Tesis Doctoral

INFLUENCIA CIRCADIANA Y MARCADORES FISIOLÓGICOS EN UNA TAREA DE VIGILANCIA E INHIBICIÓN DE RESPUESTA

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CAPITULO 1

La vigilancia hace referencia a nuestra habilidad para mantener el foco de atención y permanecer alerta durante periodos de tiempo prolongado. Uno de los hallazgos más importantes en la literatura es el deterioro en la ejecución con el paso del tiempo en tareas de vigilancia, fenómeno conocido como decremento de vigilancia.

A diario realizamos actividades en las que mantener la atención durante un periodo de tiempo relativamente largo es crucial. Del mismo modo, inhibir respuestas inapropiadas es una habilidad crítica en nuestra vida diaria. La inhibición de respuesta puede definirse como un proceso encargado de controlar las respuestas automáticas o dominantes.

La tarea de vigilancia SART requiere inhibir la respuesta ante la presentación de estímulos impredecibles e infrecuentes, ya que invierte el patrón de respuesta característico de las tareas tradicionales de vigilancia en las que hay que detectar y responder a este estímulo objetivo. En la tarea SART, por tanto, se debe mantener la atención endógena para una inhibición eficaz de las respuestas automáticas o inapropiadas.

Además del efecto del paso del tiempo en tarea, la vigilancia fluctúa a lo largo del día. Por otra parte, existen diferencias individuales de cronotipo (matutino, intermedio, vespertino) que modulan nuestras funciones cognitivas. Sin embargo, normalmente los estudios no tienen en cuenta estas diferencias individuales. La diferencia entre los momentos de máxima eficiencia en la ejecución en función del cronotipo se conoce como efecto de sincronía.

Mientras que algunos estudios sugieren que los procesos de control se modulan por la hora del día y las diferencias individuales en cronotipo, otros sostienen que este efecto de sincronía se observa en procesos de carácter automático. En esta línea, se ha observado que la habilidad para inhibir respuestas inapropiadas en la tarea SART varía en función de la hora del día. Por el contario, la velocidad de respuesta, considerada el aspecto automático de la tarea, no mostró variaciones diurnas. Sin embargo, no se ha estudiado la influencia de la tipología circadiana en la ejecución de la tarea SART.

El estudio de la influencia de estos factores circadianos tiene importantes aplicaciones prácticas, por ejemplo, el diseño de jornadas laborales, evaluaciones neuropsicológicas o en educación, y por tanto para la salud y la seguridad en general. Asimismo, anticipar y predecir fallos de vigilancia que puedan acarrear consecuencias graves (como un accidente en el ámbito laboral debido) mediante índices fisiológicos también es de especial relevancia.

Por tanto, en la presente tesis estudiamos el efecto del paso del tiempo en tarea en la habilidad para inhibir respuestas inapropiadas y si es modulado por la influencia de la hora del día y las diferencias individuales de cronotipo. Por otra parte, investigamos la relación entre la ejecución en la tarea SART y medidas fisiológicas, concretamente, la actividad eléctrica cortical y la temperatura de la piel.

En el Estudio 1 investigamos el efecto del paso del tiempo en tarea en la habilidad para ininhibir respuestas automáticas o inapropiadas mediante un protocolo de hora del día. Es decir, evaluamos a los participantes a su hora óptima y no óptima en función de su cronotipo mientras siguen su horario y actividades habituales. Por otra parte, manipulamos la estrategia que debían adoptar los participantes (precisión, rapidez). En la estrategia precisión se priorizaba la exactitud (inhibir correctamente la respuesta) sobre la velocidad de respuesta, siendo por tanto el objetivo principal alcanzar altos niveles de exactitud. En la estrategia precisión, los participantes adoptaban un estilo de respuesta de carácter controlado. Por el contrario, en la estrategia rapidez se priorizaba la velocidad de respuesta sobre la inhibición de respuesta, adoptando un estilo de respuesta más automático.

Cuando se requería la participación de procesos de control (estrategia precisión) observamos el efecto de sincronía. Los participantes matutinos mostraron un deterioro en la habilidad para inhibir respuestas inapropiadas en la sesión de tarde mientras que los vespertinos mostraron un deterioro más acusado en la sesión de mañana en comparación con la sesión de tarde. Sin embargo, la ejecución en la tarea no fue modulada por el cronotipo y la hora del día cuando los participantes adoptaban un estilo de respuesta de carácter más automático (estrategia rapidez).

