms before stimulus onset to 1000 ms after stimulus). Signal processing was performed using the Curry 7 software (Compumedics, Charlotte, NC, USA). The data were re-referenced to a Common Average Reference (CAR)[21]. Additionally, we used the frontal electrodes (FP1, FPZ, FP2, AF3 and AF4) to eliminate flicker effects. We chose these electrodes because they were located in regions that can be easily affected by possible involuntary movements. The detected artifacts were corrected following standard procedures using Principal Component Analysis (PCA)[22]. Furthermore, to constrain our analysis, we used the examination of topographic changes in EEG activity (see [23][24][25][26] for an overview).

This method studies whole-scalp EEG activity provoked by a stimulus as a finite set of alternating spatially stable activation patterns, which reflect a succession of information processing stages. The progression of whole-scalp activity can be calculated over time in order to see how it differs between experimental conditions that impose different information processing demands.

The dipole source localization (DSL) resolves the EEG inverse problem by means of a nonlinear multidimensional minimization procedure that estimates the dipole parameters that best explain the observed scalp potentials in a least-square sense. In this process, we assume that EEG is generated by one or no more than few focal sources. The dipole source model can be further categorized as moving, fixing or rotating dipoles depending on the degree of freedom of parameters. In our study, we used a rotating dipole, that may be viewed as two independent dipoles whose orientation is allowed to vary with time [27].

Boundary Element Method (BEM) was used in the head reconstruction [28]. Topographical differences were tested through a non-parametric randomization test known as TANOVA (Topographic ANOVA), which allowed quantifying differences in global dissimilarity of EEG activity between two conditions. In turn, this allowed us to assess if the topographies were significantly different from each other on a time point by time point basis. Significance level was

α=0. 05. As suggested by [29], the corresponding required number of repetitions was chosen to be p=1000.

On significant windows, we were decided to make sLORETA calculation. The sLORETA method is a standardized discrete, 3D distributed, linear, minimum norm inverse solution [30].

This method provides an exact localization of point sources since the principles of linearity and superposition would guarantee its trustworthiness as a functional imaging method, given that brain activity occurs in the form of a finite number of distributed "hot spots".

3. Results

3.1 Subjective scores

Images were scored by the participants during the experiment. The average scores for each group of pictures are shown in Table 1.

Table 1: Subjective scores of different groups (mean and standard deviation).

	Mean
Real images	7,02±1,18
3D computer-generated images with details	6,33±1,20
3D computer-generated images with no details	3,82±1,36
3D computer-generated images in gray	3,66±1,65
Sketches	2,53±1,69

3.2 EEG

Table 2: Comparison between different groups of pictures

	Real images	*Computer-generated images 3D with details*	*Computer-generated images 3D no details*	*Computer-generated images 3D gray*	*Sketches*
Real images	-	No difference	Window (94-138)	Window (124-134)	Window (102-140) and (302-394)
Computer-generated images 3D with details	No difference	-	No difference	No difference	Window (310-390)
Computer-generated images 3D no details	Window (94-138)	No difference	-	No difference	No difference
Computer-generated images 3D gray	Window (124-134)	No difference	No difference	-	No difference
Sketches	Window (102-140) and (302-394)	Window (310-390)	No difference	No difference	-

Table 2 shows the main significant time windows for the comparison of different groups of pictures (sig=0.05).

We found clear and significant differences in stimulus-elicited activity between both types of images, photographs and computer designed images 3D no details. These differences started approximately at 94 ms after the picture onset and have a duration of 45 ms (Figure 3).

We also found significant differences in stimulus-elicited activity between both real photographs and 3D computer designed images 3D in gray ($\alpha<0.05$). However, the differences were a little bit delayed regarding previous comparison and started approximately at 124 ms after picture onset (Figure 3).

When we compared real images (photographs) with very simple drawings of bedrooms (sketches) we got two windows with significant differences (Figure 3).

There images with all sorts of details were significant differences when comparing computer generated with simple sketches. These differences started approximately at 310 ms after each picture onset (Figure 3).

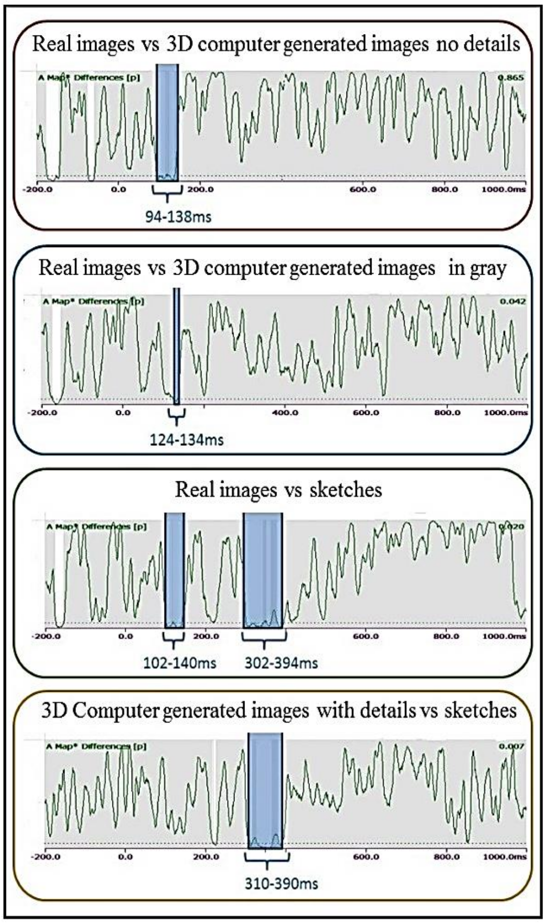

Fig 3: Time points of significant differences in EEG activity for the different contrasts of images). T ANOVA analysis, depicting 1 minus p-value across time. Significant p values are plotted ($\alpha<0.05$). The vertical rectangle contains significant differences.

3.3 Dipoles

One rotating dipole source model was used in the time windows with significant differences indicated by the TANOVA.

Comparing different groups with significant differences we obtained.

When we focused on the time window 94-138 ms (real images versus 3D computer generated images with no details) we found significant differences in the dipoles for these two different types of images. Figure 4 shows the location and coordinates of each dipole.

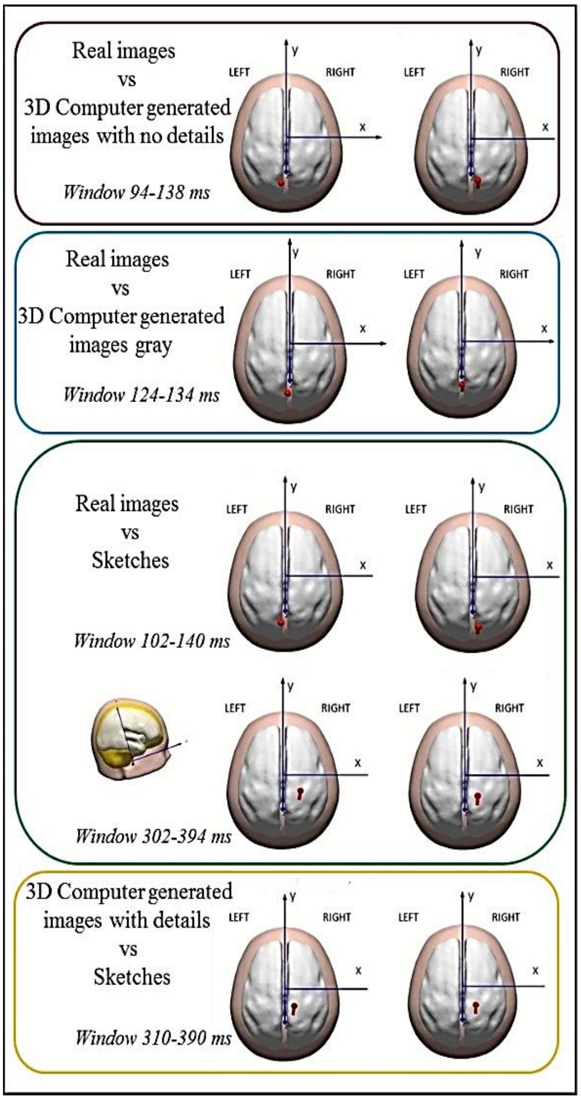

Fig 4. Head reconstruction and rotating dipoles in representative time windows

When we focused on the time window (124-134 ms) we found significant differences in the dipoles for the different types of images real versus 3D computer generated images in gray. See Figure 4.

In this case to real images versus sketches, we found two time windows with significant differences. The first window, which appears in approximately 102 ms after the stimulus comes out, lasts 39 ms. The second window appears on the 310 ms and has a duration of 81 ms (see Figure 4).

When we focused on the time window (310-390 ms, duration 81 ms) (3D computer generated images with details versus sketches) we found significant differences in the dipoles for the different types of images. Figure 4.

In the table 3 we can see the coordinates of the different dipoles represented in figure 3.

Table 3: Coordinates PAN (R,A,S). The x axis goes through PAL (left preauricular point) and PAR (right preauricular point) and points right, the y axis goes through the nasion, and the z axis points up. Coordinates en mm.

window	*x*	*y*	*z*	*x*	*y*	*z*

	Real images			*3D Computer-generated images with no details*		
94-138ms	*-7,6*	*-38,7*	*97.8*	*10,7*	*-44*	*68*
	Real images			*3D Computer-generated images gray*		
124-134ms	*-3,4*	*-45,6*	*84.4*	*0.3*	*-42.7*	*74.7*
	Real images			*sketches*		
102-140ms	*-6,4*	*-41,9*	*92,8*	*8,6*	*-52,6*	*78,8*
302-394ms	*28,8*	*-18,3*	*26*	*20,6*	*-22,2*	*43*
	3D Computer-generated images with details			*sketches*		
310-390ms	*15,2*	*-13,5*	*46,9*	*22,1*	*-19,6*	*37,7*

3.4 sLORETA.
According to results, activation was observed for different brain regions for the three representative time windows (figure 5).

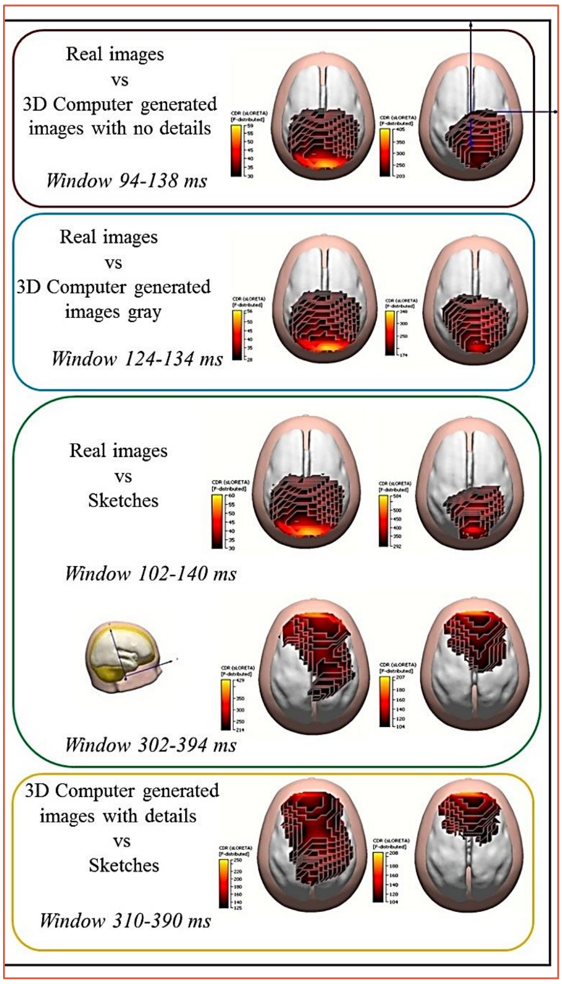

Fig 5. Head reconstruction and sLoreta reconstruction in representative time windows.

In Table 4 we can see maximum current density results with sLORETA. Coordinates and areas are indicated.

Also indicates the cerebral zone where the maximum activation occurs according to the reconstruction sLORETA.

Table 4: Coordinates in maximum current density obtaining by sLORETA. Coordinates in mm.

window	*x*	*y*	*z*	*x*	*y*	*z*
	Real images			*3D Computer-generated images with no details*		
94-138ms	*-4.1*	*-40.3*	*86.8*	*18.4*	*-37.2*	*53*
	Preconeus and Brodman 31			*Lingual Gyrus*		
	Real images			*3D Computer-generated images gray*		
124-134ms	*3.1*	*-42,8*	*88.4*	*8.7*	*-36.5*	*64.4*
	Preconeus and Brodman 31			*Lingual Gyrus and Brodman 18*		
	Real images			*sketches*		
102-140ms	*3.1*	*-45.4*	*82.6*	*14.7*	*-44.7*	*54.3*
	Preconeus and Brodman 31			*Lingual Gyrus*		

302-394ms	*26.1*	*29.2*	*13.2*	*-10.3*	*80.1*	*26.4*
	Superior Temporal Gyrus			*Media Frontal Gyrus*		
	3D Computer-generated images with details			*sketches*		
310-390ms	*22,2*	*13.1*	*24.7*	*-10.3*	*80.1*	*26.4*
	Parahippocampal Gyrus			*Media Frontal Gyrus*		

4. Discussion and conclusion

Neuroscientists and neuropsychologists have newly approached the traditional philosophical field of aesthetics aiming to characterize the neural and evolutionary foundations of our species' ability to appreciate beauty and art[31][32]. This approach, known as neuroaesthetics, has begun to provide some insights into the neurobiological bases of aesthetic appreciation [33][34], and we think that it could also be useful for advising on architecture.

In this study, we found significant differences in the subjective perception of images with details (furniture, clothing) and images without details (single bed, walls, windows and doors). The subjective scoring revealed that the participants preferred real images (photographs) or computer generated images in greater detail rather than simpler images and sketches.

Based on the results obtained when applying sLoreta reconstruction to the significant windows, we can observe that in early states of processing before real images are activated areas of Brodman 31, related to episodic memory retrieval [35] o voluntary and involuntary recall [36], when the observed images are sketches, 3D computer generated images gray o 3D computer generated images with no details, areas near to Brodman-18 are activated, these areas are related to sustained attention to color and shape [37] and visuo-spatial information processing (Right) [38], [39]. When the image processing progresses, about 300 ms after appearing, we can observe that real images and 3D computer generated images with details are related to areas of superior temporal gurys and parahippocampal gyrus, described areas related to deductive reasoning [40] recognition memory, memory recall and retrieval [41] and integration of visual elements into perceptual wholes (Right) [42]. If the images are simpler (sketches), the activated area is the medial frontal rotation, related according to the literature with internal mental calculation [43] and memory encoding and recognition [44], [45].

These differences in cognitive processing could be justified by effects related with the familiarity of the images. Thus, a number of psychological studies have shown that people usually prefer familiar stimuli, an effect currently explained under the umbrella of the processing fluency theory. In this context, Reber [46] suggested that objects vary with regards to the fluency with which they are processed. Given that fluent processing is experienced as hedonically pleasurable, and that aesthetic experiences are strongly influenced by affective states, it follows that positive aesthetic experiences arise especially from confident processing, such as that afforded by prototypical examples of a category [47]. In this framework the photographs and images with details are more familiar to most of the people and therefore they are perceived as being more pleasurable than the images without details.

Our results show that there are significant differences in the brain processing of both types of images, especially in the early stages of processing, which could help us to better understand how aesthetic judgments are made. Furthermore, while they do not address the role of each of type of images, emphasize the necessity and importance of creating computer models as realistic as possible and point to important new set of questions for further investigations, especially about how multiple cortical regions might interact for the aesthetic experience.

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Neural Recognition of Real and Computer-Designed Architectural Images

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Abstract

Neuro-architecture seeks to define and understand the relationship between our psychological state and the artificial structures in which we spend most of our time and incorporate that insight into the design. However, little is known about the subjective judgment of real architectural models and about the cognitive processes in aesthetic appreciation applied to architecture. In the present study, we used real and computer-designed architectural images of bedrooms, in order to compare both types of images. Participants were asked to judge the arousal and valence of their own emotional experience after viewing each image. Furthermore, we used EEG recording to gain a better understanding of the regions of the brain involved in the processing of these images. Our results show that there are significant differences in the early stages of processing of both types of images and emphasize the importance of generating familiar and recognizable images for the acceptance by people.

Key Words: Neuro-architecture, EEG, aesthetic appreciation, ….

1. INTRODUCTION

Since 1962 architects have been using 3D modeling instead of hand crafted designs and drawings [1]. This technology is very powerful and today it is possible to create precise 3D models for different purposes [2]. This method is normally employed to create 3D interior and 3D exterior models. Furthermore, different business firms are taking interest in creation of 3D product models, which demonstrate the significance of 3D architectural modeling.

By applying architectural 3D models, it is possible to envision the final results on a computer screen, which in general generates positive effects on the potential cutomers. [3]. Thus, we can visualize the entire building, or a given room, using 3D rendering before the building is complete. This saves time and helps to modify details that require to be changed before the actual construction, which is extremely cost effective and saves ample time. However, little is known about the subjective judgment of real photographs and 3D architectural models and about the cognitive processes in aesthetic appreciation applied to architecture [4].

Neuroscientists and neuropsychologists have recently approached the traditionally philosophical field of aesthetics aiming to characterize the neural and evolutionary foundations of our species' capacity to appreciate beauty and art. This approach, known as neuroaesthetics, has begun to provide some insights into the neurobiological bases of aesthetic appreciation [5][6], and could also be useful for advising on architecture.

In the present study we used real and computer-designed architectural images of bedrooms, in order to compare both types of visual stimuli [7][8]. Participants were asked to judge the arousal and valence of their own emotional experience after viewing each image and electroencephalography recordings (EEG) were used to compare the descriptive and judgment processes [9]. Our goal was to investigate the processing characteristics and temporal time courses associated to each type of images [10]. Our preliminary results show that there are significant differences in the early stages of processing of both types of images and provide some insights regarding the emotional response to a given image and how aesthetic judgments are made.

2. METHODS

2.1 Participants

Twenty-two participants (mean age: 24.7; range: 19.7–33; eleven men, eleven women) participated in the study. All participants had no personal history of neurological or psychiatric illness, drug or alcohol abuse, or current medication, and they had normal or corrected to normal vision. All were right handed with a laterality quotient of at least + 0.4 (mean 0.8, SD: 0.2) on the Edinburgh Inventory [11]. All subjects were informed about the aim and design of the study and gave their written consent for participation.

2.2 Stimuli

We used twelve different images. Seven images were real photographs and five were computer-designed images performed with the help of a 3D modeling software (SketchUp). The photographs were real rooms, with different decoration and arrangements of furniture, windows etc. The computer-designed rooms were similar and involved several room types with different arrangements of the door, windows and bed. All images were presented in color, equated for luminance and contrast using a commercial stimulus presentation and experimental design system (STIM2, Compumedics, Charlotte, NC, USA).

2.3 Main experiment

Figure 1 summarizes the experimental design. Each image was presented for 500ms and followed by a black screen for 3500ms. The images appeared in randomized order and only once. The participants were told that they would be asked to judge the arousal and valence of their own emotional experience after viewing each image (during the black period). Scales ranged from 1 (very unpleasant) to 9 (very pleasant).