En el Estudio 2 nuestro objetivo fue explorar los cambios en la actividad eléctrica del cerebro asociados a la habilidad para inhibir respuestas inapropiadas con el paso del tiempo en tarea. Las sesiones experimentales se realizaron a una hora neutral (11:00 h). Los estudios con tareas go-nogo sugieren que los potenciales N2 y P3, con máxima amplitud en zonas frontocentrales cuando se requiere inhibir una respuesta, son índices del proceso inhibitorio. Los potenciales relacionados con el procesamiento en etapas tempranas en estudios con tareas go-nogo, como el P1 y el N1, reciben menos atención.

En la tarea SART se han observado los potenciales N2 y P3 cuando se debe inhibir la respuesta, y una mayor amplitud se ha relacionado con una inhibición más eficaz. Sin embargo, no se ha estudiado el curso temporal de los índices electrofisiológicos de la inhibición de respuesta con el paso del tiempo en la tarea SART. Con este objetivo, analizamos las ondas P1, N1, N2 y P3 para evaluar si el efecto del paso del tiempo influía específicamente en los procesos relacionados con la selección de respuesta y control cognitivo o también en etapas de procesamiento más tempranas.

Observamos una amplitud reducida con el paso del tiempo en N2 y P3. Nuestros resultados sugieren que la amplitud de las ondas N2 y P3 podrían ser índices de la eficiencia inhibitoria con el paso del tiempo en tarea. Además, la amplitud del N1 incrementó, fue más negativa, con el paso del tiempo en tarea. Este incremento en la amplitud del N1 podría reflejar una mayor dificultad de la discriminación perceptiva con el paso del tiempo. Sin embargo, no observamos una relación entre las medidas comportamentales de la tarea (exactitud para inhibir respuestas inapropiadas y velocidad de respuesta) y las medidas neurofisiológicas, posiblemente por el tamaño de la muestra en este estudio.

En el Estudio 3, nuestro interés residía en el estudio de un índice autonómico, la temperatura de la piel. El objetivo de esta serie experimental fue investigar si la temperatura de la piel podría ser un índice fiable y sensible de la ejecución en la tarea SART, con la ventaja de ser un método fácil y de bajo coste, portátil y no invasivo.

La temperatura de la piel, especialmente la temperatura proximal, se ha relacionado recientemente con respuestas más lentas y una mayor frecuencia de lapsus atencionales en una tarea de tiempo de reacción simple. Sin embargo, no se ha estudiado si esta relación temperatura-ejecución puede generalizarse a tareas de vigilancia más complejas que requieren control ejecutivo como la tarea SART. Por otra parte, no se ha investigado si las fluctuaciones en temperatura de la piel son selectivas a las demandas impuestas por la tarea que se realiza ni el curso temporal de la temperatura de la piel durante la tarea. Por tanto, llevamos a cabo dos experimentos. En el Experimento 1, los participantes asignados al grupo Tarea realizaron la tarea SART mientras que los participantes asignados al grupo No Tarea recibieron la misma estimulación sensorial pero no realizaron la tarea. Las sesiones se realizaron a una hora neutra (11:00 h) y se evaluó a participantes principalmente con cronotipo intermedio (es decir, participantes sin puntuaciones extremas en el cuestionario de Matutinidad-Vespertinidad). En el experimento 1 no observamos una relación entre temperatura de la piel y ejecución. Las temperaturas de la piel mostraron el patrón típico de la temperatura durante la mañana y nuestra manipulación de las demandas de tarea (Tarea, No Tarea) pudo no ser suficientemente robusta.

En el Experimento 2, se llevó a cabo una manipulación de las demandas de la tarea mediante el paradigma de doble tarea. Los participantes debían realizar dos tareas simultáneamente en la condición dual (SART y una tarea de conteo) y solo la tarea SART en la condición simple. En el experimento 2, las sesiones experimentales se realizaron a diferentes horas del día (9:00, 11:00, 13:00, 16:00, 18:00 y 20:00 h) para minimizar la influencia de los ritmos circadianos y mejorar la generalización de nuestros resultados. En el experimento 2, nuestros resultados sugieren que la temperatura proximal en particular podría ser un índice de la ejecución en tareas de vigilancia más complejas como la tarea SART, que requiere inhibición de respuesta. Un incremento en la temperatura proximal se relacionó con una mayor exactitud y una velocidad de respuesta más lenta, sugiriendo un estilo de respuesta de carácter más controlado con una temperatura proximal alta. Además, nuestros resultados mostraron por primera vez que la temperatura proximal fue sensible a las demandas de la tarea y al efecto del paso del tiempo. Sin embargo, futuras investigaciones deben estudiar la relación entre temperatura y ejecución y esclarecer su interpretación como índice fisiológico.