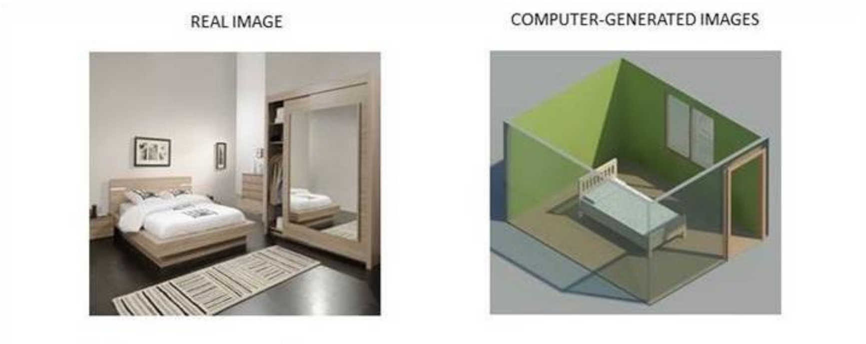

Figure 1.A: Stimulus type representative

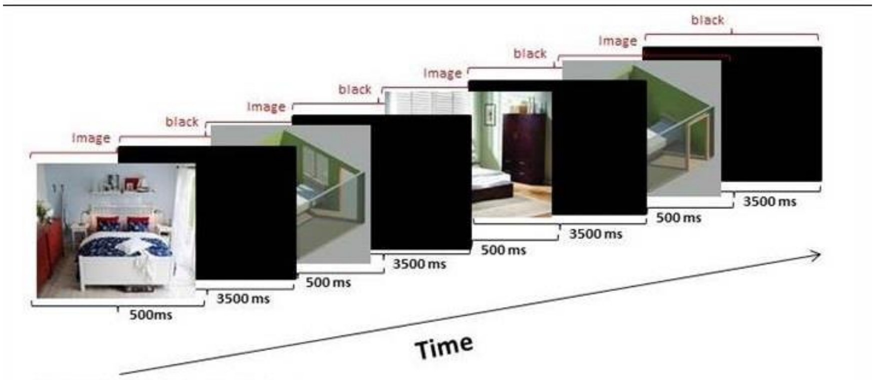

Figure 1.B: Structure serial representative

Figure 1: Representative stimulus examples.

2.4 EEG Recordings

We instructed subjects to remain as immobile as possible, avoiding blinking during image exposure and trying to keep the gaze toward the monitor center. EEG data was continuously recorded at a sampling rate of 1000 Hz from 64 locations (FP1, FPZ, FP2, AF3, GND, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, REF, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, CB2) using the international 10/20 system [12]. EEG was recorded via cap-mounted Ag-AgCl electrodes. A 64-channel NeuroScan SynAmps EEG amplifier (Compumedics, Charlotte, NC, USA) was used for EEG signal amplification and digitizing. The electrodes were filtered using a 45 Hz low-pass filter and a high-pass filter of 0.5 Hz. The impedance of recording electrodes was monitored for each subject prior to data collection and the thresholds were kept below 25 kΩ. All recordings were performed in a dimly lit and silent room.

2.5 Data analysis

Experimental stimuli consisted of real photographs and 3D computer-designed images. To study the event-related EEG dynamics, we extracted data from an epoch 100 ms before stimulus onset to 1000 ms after stimulus. Signal processing was performed using the Curry 7 software (Compumedics, Charlotte, NC, USA). Data were re-referenced to a Common Average Reference (CAR), because the subsequently applied statistical and source analysis methods required CAR data. Furthermore, we used the frontal electrodes (FP1, FPZ, FP2, AF3 and AF4) to eliminate flicker effects. We chose these electrodes because they were located in regions that can be easily affected by possible involuntary movements. The *pre* and *post* times (-200ms, +500ms) defined the interval from the point at which the artifact was detected. The detected artifacts were corrected following standard procedures using Principal Component Analysis (PCA) [13]. Furthermore, to constrain our analysis, we used the examination of topographic changes in EEG activity [14][15]. This approach considers whole-scalp EEG activity elicited by a stimulus as a finite set of alternating spatially stable activation patterns, which reflect a succession of information processing stages. Therefore, the evolution of whole-scalp activity can be assessed over time in order to see how it differs between experimental conditions that impose different information processing demands.

Boundary Element Method (BEM) was used in the head reconstruction [19]. Topographical differences were tested through a non-parametric randomization test known as TANOVA (Topographic ANOVA), that allows to quantify differences in global dissimilarity of EEG activity between two conditions. This allows us to assess if the topographies are significantly different from each other on a timepoint-by-timepoint basis. For this paper, significance level is α=0.01. As suggested by[17], the corresponding required number of repetitions was chosen to be $p > 1000$.

3. RESULTS

3.1 Subjective scores

Images were scored by the participants during the experiment. The average score for the group of real photographs was 6.6 (SD: 0.9). By contrast, the average score for the group of images designed by computer was significantly lower: 4.2 (SD: 1.7); $p<0.01$ (Figure 2).

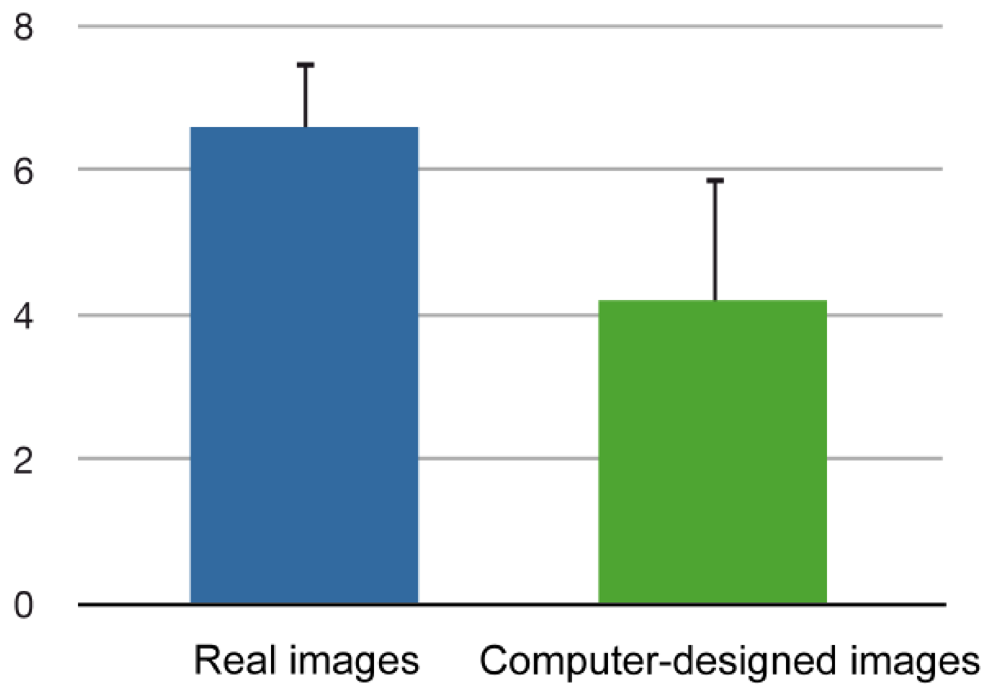

Figure 2: Subjective scores of real photographs and computer-designed images (mean and standard deviation).

3.2 EEG

We found significant differences in stimulus-elicited activity between both types of images, photographs and computer designed images (α<0.01). These differences started approximately at 189 ms after picture onset. The time intervals with the larger differences were: 189-203 ms, 296-344 ms and 424-474 ms (Figure 3).

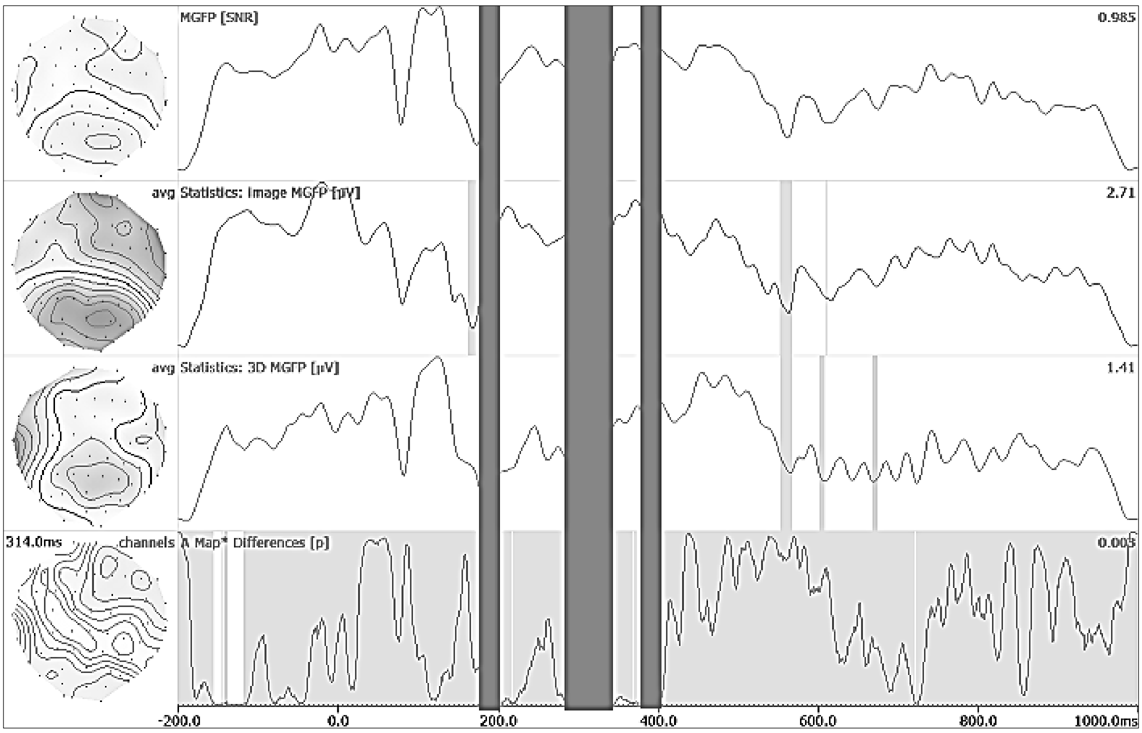

Figure 3: Time points of significant differences in EEG activity for the 2 contrasts (photographs and computer designed images) as indicated by the T ANOVA analysis,

depicting 1 minus p-value across time. Significant p values are plotted (α<0.01). The three vertical rectangles contain significant differences.

Figure 4 shows the isopotential areas during these periods, what provide information about the spatial configuration of the activated brain areas when looking real photographs or computer-designed images.

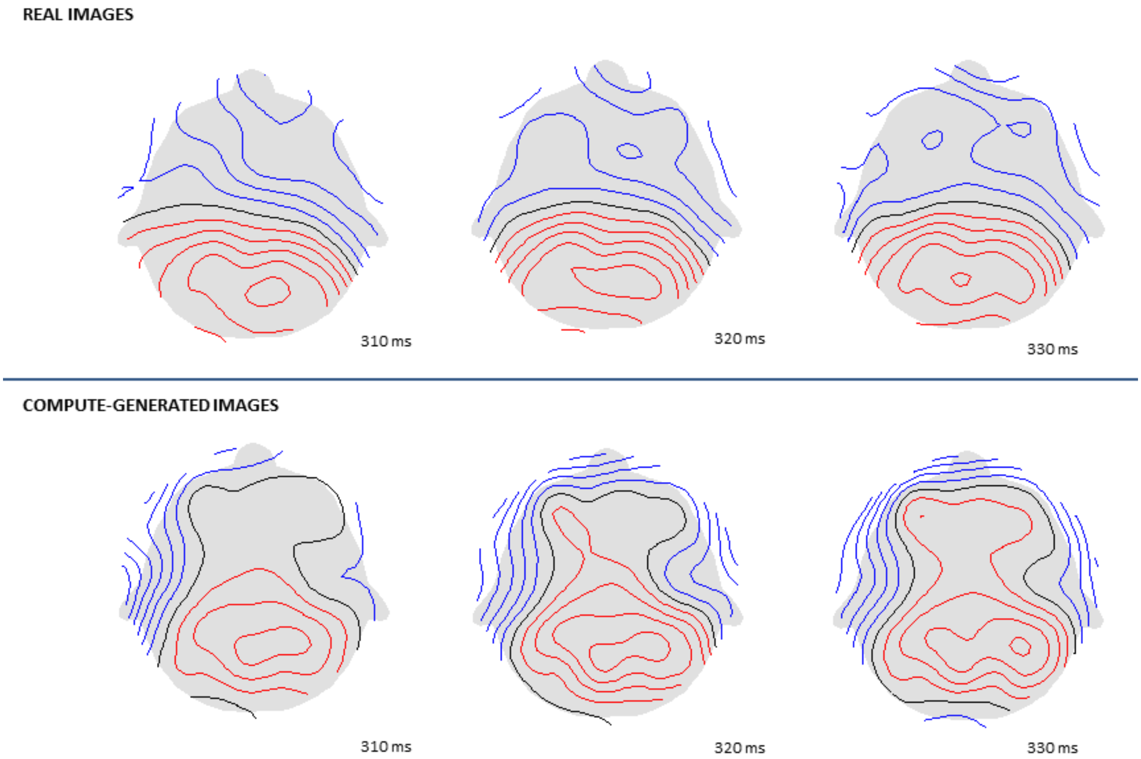

Figure 4: Isopotential values of the EEG activity at different time windows

4. DISCUSSION AND CONCLUSION

In this study we found significant differences in subjective perception of real photographs and computer-designed images. The subjective scoring revealed that the participants preferred real images (photographs) rather than computer-designed images. Moreover, our preliminary results show that there are significant differences in the brain processing of both types of images, especially in the early stages of processing, what could help to better understand how aesthetic judgments are made.

These differences in cognitive processing could be justified by effects related with the familiarity of the images. Thus, a number of psychological studies have shown that people usually prefer familiar stimuli, an effect currently explained under the umbrella of the processing fluency theory. In this context, Reber [20] suggested that objects vary with regards to the fluency with which they are processed. Given that fluent processing is experienced as hedonically pleasurable, and that aesthetic experiences are strongly influenced by affective states, it follows that positive aesthetic experiences arise especially from confident processing, such as that afforded by prototypical exemplars of a category [21]. In this framework the photographs are more familiar to most of the people and therefore are perceived as being more pleasurable than the 3D images created by a computer.

One would assume that if the images were more realistic 3D models, not only representing walls, bed, window, door, etc.; the differences would be lower. In future work we will conduct more realistic computer models; we will study if there are still differences in the processing or if instead, the brain is not able to distinguish among very realistic computer generated images and real photographs.

Acknowledgments

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• Publicaciones de trabajos con técnicas eye tracking

Artículo: Use of Eye Tracking as an Innovative Instructional Method in Surgical Human Anatomy

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Case study: using a portable eye tracking during objective structured clinical examination (OSCE) of medical students

María Dolores Grima Murcia, Francisco Sánchez Ferrer, José Manuel Ramos Rincón, Javier González de Dios, Antonio Compañ Rosique, Eduardo Fernández

Artículo en revisión en BMC Medical Education

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USE OF EYE TRACKING AS AN INNOVATIVE INSTRUCTIONAL METHOD IN SURGICAL HUMAN ANATOMY

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Abstract

Objective: Tobii glasses can record corneal infrared light reflection to track pupil position and to map gaze focusing in the video recording. Eye tracking has been proposed for use in training and coaching as a visually guided control interface. The aim of our study was to test the potential use of these glasses in various situations: explanations of anatomical structures on tablet-type electronic devices, explanations of anatomical models and dissected cadavers, and during the prosection thereof. An additional aim of the study was to test the use of the glasses during laparoscopies performed on Thiel-embalmed cadavers (which allows pneumoinsufflation and exact reproduction of the laparoscopic surgical technique). The device was also tried out in actual surgery (both laparoscopy and open surgery). **Design**: We performed a pilot study using the Tobii glasses. **Setting**: dissection room at our School of Medicine and in the operating room at our Hospital. **Participants:** To evaluate usefulness, a survey was designed for use among students, instructors, and practicing physicians. **Results:** The results were satisfactory, with the usefulness of this tool supported by more than 80% positive responses to most questions. There was no inconvenience for surgeons and that patient safety was ensured in the real laparoscopy. **Conclusion** to our knowledge, this is the first publication to demonstrate the usefulness of eye tracking in practical instruction of human anatomy, as well as in teaching clinical anatomy and surgical techniques in the dissection and operating rooms.

Key Words: Tobii glasses, eye tracking, teaching human anatomy, teaching endoscopy surgery.

Highlights.

1. Eye tracking has been proposed for use in training as a visually guided control interface.

2. We conducted a pilot study to explore the usefulness of Tobii glasses in anatomical models.

3. The glasses were tested during real surgical procedures and laparoscopies performed in cadavers.

4. Students, instructors and practicing physicians were surveyed to learn their opinion about glasses.

5.The results were highly satisfactory, with >80% positive opinions. Patient safety was ensured.

Introduction

New technologies are increasingly applied to the field of medicine. In recent years, eye tracking has been used to teach and to hone skill sets in relation to clinical anatomy and surgical technique (particularly laparoscopy) and to explain image-guided diagnostic techniques, such as ultrasound.

The use of single-camera technology to track eye movement is a well-established concept first described in airplane pilots in 1950[1]. New techniques have since been developed, and eye tracking has been documented using stationary cameras or cameras fitted to normal glasses. These glasses can record corneal infrared light reflection to track pupil position, to map gaze focusing in the video recording, and to calculate other parameters, such as tracking rate or dwell time (used to measure the importance of the stimulus) and pupil dilation (used as a marker of effort and concentration).[2-4]

It has been suggested that measurement differences between subjects with different levels of surgical skill could be used as skill markers[5,6]. In fact, eye tracking has been proposed for use in assessment, as well as in training and coaching as a visually guided control interface[7]. This could be of particular interest in surgical theaters, where aseptic conditions must be maintained. Visual orientation may be a greater problem in laparoscopic surgery and, therefore, the analysis and identification of efficient orientation strategies based on eye tracking have proven to be potentially helpful. [3,5]

Material and Method

We performed a pilot study using Tobii glasses (Figure 1) in the dissection room at the School of Medicine of the Miguel Hernández University in Elche, Spain. To record eye-tracking data, Tobii glasses are worn like normal glasses and weigh only 45 g. The visual field is 160 degrees (horizontally), with minimal vision loss during extreme eye movements. The system must be calibrated separately for each participant by asking participants to look at a calibration card placed in front of them for several seconds. The investigator then starts recording the participant's vision through the Tobii glasses. Total battery time is 120 minutes, and the software is run on a Windows 8/8.1 tablet or Windows 7 or 8/8.1 computer. This allows the investigator to view the eye-tracking session, both in real time (streaming by Wi-Fi or cable connection) and after recording. When watching a recording in real time, the participant can view a circle displayed in the video display of the camera used to record the scene with the built-in HD camera fitted to the Tobii glasses. This circle represents the participant's macular vision.

We found the Tobii glasses to be useful in teaching human anatomy in this context. To test them, the instructor wore the glasses while dissecting a forearm specimen. As seen in the videos, the images produced by the glasses show the instructor's visual field and a circle is used to point out the focus of eye gaze (specifically, macular vision), pointing out the element of interest by gaze. This means that the viewer will see the same image as the instructor at the same angle and with the same visual field. Images and sounds are transmitted by Wi-Fi to any computer or projector with a delay of less than 1 second. The Tobii eye-tracking glasses are fitted with a direct vision function that allows investigators to observe in the video exactly where the wearer is looking, and in real time to see the image on any Windows 8 tablet, while moving about freely in any environment, thanks to a Wi-Fi wireless connection. In addition, the device can record and then analyze different data, such as the rate at which each point is observed. The circle is several seconds ahead of the hand location, as the gaze moves earlier to the structure to be dissected (video 1and 2).

We tested the use of Tobii glasses in a lecture class and with anatomical models. As the instructor explained the various structures shown on an anatomy card, he looked at them and then pointed them out on the monitor viewed by the students, with no need for a pointer (video 1 and 2). We also tested the glasses in laparoscopic procedures on Thiel-embalmed cadavers, which allows abdominal cavity pneumoinsufflation and exact reproduction of the surgical technique. After we also probed them in a real laparoscopic procedure at "Virgen de la Arrixaca" University Clinical Hospital, Murcia, Spain (video 2).

To measure the usefulness of this instrument, we designed an anonymous online survey (Table 1). A computer application from the University of Murcia (encuestas@um.es) contained a link to view video 1 and the survey. This was sent to students from the School of Medicine at the University of Murcia, as well as instructors and physicians from the Department of Obstetrics and Gynecology at Virgen de la Arrixaca University Clinical Hospital.