RESUMEN GENERAL

CAPITULO 1

Capítulo 2: Introducción

CAPITULO 2

A diario realizamos actividades en las que mantener la atención durante un periodo de tiempo relativamente largo es crucial, una importante función atencional a la que denominamos vigilancia o atención sostenida. Por ejemplo, cuando conducimos necesitamos atender durante todo el recorrido para evitar posibles situaciones de riesgo. Sin embargo, nuestra habilidad para mantener la atención no es constante y no puede mantenerse indefinidamente.

Volviendo al ejemplo anterior, a veces no reaccionamos cuando la luz del semáforo pasa a ser verde. Sin embargo, las demandas de la situación pueden ser distintas y ocasionar consecuencias más negativas que el enfado de otros conductores. A pesar de que la luz verde del semáforo nos da paso, es posible que en ese momento un vehículo o un peatón invadan nuestro carril. En este caso, la acción apropiada no es acelerar para seguir con nuestro recorrido como de costumbre, sino frenar para evitar una situación peligrosa. Un nivel atencional bajo ante estas situaciones compromete nuestra seguridad y la de otros. Con el paso del tiempo realizando una tarea monótona como la conducción, mantener la atención puede ser complicado. Durante trayectos largos es habitual que experimentemos fatiga o somnolencia. Por otra parte, todos sabemos que conducir por la noche entraña mayores riesgos, la fatiga o somnolencia pueden ser más intensas y tenemos un bajo nivel atencional. Estas variaciones diurnas difieren incluso entre personas, por lo que podemos encontrarnos en una situación de mayor o menor vulnerabilidad en función de la hora del día.

Aunque hemos centrado nuestro ejemplo en el ámbito de la seguridad vial, la importancia de estas fluctuaciones en atención se extiende a otros contextos como el de los profesionales sanitarios (por ejemplo, un cirujano durante una operación), el rendimiento académico (atender en clase) o la supervisión de procesos industriales (supervisor de una central nuclear o un operario de una cadena de producción), por citar algunos ejemplos. En este sentido, podemos considerar estas fluctuaciones del nivel de vigilancia como un problema de naturaleza práctica.

1.1. Vigilancia

La vigilancia hace referencia a nuestra habilidad para mantener el foco de atención y permanecer alerta durante periodos de tiempo prolongado (Davies & Parasuraman, 1982; Warm, Parasuraman, & Matthews, 2008). Aunque en la literatura encontramos distintos términos asociados al concepto de vigilancia como atención sostenida, alerta tónica o atención vigilante (Posner, 2008; Robertson & Garavan, 2004; Robertson & O´Connell, 2010), a lo largo de este trabajo utilizaremos indistintamente vigilancia y atención sostenida para hacer referencia a la función atencional encargada de optimizar el procesamiento de la información durante un periodo de tiempo continuado.

Los primeros estudios sistemáticos sobre la vigilancia comienzan con los trabajos de Norman Mackworth sobre los fallos de los observadores de radar para detectar señales que advertían la presencia de submarinos enemigos durante la II Guerra Mundial. Mackworth trasladó este problema al laboratorio y diseñó su conocida "prueba del reloj", un radar simulado donde los observadores debían detectar y responder durante aproximadamente 2 horas ininterrumpidas a una señal infrecuente, definida por un salto doble en lugar de simple, en la aguja de un reloj. La investigación realizada por Mackworth reveló uno de los hallazgos más importantes en la literatura sobre vigilancia: durante los 30 primeros minutos de tarea se observaba un declive en la detección de señales críticas que continuaba gradualmente durante el resto de la tarea. Este efecto del paso del tiempo en tarea se conoce como decremento de vigilancia (Mackworth, 1948). A partir de su trabajo, la investigación sobre vigilancia se centró en estudiar bajo qué condiciones ocurría el decremento de vigilancia mediante tareas de larga duración consideradas monótonas y aburridas.

Mackworth definió la vigilancia como "un estado de preparación para detectar y responder a cambios en el entorno que ocurren en intervalos de tiempo aleatorio" (Mackworth, 1957; cf. Parasuraman, Warm, & See, 1998; p. 221). Ya en esta definición de vigilancia se hace referencia a su estrecha relación con la activación fisiológica o arousal (entendido como estado de receptividad o preparación del sistema nervioso a la estimulación; Kahneman, 1973).

La habilidad para mantener la atención y ejecutar de manera eficiente una tarea de vigilancia requiere la activación focalizada de áreas cerebrales y, por tanto, se relaciona con el arousal cortical. Sin embargo, la interpretación de estas medidas fisiológicas necesita definirse con medidas comportamentales (Sarter, Givens, & Bruno, 2001). Como índices fisiológicos del nivel de arousal podemos considerar los registros de actividad electrocortical mediante electroencefalografía (EEG), o las medidas de dominancia simpática como la actividad cardíaca o electrodérmica. En cuanto a las medidas comportamentales, las tareas tradicionales de vigilancia requieren la detección de un estímulo que aparece con escasa frecuencia y que es impredecible durante un largo periodo de tiempo. Los índices comportamentales que reflejan el decremento de vigilancia normalmente son el enlentecimiento de los tiempos de reacción y/o la disminución de señales críticas detectadas (Davies & Parasuraman, 1982).