Results

A total of 62 completed surveys were returned, and participation was 54.8% among students, 21% among professors and 24.2% among practicing physicians. The global survey results were highly satisfactory (Figure 2).

Below we describe the overall results independent of status (medical student, instructor, or practicing physician) (Figure 3). The items most highly valued, in order, with more than 80% answering "agree" or "totally agree" were for the questions that considered it a good tool during theoretical anatomy classes, for specialization in more complex surgical techniques, during prosection and dissection of anatomical structures in the dissection room and in anatomical models; for postgraduation instruction in actual teaching laparoscopies and in laparoscopic surgical techniques in Thiel-embalmed cadavers. The worst results (61.3% positive opinions) were obtained by the questions on whether the Tobii glasses were a good tool for practical examinations in the dissection room and on whether it was an efficient product (43% positive opinions).

When breaking down the results according to status, the best evaluations were from students. This groups answered "agree" or "totally agree" 90% of the time for the same items described above. The worst evaluations were for usefulness during practical examinations.

The worst overall evaluation was given by the instructors. Interestingly, the question best evaluated by this group was on the usefulness of the device in practical examinations, with 77% positive responses. Other responses evaluated highly were related to usefulness during prosection and dissection of anatomical structures, in anatomical models, and during learning of more complex surgical techniques.

Practicing physicians gave high evaluations to specialization in more complex surgical techniques (93.3% positive responses) and to anatomy instruction applied to clinical medicine in postgraduate courses using Thiel-embalmed cadaver models (86.7% “agree” responses) and to actual teaching laparoscopies (86.6% positive evaluations). The worst evaluation was related to efficiency (20% positive responses).

The observational data available in this survey (at the end we wrote **“**Please add any comments or remarks that you feel might be useful”) were that eye-tracking technology allows visual instruction that improves completion times and reduces errors in a simulated environment (laparoscopy in Thiel cadaver). Surgeons also felt that less time was spent scanning the screen and that their instrument movements were more precise and less hesitant. Another interesting comment was that eye-tracking was a possible tool that provided “a third hand” to the surgeon. An additional opinion was that eye-tracking could aid communication between surgeons during surgery procedure, improve training, and assist in using surgical instruments.

Discussion

To our knowledge, this is the first publication to demonstrate the usefulness of eye tracking in practical and theoretical instruction of clinical human anatomy, as well as in teaching clinical anatomy and surgical techniques in the dissection room and in a real laparoscopic procedure. The device is easily manageable, even for first-time users, and serves as a highly valuable tool for many types of qualitative research. We have used this system in radiologic image reading, anatomical models, cadaver dissection, and laparoscopy. Some techniques, such as orotracheal intubations or spinal taps, can only be performed when the person is properly positioned, making eye tracking an extremely useful tool when instructing or monitoring students' or residents' technique. The tool allows simple examinations or surgical operations to be monitored even when the instructor or physician supervising the procedure in real time is in another room, ensuring that the student is focusing on key elements for each situation. We also demonstrated its usefulness in the dissection room, where a pointer cannot be used during dissection, due to the use of gloves.

Our literature review found no article that mentioned the use of this technology in medical school or clinical anatomy instruction, areas of great importance for postgraduate courses in which specialists learn, perfect, or innovate surgical techniques, although we did find an article in the field of nursing education[8]. We believe that eye tracking could be extremely useful for the practical teaching of human anatomy, as evidenced by our pilot study.

When anatomists perform dissections, students view the entire field and, unless otherwise instructed or pointed out, will not focus on the details seen by the dissector. We believe it would be useful for the student to see a circle on the monitor to point out the dissector's macular vision in real time, thus indicating the most interesting detail of the dissection.

Eye tracking can also be used to learn image-based diagnostic techniques, such as ultrasound, CT scan, or MRI [9,10], which also allows visual cues to be given in real time. This technology also allows real-time volumes to be calculated[11] which may be extremely useful when planning the best approach for each patient.

A number of studies have been published on the use of eye tracking in other clinical fields, including radiology[12,13], surgery[14-17], pathology[18], and unit cares[19]. One study looked at the use of eye tracking to understand learning in students of gross anatomy; however, the study did not focus on using the tool to teach anatomy[20].

Eye tracking has been used with virtual laparoscopy simulators[21] to compare specific skills between expert and novice surgeons, as it is enormously important to detect differences and to improve training and perfecting in these techniques.
Wilson et al.[21] provide support for the utility of assessing strategic gaze behavior to better understand how surgeons utilize visual information to plan and control tool movements in a virtual-reality laparoscopic environment. For instance, these authors showed that gaze analyses revealed that experienced surgeons spent significantly more time fixating target locations than novices, who split their time between focusing on the targets and tracking the tools. Previous research[22] has demonstrated that experts are more likely to fixate on the target while novices are more likely to track the tool as it moves toward the target. In virtual laparoscopy, it has been shown that the economy of movement of the left (nondominant) hand varied significantly between experienced and novice operators[21]. In video-assisted surgery, Kocak et al.[23] found that surgeons with greater experience tended to move their eyes less and to spend more time fixed on a given point. Experiments have also been carried out in virtual laparoscopy simulators to compare outcomes when only verbal instructions were given to novice surgeons and when verbal instructions were combined with visual cues given by a visual recording provided by eye-tracking vision[7]. It was concluded that surgeons took less time to complete a surgical task or step, showed greater precision, and committed no errors when the guidelines were given both verbally and visually simultaneously.

In another article[6], the authors used real-time eye tracking during laparoscopic surgery undertaken by expert and novice surgeons and then analyzed these recordings. Eye-gaze patterns obtained from the expert surgeon should be recorded during the actual operation and then superimposed on the recorded surgical video. They found significant differences between the two patterns. Novice surgeons had eye-gaze patterns that often wandered from key areas of the operative field, whereas expert surgeons demonstrated closer eye-gaze patterns that focused on these key target areas. Expert surgeons developed an ability to scan over surgical sites using a replicable strategy over different trials. In contrast, novice surgeons did not develop a stable strategy and had a lower chance to copy the expert's visual strategy. This technology opens an opportunity to scrutinize a surgeon learning process in an objective way. These authors also demonstrated that gaze overlay is affected by the complexity of the surgical procedure. This would provide additional information to novice surgeons as to where the expert surgeon is focusing his/her attention during each step of the operation. Eyemetrics together with eye tracking while watching surgical videos can be used as adjuncts to assessing surgical skill and level of competence. The next step is to have a novice surgeon perform a laparoscopic task in the operating room while being supervised by an expert surgeon and to record the eye-gaze patterns of both surgeons while they are watching on the monitor, and then to analyze the differences between novice and expert surgeons during a real operation and how these differences can be used to assess surgical performance and competence. We have already tried out the device in actual surgery (both laparoscopy and open surgery), once it was shown that there was no inconvenience for surgeons and that patient safety was ensured. Video 2 is indicative of its applicability in clinical practice.

After this positive proof of concept, we will follow this line of research to provide quantitative results for parameters that measure the efficiency of learning.

Conclusion

We believe that Tobii glasses will also make it possible to monitor and shorten the learning curve of novice surgeons and will be particularly useful in postgraduate education (courses, congresses) in the human anatomy dissection rooms increasingly used in our setting, where Thiel-embalmed cadavers are used. Another field that could be of vital importance is patient safety, as the glasses could be used to record real surgeries and examinations, confirming that the physician has performed an accurate examination and remained alert at all key points of the procedure.

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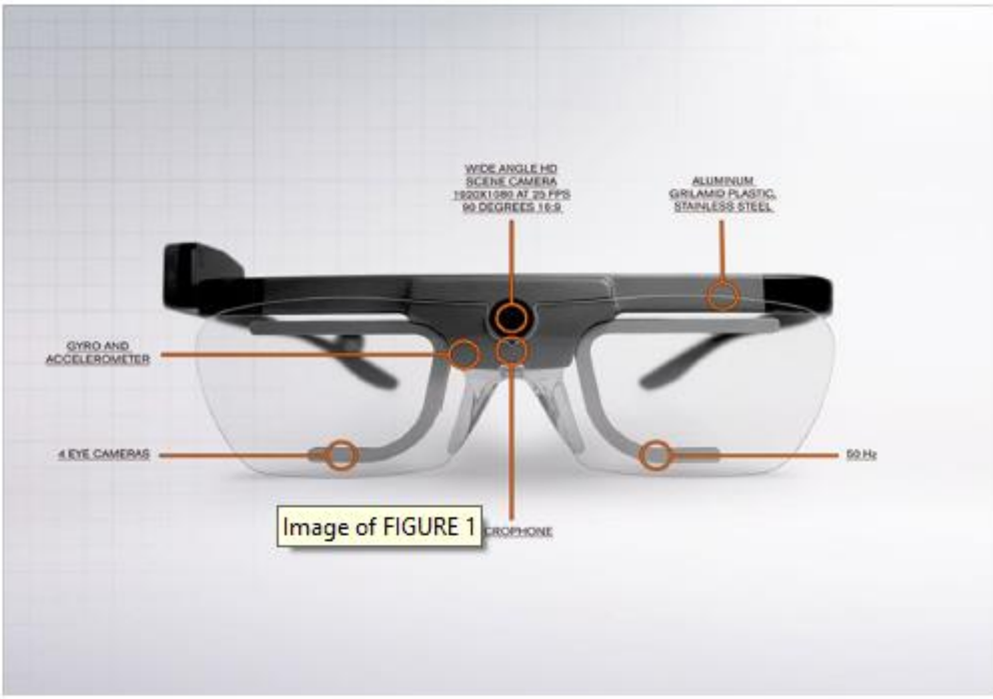
Figure Legend.