CAPITULO 2

Dos teorías han destacado en la literatura a la hora de explicar el decremento de vigilancia, la Teoría del Arousal y la Teoría de los Recursos. La primera de ellas asume una relación directa, causal, entre arousal y ejecución. La segunda, sin embargo, asume una relación más compleja.

La *Teoría del Arousal* considera que hay un nivel óptimo de activación por encima y por debajo del cual la ejecución empeora, y que decrece con el paso del tiempo en tarea (Loeb & Allusi, 1980). La hipótesis del arousal asume que las demandas de procesamiento de la información en tareas de vigilancia son bajas. El decremento de vigilancia se debe a una habituación por la falta de estimulación, necesaria para mantener un nivel de activación fisiológica óptimo y, por tanto, una ejecución eficiente. Es decir, debido a la estimulación repetitiva de las tareas de vigilancia, a su naturaleza monótona, la ejecución decae en paralelo con el nivel de arousal.

Por el contrario, para *la Teoría de los Recursos* (hipótesis de la fatiga) las tareas de vigilancia imponen altas demandas de procesamiento de la información y se relacionan con altos niveles de estrés y carga mental debido a que la cantidad de información que podemos procesar es limitada (Grier, et al., 2003; Warm, Parasuraman, & Matthews, 2008). Es decir, mantener la atención cuando una tarea no es novedosa requiere un alto esfuerzo cognitivo. Esta teoría predice que cuando las demandas de la tarea exceden los recursos atencionales disponibles, por ejemplo por la dificultad de la tarea o por realizar tareas simultáneamente, la ejecución empeora (Davies & Parasuraman, 1982; Warm, Parasuraman, & Matthews, 2008). Con el paso del tiempo haciendo una tarea los recursos disminuyen y, debido a las demandas impuestas de manera continua, no es posible reemplazarlos y se produce un decremento en la eficiencia con la que ejecutamos la tarea.

La investigación sobre vigilancia se ha centrado tradicionalmente en el estudio del deterioro en la ejecución mediante tareas de larga duración. Recientemente, Robertson y colaboradores (1997) proponen una medida alternativa para el estudio de la atención sostenida o vigilancia, los lapsus atencionales o fallos transitorios de la atención. La *Teoría de la distracción* (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) propone que estos fallos atencionales se deben a una falta de atención endógena, que debe mantenerse en ausencia de estimulación exógena debido a la naturaleza repetitiva y aburrida de las tareas de vigilancia. Desde esta perspectiva, los decrementos de vigilancia son el resultado de la retirada de control consciente o voluntario debido a las escasas demandas de procesamiento de la información propias de las tareas de vigilancia.

Robertson y colaboradores (1997) desarrollaron la tarea SART (Sustained Attention to Response Task) como una medida sensible de fallos transitorios de la atención. En esta tarea "go-nogo" de corta duración (4,3 minutos aproximadamente) se debe responder tan rápido como sea posible a la presentación aleatoria de números del 1 al 9 (ensayos go), pero no hay que responder cuando se presenta el número 3 (ensayos no-go). La tarea SART invierte el patrón de respuesta típico de las tareas de vigilancia y presenta un alto porcentaje de ensayos go en relación con ensayos no-go, por lo que induce una tendencia a automatizar la respuesta. Por tanto, se debe mantener la atención endógena para controlar la respuesta automática inducida durante los ensayos go y no responder en los ensayos no-go.

Normalmente, en las tareas go-nogo, la medida por excelencia son las falsas alarmas o errores en los ensayos no-go. Según Robertson y colaboradores (1997), estos errores pueden ocurrir debido a un fallo del mantenimiento óptimo de la atención durante la tarea, por las fluctuaciones de la vigilancia. La sensibilidad de la tarea SART como medida de vigilancia o atención sostenida así como su validez ecológica se apoya en medidas comportamentales de la pérdida de atención voluntaria como la aceleración de la respuesta antes de un error, la relación entre la ejecución y medidas subjetivas sobre la predisposición a fallos atencionales (“Cognitive Failures Questionnaire” –CFQ- de Broadbent,1982) y su capacidad para distinguir entre población clínica (pacientes con lesión frontal por traumatismo craneoencefálico) y no clínica.