Figure 1: Tobii glasses with technical details. Characterics of the Tobii glasses. These glasses were equipped with the following: 1. High-definition scene camera to capture a video of everything in front of the participant at a 160º angle of vision; 2. Microphone to pick up sounds from the participant and his/her surroundings; 3. Eye-tracking sensors to track eye gaze direction, among other parameters; 4. Eye lighting system to support the eye-tracking sensors; 5. HDMI microconnector (to connect the Tobii glasses to the recording unit with the HDMI cable provided); 6. Cable guide to hold the HDMI cable at the participant's back; 7. Protective lenses; 8. Computer with recording and analysis software; and 9. Dissection room projectors to display the software image.



Video 1: Examples of practical applications of the Tobii glasses in dissection room

Video 2: Examples of practical applications of the Tobii glasses in a real laparoscopy.

Table 1: Survey administered.

Please state your current status:
1. Medical student, 2. Instructor, 3. Practicing physician

After viewing the video tapes on the applications of Tobii glasses, do you:
1. Completely agree. 2. Agree. 3. Undecided. 4. Disagree. 5. Completely disagree

1. This could be a good tool during *theoretical classes* on anatomy, as it allows the instructor to point out structures over the place where the anatomical images are being shown.

2. This seems to be a good tool for use in dissection rooms during *prosection and dissection of anatomical structures* in the cadaver because structures pointed out with forceps may not always be visible from all angles, as the instructor's own body can interfere with students' line of sight.

3. This seems to be a good tool for use in *anatomical models* because structures pointed out with forceps may not always be visible from all angles, as the instructor's own body can interfere with students' line of sight.

4. This seems to be a very useful tool to point out anatomical structures while teaching applied anatomy in clinical medicine for *postgraduate courses*, using Thiel-embalmed cadaver models, which allows laparoscopic surgical techniques to be performed.

5. This might be a good tool for practical examinations in the dissection room because there is no need to touch structures directly, but simply to point them out "visually" and, therefore, to avoid the deterioration of anatomical specimens by preventing handling.

6. This might be a good tool for postgraduate instruction, as it allows structures to be pointed out to residents during *actual instructional laparoscopies*.

7. This might be a good tool for *specialization in more complex surgical techniques*, as it allows more expert surgeons to show novice surgeons the surgical maneuvers to be made during more complex laparoscopies.

8. The current cost of the glasses is approximately €20,000. Do you consider that this is an efficient product for acquisition by Schools of Medicine in the public university system, in the light of the effort to include innovative instructional strategies?

Figure 2: Overall survey results. Positive results ("Totally agree" or "Agree") are shown in blue. Negative results ("Disagree" or "Totally disagree") are shown in red.

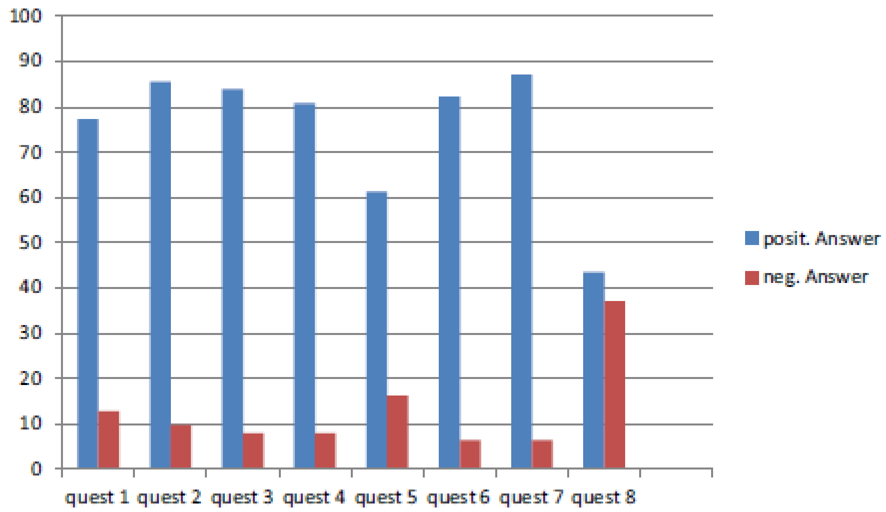
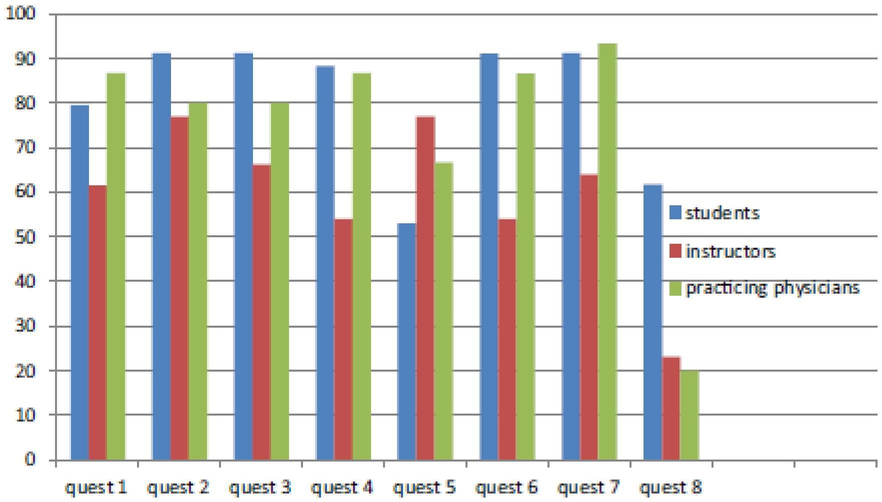


Figure 3: Survey results according to status. Positive results ("Totally agree" or "Agree") are shown for students, instructors and practicing physicians.



Case study: using a portable eye tracking during objective structured clinical examination (OSCE) of medical students

Short title: Pilot study on portable eye tracking in the OSCE

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Abstract

Introduction. The objective structured clinical examination (OSCE) is a new test that evaluates the clinical competencies of sixth-year medical students in Spain. The OSCE includes examination of medical skills and procedures with simulated patients as well as performance of complementary explorations. In this framework the main goal of the present case study research is to explore possible applications and usefulness of portable eye tracking systems in the context of this new kind of tests, particularly questions related to attention and engagement.

Material and methods. We used the portable Tobii Glasses 2 eye tracker, which monitors, in real time, the image and sounds perceived by the people wearing the device. We performed both a qualitative and quantitative analysis on the fields of vision and gaze points attracting attention as well as the visual itinerary. This information was used to get useful information about visual attention.

Results. The greatest utility of portable systems lies in patient simulators and mannequin stations. Our results showed that during medical history, the attention was focused on faces. Furthermore, this technology proved to be useful to better identify the areas of the medical images that were provided.

Conclusion. Portable eye trackers offer the opportunity to improve the objective evaluation of candidates and the self-evaluation of the used stations and medical simulations by examiners. Our preliminary results suggest what elements of the OSCE are most amenable to evaluation through eye tracking and provide insights for the design of future studies in this field.

Key words:

Visual perception, Medical education, Eye tracking, Objective Structured Clinical Examination (OSCE)

INTRODUCTION

The objective structured clinical examination (OSCE) is a new student evaluation of medical students that aims to assess candidates' skills and attitudes in certain clinical situations. This goal is different from typical written exams, which primarily evaluate knowledge. Basically, evaluating clinical competencies entails to objectively measure if a candidate has used and applied theoretical knowledge correctly[1]. The exam is used not only for undergraduate students but also in the graduate context[2,3] and in different medical specialties[4,5]. These tests have been used since the 1970s and have proven to be a reliable and valid tool for evaluation, even when using the same stations[6].

The OSCE incorporates diverse evaluation instruments, which are deployed in successive stations that simulate real clinical situations[7]. The power of this format lies in the mixed-methods evaluation, which allows examiners to explore three of the four levels of Miller's pyramid: to know, to know how and to show how[3]. The number of stations ranges from 5 to 20, according to the objectives under evaluation[8].

In Spain, different medical schools have implemented this testing method unevenly, with universities in Catalonia – like many medical schools worldwide[9] – accumulating the most experience in the 20+ years since they began using it [10].

Recently, the National Deans Conference in Spain agreed on an OSCE of 20 stations that all sixth-year medical students should take. The general characteristics of the test are as follows: practical character; oriented towards evaluating the professional competencies of the candidate relative to the specific competencies of the Medical Degree, established by the Order ECI/332/2008 (published in the Official State Gazette on 15 February 2008); performed through the resolution of clinical cases; and having the objective of demonstrating clinical skills.

The OSCE explores diverse areas of evaluation through a range of methodologies. The stations include simulated and standardised patients, mannequins, questions with short answers, performance of complementary explorations adjusted to the particular case, drafting of clinical reports, structured oral examinations, skills and procedures, computer functions, and simulators.

The OSCE entails a considerable collective effort both for candidates and examiners; however, diverse papers have also reported good cost-effectiveness[11] compared to traditional testing[8].

Recording videos for the purpose of clinical training is already employed successfully, even for evaluating procedures, techniques or diagnostic tests[12,13]. However, the technique proposed in the present study is different from these recordings and has substantial implications for teachers[14]. Thus, using an eye tracker, we can see and analyse candidates through their own unique perspective, similarly to how this technology is used for training in gastroscopy or locoregional anaesthesia, alone or in conjunction with conventional video[15], or in the field of radiology[16,17]. Consequently, using this device, it is possible to perform a qualitative analysis of the test (also allowing examiners to self-evaluate their station) and also to objectively analyse those elements that – due to the test design – may introduce subjectivity in the examination, such as the relationship with different speakers or the dynamics of evaluating complementary medical tests [18].

With the above in mind, we designed a feasibility study to assess the real possibilities that eye tracking has as a tool for teaching and evaluating in the OSCE, according to each station model.

MATERIAL AND METHODS

We carried out an OSCE for 117 sixth-year medical students in the Medical School of the University of Miguel Hernández (Spain). The OSCE consisted of a circuit of 20 stations or situations and the candidates had to go consecutively through all of them, spending nine minutes on each with resting periods of two minutes between each new station. The stations and the skills areas included were: history taking, physical examination, doctor-patient communication, drafting of clinical reports, clinical judgement, technical skills, preventive activities and ethical-legal aspects (Table 1).