Por tanto, la tarea SART proporciona una medida de la habilidad para mantener el control ejecutivo para inhibir la respuesta durante un periodo de tiempo determinado. El control inhibitorio es una función ejecutiva fundamental que permite filtrar y suprimir la información relevante para evitar la interferencia e inhibir respuestas dominantes. En la presente tesis nos centraremos especialmente en la respuesta de inhibición de la tarea SART como índice de control. La inhibición de respuesta puede definirse como un proceso encargado de controlar las respuestas automáticas.

La ejecución óptima en la tarea SART se relaciona por tanto con la capacidad del mecanismo de supervisión y regulación de la atención voluntaria o sistema ejecutivo central. Según Norman y Shallice (1986) este mecanismo se activa en situaciones que requieren planificación y toma de decisiones, solución de problemas, no aprendidas o novedosas, o cuando es necesario inhibir respuestas habituales que son inapropiadas, permitiendo que nuestro comportamiento sea flexible en función de nuestros objetivos. Las regiones prefrontales se consideran el sustrato anatómico del control ejecutivo (Cohen & Miller, 2001), por eso esta tarea es sensible a pacientes con lesión frontal (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Manly et al., 2003).

Los estudios de neuroimagen y neuropsicológicos sugieren que la base neural de la vigilancia o atención sostenida se encuentra principalmente localizada en las áreas frontales y parietales del hemisferio derecho, la corteza cingulada anterior, el tálamo y el tallo cerebral (Posner & Petersen, 1990; Posner, 2008; Paus, et al., 1997; Coull, Frackowiak, & Frith, 1998). Estudios de neuroimagen con la tarea SART han observado la activación de esta red frontoparietal derecha (Manly et al., 2003).

Las fluctuaciones en el nivel de vigilancia, reflejadas en los índices comportamentales, no solo se observan en la escala temporal de las tareas de vigilancia (de minutos a horas) sino también a lo largo del día (Posner, 2008).

1.2. Influencias circadianas en la vigilancia

Nuestras funciones biológicas muestran variaciones cíclicas que se repiten día a día. Desde un punto de vista evolutivo, estas fluctuaciones diarias son una respuesta adaptativa, nos permiten anticipar y adaptarnos a cambios en el ambiente. Por ejemplo, nos aseguran el descanso o el ahorro de energía. Estas variaciones diarias se conocen como ritmos circadianos y se definen como fluctuaciones de variables biológicas con un periodo en torno a las 24 horas. El ciclo sueño-vigilia o la temperatura corporal son ejemplos de estos ritmos biológicos. Los ritmos circadianos los genera un mecanismo endógeno (el reloj biológico o marcapasos) situado en el Núcleo Supraquiasmático (NSQ) del hipotálamo y se sincronizan con factores ambientales (zeitgebers o sincronizadores) como el ciclo de luz-oscuridad o los horarios sociales (Roenneberg, Wirz-Justice, & Merrow, 2003). El NSQ proyecta indirectamente (vía Núcleo Hipotalámico Dorsomedial) al Locus Coeruleus, regulando el ritmo circadiano de la actividad noradrenérgica relacionada con la vigilia y el estado de alerta (Aston-Jones, Chen, Zhu, & Oshinsky, 2001; Aston-Jones & Cohen, 2005).

El Locus Coeruleus forma parte del Sistema Activador Reticular Ascendente, implicado en la regulación de los ciclos sueño-vigilia. Las proyecciones noradrenérgicas del Locus Coeruleus se distribuyen ampliamente en el cerebro, e influye en áreas frontales relacionadas con importantes funciones cognitivas como la memoria y la atención (Sara, 2009).

Numerosos estudios observan variaciones diurnas en funciones cognitivas (véase para una revisión, Schmidt, Collette, Cajochen, & Peigneux, 2007; Blatter & Cajochen, 2007). Asimismo, se ha observado una modulación de la hora del día en la activación de regiones frontales (Vanderwalle, et al., 2009).

La influencia de los ritmos circadianos puede ser estudiada con tareas atencionales como la SART. Manly y colaboradores (2002) observaron una modulación de la hora del día en la inhibición de respuestas mediante esta tarea. Concretamente, la exactitud (inhibir correctamente la respuesta en los ensayos nogo) de los participantes fue mayor en las sesiones de tarde (a las 13 h y 19 h) y menor durante las primeras horas de la mañana y la noche (a las 7 h y 1 h, respectivamente). Por otra parte, el componente más automático de la tarea, la velocidad de respuesta en los ensayos go, no fue modulado por la hora del día (Manly, Lewis, Robertson, Watson, & Datta, 2002). Sin embargo, Manly y colaboradores (2002) no tuvieron en cuenta las diferencias individuales en relación con la tipología circadiana de los participantes.

Las variaciones diurnas en la ejecución de tareas cognitivas pueden ser evaluadas con mayor precisión si tenemos en cuenta el cronotipo o tipología circadiana. Las personas se pueden clasificar a lo largo de una dimensión de Matutinidad-Vespertinidad en tres grupos de cronotipos: matutinos, intermedios y vespertinos. Las personas con cronotipo matutino se levantan y acuestan pronto y presentan sus máximos de actividad en la primera mitad del día. Por el contrario, las personas con cronotipo vespertino se levantan y acuestan tarde y sus máximos de actividad se producen al final de la tarde o incluso en las primeras horas nocturnas. Las personas intermedias no muestran una preferencia clara con respecto a sus hábitos de sueño y el horario para realizar actividades (Adan, 2006).

El cuestionario más utilizado para clasificar a las personas en función de su cronotipo es el de Horne y Östberg (Morningness-Eveningness Questionnaire –MEQ-; 1976). Una versión reducida del MEQ ha sido estandarizada en población española para evaluar cronotipo (rMEQ; Adan & Almirall, 1991). La Matutinidad-Vespertinidad puede ser también evaluada en adolescentes mediante la escala MESC (Morningness-Eveningness Scale for Children) adaptada al español (Díaz-Morales & Gutiérrez, 2008). Los estudios en personas adultas muestran que un 60% de la población tiene un cronotipo intermedio mientras que los cronotipos extremos representan el 40 % de la población. Los adolescentes generalmente presentan un sesgo hacia la vespertinidad, siendo las chicas las que muestran una mayor tendencia a la vespertinidad (Adan, Natale, & Caci, 2008; Díaz-Morales & Sorroche, 2008; Díaz-Morales, 2015).

La dimensión Matutinidad-Vespertinidad describe diferencias individuales, que tienen una base genética (Katzenberg, et al., 1998), en función de ritmos circadianos de variables biológicas y psicológicas, como se observa en el pico circadiano o acrofase de la temperatura (Kerkhof, 1985; Kerkhof & van Dongen, 1996; Adan et al., 2012). Baehr, Revelle y Eastman (2000) observaron que el valor mínimo más tardío de temperatura se asociaba con un horario de sueño más tardío y con puntuaciones claramente vespertinas en el cuestionario de cronotipo. La temperatura mínima media de los participantes matutinos presentaba un avance de fase de dos horas con respecto a los vespertinos (Baehr, Revelle, & Eastman, 2000).

Con una especial relevancia para nuestra investigación, la ejecución de tareas cognitivas dependen de la hora del día a la que se realizan y de la tipología circadiana. Así, alcanzamos nuestro máximo rendimiento a nuestra hora óptima: *efecto de sincronía* (May & Hasher, 1998). Cuando el efecto de sincronía ocurre, se observa un mayor grado de eficiencia en la ejecución de las personas matutinas durante la mañana y de las personas vespertinas por la tarde. Es decir, el cronotipo se relaciona con las diferencias horarias en los momentos óptimos de las capacidades de ejecución (Adan, 2006).

Algunos estudios han analizado cómo varían los procesos de control en función de la tipología circadiana y el momento de realización de la tarea. Estudios con tareas de memoria sugieren que el efecto de sincronía ocurre en procesos de carácter controlado más que automático (May, Hasher, & Foong, 2005). May y colaboradores (2005) realizaron un estudio en el que utilizaron una tarea para medir el recuerdo implícito y explícito de los participantes que consistía en completar raíces de palabras, bien con la primera palabra que llegase a su mente (tarea de recuerdo implícito) o con palabras utilizadas durante la fase de aprendizaje (tarea de recuerdo explícito). Estas autoras observaron el típico efecto de sincronía en la tarea de memoria explícita, recordando más palabras por la mañana los participantes con cronotipo matutino y por la tarde los vespertinos. Estos resultados son consistentes con el estudio de Manly y colaboradores (2002), donde la habilidad para inhibir respuestas inapropiadas fue modulada por la hora del día.

A pesar de las citadas evidencias a favor de que los procesos de control son modulados por la influencia de los ritmos circadianos, no existe un acuerdo general sobre la relación entre ritmos circadianos, procesos de control y procesos automáticos. Natale y colaboradores (2003) observaron el efecto de sincronía en las respuestas afirmativas (presencia del estímulo objetivo) de una tarea de búsqueda visual, con una mayor velocidad de respuesta los participantes matutinos por la mañana y los participantes vespertinos por la tarde. Sin embargo, no lo observaron en tareas de razonamiento lógico, espacial y matemático (Natale, Alzani, & Cicogna, 2003). Por otra parte, Bennett y colaboradores (2008), observaron el efecto de sincronía en la Wisconsin Card Sorting Task (WCST), una tarea que demanda procesos de control ejecutivo, pero no en pruebas como la CPT (Continuous Performance Test), amplitud de dígitos (WAIS-III) y la COWAT (Controlled Oral Word Association Task; Bennet, Petros, Johnson, & Ferraro, 2008). Con el objeto de aclarar esta divergencia de resultados, en la presente tesis estudiamos el efecto de sincronía con la tarea SART, ya que permite evaluar cómo varían los índices de procesamiento automático (velocidad de respuesta en los ensayos go) y de procesamiento controlado (proporción de inhibiciones correctas en los ensayos no go) bajo el mismo contexto experimental dentro de la misma tarea.