Table 1. Station, type of station and skills map for the OSCE test.
1: history taking; 2: clinical exploration; 3: technical skills and procedures; 4: communication skills; 5: clinical judgement, diagnostic and therapeutic management plan; 6: disease prevention and health promotion; 7: interprofessional relationships; 8: ethical aspects – legality and professionalism.

	Station	**Type**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
1	MSP of the digestive tract	SP	65.5	24.1		10.3					100
2	MSP of the digestive tract	Report					34.8	65.3			100
3	Pathology of infectious diseases	SOE							90.0	10.0	100
4	Emergency medicine	M-T		35.0	55.0					10.0	100
5	Legal medicine	Report						38.1	61.9		100
6	Emergency	SP		96.8		3.2					100

7	MSP of the nephrourinary system	M-P			55.0		35.0			10.0	100
8	Psychiatry	SP	22.6	35.5		12.9	29.0				100
9	MSP of the musculoskeletal system	M-P		57.2	28.6		14.3				100
10	Paediatrics	SOE					42.1		47.4	10.5	100
11	Pathology of infectious diseases	SP	43.3	13.3		10	33.4				100
12	MSP of the endocrine system	SOE	20		30		10		40		100
13	Surgery	M-P			83.3				12.5	4.2	100
14	Gynaecology and obstetrics	SP	50.0			15.0	25		10		100
15	Gynaecology and obstetrics	M-P		15.8	26.3		47.4		10.5		100
16	Paediatrics	SP	38.5	30.8		11.5	11.5		7.7		100
17	MSP of the respiratory system	Report					70	30			100
18	MSP of the cardiovascular system	SP	44	36		12	8				100
19	MSP of the cardiovascular system	Report					100				100
20	Microbiology and legal medicine	Report					38.9		22.2	38.9	100
	Average percentages		13.4	15.4	14.9	5.4	24.3	11.9	7.5	7.0	100

Notes: MSP: medical and surgical pathology; SP: standardised patients; SOE: structured oral examination; M-P: mannequin-procedure.

The exam was carried out in two parallel rounds of 23 candidates each. Forty consult areas were prepared in line with the needs of the specific stations, each equipped with a computer programme created for candidate evaluation. The simulated patient or examiner completed a checklist of evaluation items for the skills area under assessment. Exams were uninterrupted, with rotations communicated via a computer programme with speakers. The exams lasted 4.5 hours. Candidates could not carry any electronic item (including mobile phones or watches), and all had a white coat, stethoscope, pencil or pen, and two blank sheets of paper.

The portable eye trackers used were the Tobii Glasses 2[15]. This device weighs 45 g and has a 160° field of vision, with minimal visual loss with extreme eye movements (Figure 1). The system was calibrated upon starting up, for each wearer. Both image and sound were recorded simultaneously. The recordings were registered on memory cards for subsequent analysis and also transmitted through a wireless network to a projector and/or computer for real-time visualisation of the teachers (recording delay of one second via Tobii Glasses Controller). Some of the research questions were: Can users recognize the purpose of each specific station? If not, what are the obstacles? Which was the main focus of attention in each station? Were the medical images provided easy to read and understand?

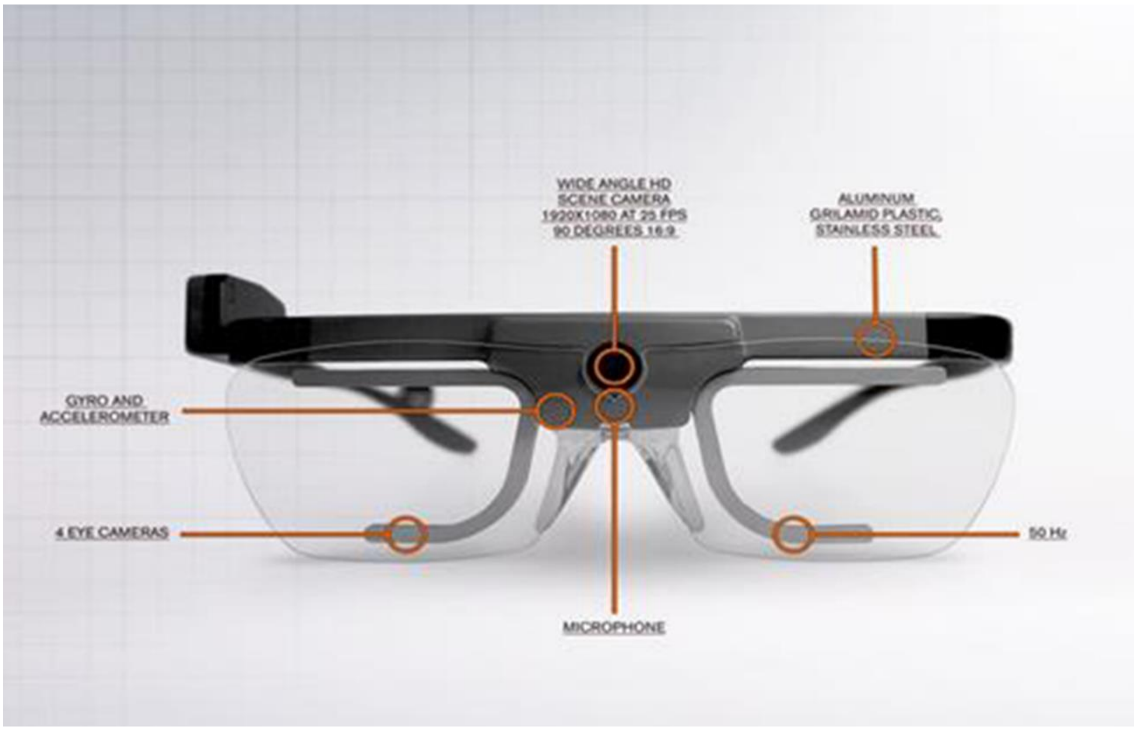

Figure 1

The videos for each station were edited to eliminate the waiting periods and to include only the time period from which the participants read the case being evaluated prior to entering the consult area. The audio recordings in each station were also homogenised so that the volume levels were approximately the same for all stations.

The analysis was performed with the help of Tobii Glasses Analysis Software and included a quantitative study of gaze points and the order in which they appeared for each subject. Furthermore, we used heat maps for eye tracking visualization. Thus we identify the areas of interest in each station and the percentage of the total area that they occupied within the image as a whole. Using these percentages, we calculated the locations where the participants gazed most frequently, the number of gazes, and the visual itinerary (i.e. the order in which the gazes occurred). We also measure pupil dilation, but we found out that it was extremely difficult to control luminance and keep the lightning condition stable in our 20 different experimental conditions. Hence we discover that this particular measure was not appropriate for this type of studies. Results were exported to Excel for statistical analysis.

Finally, each of the station examiners, together with three of the authors (JMR, FSF, AC), used a questionnaire to assess the usefulness of the eye tracker in: the visualisation and interpretation of complementary tests; the assessment of the attitude of simulated patients/examiners; the evaluation of the candidate; the characterisation of empathy/eye contact; the assessment of the design of the physical space where the exam was performed; the stimulation of ideas on training possibilities for examiners; and the external evaluation of the exam. Each of these questions was scored according to the usefulness of the device as follows: 0 not at all useful; 1 a little useful, 2 somewhat useful, 3 very useful.

Table 2. Utility of portable eye tracking devices in the objective structured clinical examination (OSCE), by type of station

	Type of station			
Opportunities for eye tracking	**Standardised patients**	**Mannequin/ procedure**	**Report**	**SOE**
Evaluation of complementary tests	**0**	**0**	**2**	**1**
Evaluation of simulated patient/examiner	**3**	**3**	**0**	**2**
Re-evaluation of candidate	**2**	**3**	**0**	**1**
Empathy/eye contact	**3**	**1**	**0**	**1**
Design of OSCE consult area	**3**	**3**	**0**	**0**
Candidate preparation for OSCE	**2**	**3**	**0**	**2**
External evaluation of OSCE	**3**	**3**	**0**	**2**

Notes. 0 not at all useful, 1 a little useful, 2 somewhat useful, 3 very useful.

SOE: structured oral examination

RESULTS

The OSCE exam consisted of seven stations with simulated patients, five testing technical skills and procedures with or without mannequins, five testing candidates' abilities to draft a clinical report, and three structured oral examinations (SOE) on practical clinical situations.

Of the 20 stations, we obtained useful recordings of 16 of them (80%). We did not make any recording for 3 of the stations because the specific tasks consisted of writing reports (stations 5, 19 and 20). Furthermore, we encountered some technical problems in the recordings associated with station 7 (due possibly to battery) therefore we discarded these data.

Eye tracking in stations with simulated patients

We evaluated seven stations with simulated patients (stations 1, 6, 8 11, 14, 16 and 18). The mean time for history taking was 242 seconds (28,4 standard deviation) In this group of stations the eye tracking device provided a wealth of usable data, demonstrating the extent to which the candidate 'connected' on a visual level with the simulated patient. In this case, the candidate looked mainly at the patient's eyes and mouth (83.3% of the time).

In station 16, this pattern was of special interest, as it involved a simulated mother with a paediatric mannequin. The areas of visual interest were the faces of the mother and the child (Figure 2). Of the entire image, the area of the mother's face was 12.1% of the total, while the child's face corresponded to 5.6%. Figure 2 shows a heatmap of the areas of interest (in blue and purple) for a given participant. The quantitative result for the time dedicated to looking at both areas was 84.4%: 76.5% of the time for the mother and 7.8% for the mannequin. Thus, of the 220 total gazes, 173 were focused on the mother's face, 25 on the child's face, and 22 on other locations. Moreover, the length of the gazes on other locations was shorter than for the two main areas of interest.

Figure 2

Eye tracking in technical skills with or without mannequins

We evaluated five stations (4, 7, 9, 1 y 15) related with the assessment of technical skills. Given that the students were constantly moving in these stations, for example in the station related to cardiopulmonary resuscitation (CPR) or in the station to probe suturing skills, it was difficult to analyse the results. Thus, the analysis of these data requires manual coding of the video to quantify the steadiness of the gaze[19], what was excessively complex and outside of the scope of this research.