El estudio de la influencia de la hora del día y las diferencias individuales en cronotipo es importante para la evaluación de funciones cognitivas, tanto en un contexto experimental como clínico, debido al impacto negativo o favorable de la interacción de ambos factores circadianos. En este sentido, el menoscabo de la atención en situaciones de vigilancia puede agravarse cuando la evaluación se realiza a una hora del día que no es óptima de acuerdo a nuestro cronotipo. El estudio conjunto de la influencia de la hora del día y el cronotipo, por tanto, conlleva importantes aplicaciones prácticas para el campo de la vigilancia, puesto que nuestra vulnerabilidad a los efectos del paso del tiempo en tarea podría modularse por nuestro cronotipo y la hora del día.

En esta línea, el estudio de medidas fisiológicas como índices de las fluctuaciones en vigilancia mediante métodos no invasivos es de especial relevancia para la investigación aplicada y para la presente tesis, ya que el nivel de vigilancia determina la eficiencia con la que realizamos una gran variedad de tareas cotidianas. La investigación sobre predictores sensibles de la ejecución en situaciones que requieren vigilancia nos puede ayudar a anticipar fallos en la vigilancia y a prevenir sus consecuencias negativas.

1.3. Marcadores fisiológicos de la vigilancia: Electroencefalografía y temperatura de la piel

Como comentábamos al principio de la presente tesis, tanto medidas fisiológicas centrales como periféricas se han propuesto como marcadores de la vigilancia. Sin embargo, muchas de estas medidas no son ergonómicas y adecuadas para estudios de campo, como es el caso de técnicas de neuroimagen como la imagen por Resonancia Magnética Funcional (iRMF) o la Tomografía por Emisión de Positrones (TEP; Mehta & Parasuraman, 2013), que aún no son portátiles y requieren la inmovilización del sujeto.

Recientemente, la espectroscopia funcional por luz cercana al infrarrojo (fNIR) y la sonografía transcraneal Doppler (TCD) se han propuesto como herramientas útiles para medir el estado cognitivo en situaciones de la vida real. Mediante TCD se ha observado que el deterioro en la ejecución de tareas de vigilancia se acompaña de un declive en la velocidad del flujo sanguíneo cerebral del hemisferio derecho (Warm & Parasuraman, 2007; Warm, Matthews & Parasuraman, 2009), consistente con la lateralización de la red neural de la vigilancia (Posner & Petersen, 1990; Posner, 2008).

En la presente tesis, nos centraremos en el estudio de dos posibles marcadores fisiológicos: la electroencefalografía (EEG) y la temperatura de la piel. El registro de actividad eléctrica cerebral mediante la técnica de potenciales evocados relacionados con eventos (ERP en inglés) es una técnica neurofisiológica objetiva que permite una medida continua y en tiempo real de las etapas de procesamiento de la información debido a su alta resolución temporal. Aunque el desarrollo tecnológico está propiciando un mayor uso ergonómico del EEG, sin cables y portátil, su aplicación en estudios de campo es aún costosa y no está muy extendida en la literatura. Por este motivo la presente tesis pretende innovar en este campo con la propuesta de una medida más ergonómica que el EEG, la temperatura de la piel.

La temperatura de la piel permite una monitorización continua durante largos periodos de tiempo y es una medida no invasiva, portátil, de bajo coste y muy fácil aplicación. Esta medida se ha utilizado ampliamente en el estudio de las variaciones circadianas, incluyendo su relación con la ejecución de tareas sencillas de tiempo de reacción. Sin embargo, aún se desconoce la viabilidad de su aplicación para estudiar su relación con la ejecución de tareas cognitivas más complejas (por ejemplo, que requieran el control inhibitorio de respuestas) a lo largo de una tarea (es decir en un contexto temporal mucho más corto que los periodos circadianos). En esta tesis precisamente nos proponemos evaluar las ventajas y limitaciones del registro de la temperatura de la piel para inferir el estado cognitivo de las personas que realizan una tarea de vigilancia.