Eye tracking in clinical reporting with pictorials

In drafting clinical reports, for example on electrocardiograms, X-rays or other images, the eye tracker was not useful, as it only showed the candidate's writing. However, in the stations evaluating a diagnostic test (for example a chest X-ray), it was possible to measure the time that the candidates spent evaluating the image and the potential relationships between the focus of attention and the student's interpretation of the clinical case.

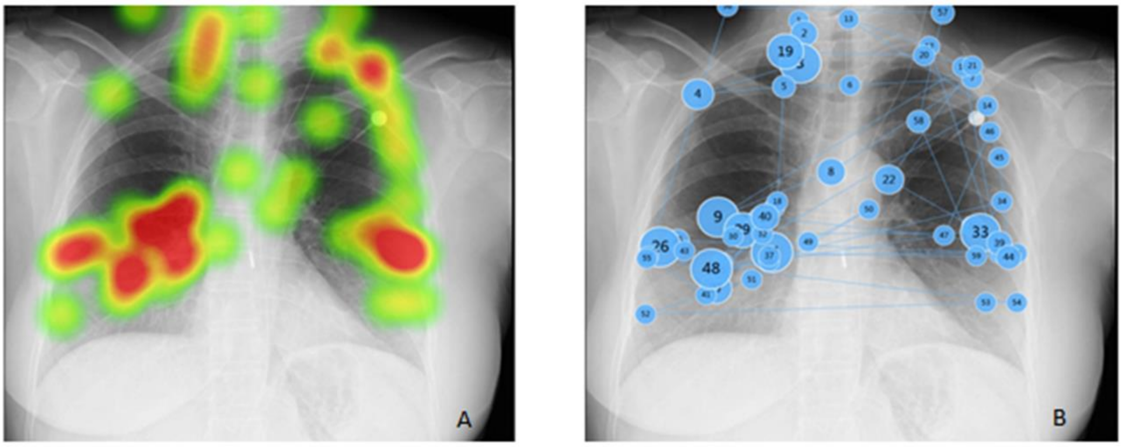

Figure 3

Figure 3 shows a representative example for station 19, dealing with a clinical report based on a pictorial prompt (chest X-ray). The time spent by the medical student looking at the chest X-ray for this particular subject was 27.61 seconds The area of interest selected – on the hila – made up 15.9% of the total area of the image and he spent 34% of his time (9.5 seconds) in this particular area (the first gazes focused on the upper left zone). Furthermore, of the 59 total gazes, 26 were on hila, and these gazes were also the longest.

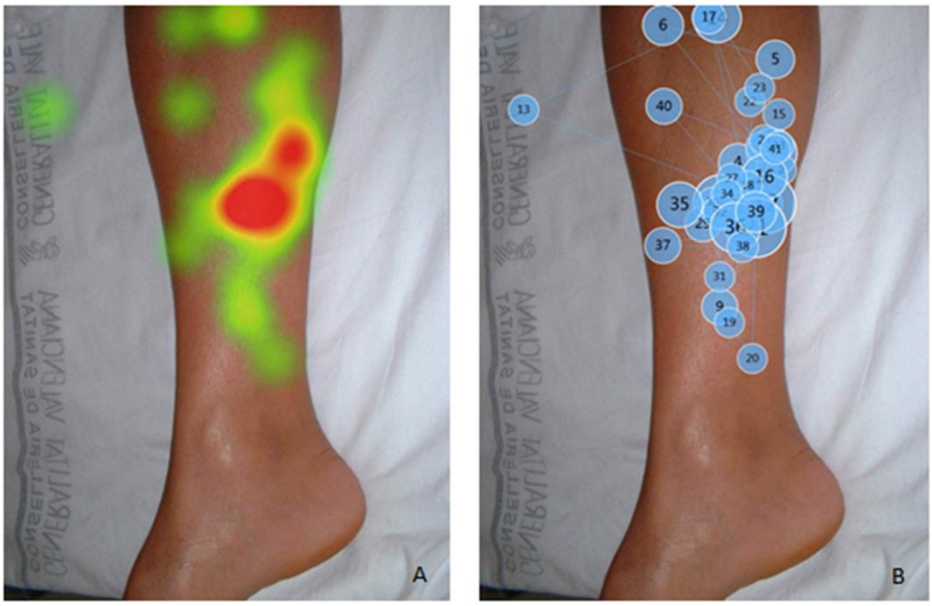

Figure 4

Figure 4 illustrates a different finding for another Station 11, which had a simulated patient but also an image of skin lesions on a lower limb. The averaged time looking at this image was 17.8 seconds, but we did not found apparent areas of interest nor a systematic approach in the order of the gazes. Nevertheless, eye tracking was also useful to assess the elements of the station that the candidates did not look.

Evaluating the usefulness of eye trackers according to the station.

Table 2 shows the averaged subjective perceptions of the examiners regarding the potential usefulness of a portable eye tracking in the evaluation of OSCE's. The utility of eye tracking seems to be virtually null in all domains for the reports, while it was 'somewhat useful' for the SOE, the evaluation of the simulated patient/examiner, and the preparation of the candidates. We did not observe any utility for other areas of interest.

In contrast, the eye tracker was 'very useful' for stations with standardised patients and mannequin procedures. This was true in practically every domain (with the exception of the evaluation of complementary tests and in the mannequin procedures to measure empathy or eye contact). Furthermore, portable eye tracking seemed of particular interest in the re-evaluation of the candidates and in candidate preparation for the mannequin procedures.

DISCUSSION

OSCE testing has now been implemented in all the medical schools of Spain, with some programmes dating back more than 20 years [10]. The effectiveness of the OSCE has also been demonstrated in diverse studies [6,8,11], although the exams being evaluated are heterogeneous in terms of design, number of stations, length, appropriateness of the simulated patients, the number of elements for assessment in each station and the scales used to grade candidates' behaviour or attitudes[15].

The use of portable eye tracking technology has been introduced in medicine much more recently[2,4,9,13,15,16,18,20–23] and there are still many open questions, particularly in the field of medical teaching and evaluation. In this framework, research regarding looking at faces is widespread, but research on the use of eye tracking for assessing students, performance is scarce. Therefore, the present study represents the first attempt in this field.

Our preliminary results show a wide range of possibilities for future work. First of all, the technology allows evaluators to objectively measure the empathy shown by the candidate in the stations with simulated patients, by characterising the features of the candidate's gaze (establishment of eye contact, steadiness, etc.)[23]. Indeed, the OSCE is intended as an objective test, but some elements are assessed with a certain degree of subjectivity, for example the scores related to candidates' treatment of patients, non-verbal communication, and conversation and empathy [24,25]. Compared to external video recording, the eye tracker and recording represents an improvement with respect to this evaluation, as it is possible to measure the amount of time that the candidate maintains eye contact with the patient – a novel and objective way to evaluate this item. Furthermore, the video is highly useful to professors, allowing them to evaluate the performance of the simulated patient (adherence to the script) and to obtain a comprehensive vision of the station from the candidate perspective. This functionality also allows teaching staff to visualise what elements are used in the station, as some are not seen by the candidates due to the objects' location.

Until now, in the stations assessing candidates' interpretation of pictorial prompts (electrocardiogram, X-ray, photos, etc.), it has not been possible to know whether candidates were able to respond correctly to the questions as a result of an adequate systematic approach that included a revision of all relevant points, or whether their responses were due to chance or previous knowledge of the answer[26]. However, using the eye tracker and the subsequent analysis, we have a better idea of what approach candidates use to reach their conclusion and what basis their response has in the image provided. In this case, there have been studies on eye trackers that evaluate candidates' interpretation of an electrocardiogram[27] or other medical images[20,21]. At the same time, follow-up research should keep in mind that gaze does not necessarily have a direct correlation with a complex cognitive process·

On the other hand, the usefulness of eye tracking varied according to the station, whether these dealt with clinical reporting based on a pictorial, images shown to the candidate, simulated patients (as a method to quantify doctor-patient empathy), and procedures and/or mannequins in the re-evaluation of the candidate. Thus, in the stations with pictorials, we believe that it could be more practical to use optical tracking by means of a device placed directly on the monitor showing the image. As in other studies[16,17], this would allow a more accurate and straightforward quantitative analysis, in which more participants could take part.

Taken it together, portable eye tracking devices open up different opportunities in the field of evaluating OSCEs: in the design, set up, and counter-evaluation of the examiners in each station. The devices may also provide clues on how to improve the evaluation of candidates during the exams, particularly in the few stations assessing subjective elements. However, more studies are still needed in this field.

Declarations

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Availability of data and materials

The datasets during and/or analyzed during the current study available from the corresponding author on reasonable request.

Authors' contributions

Maria Dolores Grima Murcia contributed to design, data acquisition, data analysis, interpretation; critically revised the manuscript; gave final approval and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy; Francisco Sánchez Ferrer contributed to design, data acquisition, data analysis, interpretation; critically revised the manuscript; gave final approval; and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy. Javier Gonzalez de Dios, contributed to data acquisition, interpretation; critically revised the manuscript; gave final approval; and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy. Antonio Company Rosique, contributed to data acquisition, data analysis, critically revised the manuscript; gave final approval; and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy. Eduardo Fernández Jover contributed to design, data acquisition, data analysis, interpretation; critically revised the manuscript; gave final approval; and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy. Jose Manuel Ramos Marco, contributed to conception, design, interpretation; drafted and critically revised the manuscript; gave final approval; and agrees to be held accountable for all aspects of work, ensuring integrity and accuracy.

Competing of interests

The authors declare that they have no competing interests.

Consent for publication

The author(s) declared that it has been signed the "consent form" according to the editorial policy.

Ethical approval and consent to participate

No applicable

Abbreviations (in order, text and table 1)

OSCE: The objective structured clinical examination

JMR: Jose Manuel Ramos

FSF: Francisco Sánchez Ferrer

AC: Antonio Company

MSP: Medical and Surgical Pathology;

SP: Standardised Patients;

SOE: Structured Oral Examination;

M-P: Mannequin-Procedure.

Annex:

Video of the eye tracker for station 16.

Annex 2:

From image and video: Personal consent to be recorded and published and from the person wearing the recording device.

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