1.3.1. La temperatura corporal

La temperatura corporal no es constante a lo largo del día, sino que se encuentra sujeta a una modulación circadiana. Concretamente, el NSQ lleva a cabo el ajuste del ritmo circadiano de la temperatura, mientras que el Área Preóptica, situada también en el Hipotálamo, se encarga de su mantenimiento dentro de unos valores fisiológicos óptimos. A través del flujo sanguíneo, el calor es canalizado hacia las zonas distales y proximales. En las regiones distales se encuentran las anastomosis arteriovenosas, conexiones directas entre las arterias y las venas que hacen posible la conservación y la pérdida de calor. La disminución de la temperatura central es el resultado de la pérdida de calor debido al incremento de la vasodilatación distal, que conlleva un aumento de la temperatura periférica de la piel (Kräuchi, Cojechen, & Wirz-Justice, 2005; Kräuchi, 2007).

La temperatura corporal central es un marcador robusto del sistema circadiano. La temperatura central muestra una relación inversa a la temperatura de la piel distal durante el ciclo circadiano. El valor mínimo de temperatura central (nadir) tiene lugar durante la noche debido a una disminución de la producción de calor y una vasodilatación en las zonas distales del cuerpo (es decir, un mayor flujo sanguíneo que se traduce en un aumento de la temperatura distal). Al atardecer, la temperatura central y la proximal disminuyen progresivamente mientras que la temperatura distal va aumentando (Kräuchi, Cajochen, & Wirz-Justice, 1997; Kräuchi & Wirz-Justice, 2001; Kräuchi, 2007).

El aumento de la temperatura distal se ha propuesto como un mecanismo clave que favorece la somnolencia a medida que la temperatura central baja. Es decir, el factor clave en el inicio del sueño es la vasodilatación de las regiones distales de la piel. En esta línea, se ha sugerido que las dificultades para una vasodilatación apropiada pueden ser la causa fisiológica de algunas alteraciones del sueño, especialmente en la vejez (Ancoli-Israel et al., 1986; Van Someren, 2000; Pache et al., 2001). La pérdida de calor normalmente se mide mediante el gradiente distal-proximal o GDP (Kräuchi & Wirz-Justice, 1994; Krauchi, 1999; Kraüchi et al., 2000; Kräuchi & Wirz-Justice, 2001; Kräuchi, 2007).

En general, el menor nivel de alerta coincide con el valor mínimo de temperatura central y máximo de la temperatura distal, en las horas centrales del sueño, entre las 3 y las 6 de la madrugada (Gradisar & Luck, 2004). En condiciones normales, la temperatura corporal y la ejecución en tareas de tiempo de reacción simple presentan un patrón circadiano, observándose en ambos altos niveles durante la vigilia y bajos niveles durante la noche (Kleitman & Jackson, 1950; Wrigth, Hull, & Czeisler, 2002; Blatter & Cajochen, 2007). Por tanto, combinar medidas comportamentales y fisiológicas como la temperatura corporal nos puede proporcionar una estimación objetiva y más completa del grado de eficiencia con que las personas se enfrentan a situaciones que requieren una vigilancia óptima.

Recientemente, Romeijn y colaboradores (2011) han observado que las fluctuaciones en temperatura podrían considerarse un predictor de la ejecución en una tarea de tiempo de reacción simple. Los incrementos en la temperatura distal, la temperatura proximal en particular, y su gradiente distal-proximal, se relacionaron con tiempos de reacción más lentos y una mayor frecuencia de lapsus atencionales (Romeijn & Van Someren, 2011). En estudios en los que se ha manipulado experimentalmente la temperatura corporal también se ha observado esta relación. Raymann y colaboradores (2007) observaron que un incremento en la temperatura proximal mediante la ingesta de bebidas calientes aceleraba el decremento de vigilancia en la Tarea de Vigilancia Psicomotora (PVT; Raymann & Van Someren, 2007).

El estudio de la temperatura periférica es más reciente. La temperatura distal es de gran relevancia en la regulación de la temperatura central, lo que aporta evidencia a favor de su origen endógeno (Sarabia, Rol, Mendiola & Madrid, 2008). Sarabia y colaboradores (2008) proponen que la temperatura de la muñeca es un índice fiable de la ritmicidad circadiana, con la ventaja añadida de que es una medida fácil de registrar y de bajo coste, lo que la convierte en una medida ideal para el diseño de dispositivos ergonómicos y el estudio de correlatos fisiológicos de la vigilancia en contextos naturales.

1.3.2. Electroencefalografía (EEG)

La electroencefalografía (EEG) es una medida potencialmente viable para el estudio de las fluctuaciones en vigilancia puesto que detecta cambios en tiempo real. Los potenciales evocados son oscilaciones transitorias en el voltaje del cerebro en respuesta a un evento. Esta técnica permite una medida continua del procesamiento entre un estímulo y una respuesta (e incluso en ausencia de la respuesta) mediante la que podemos determinar qué etapa del procesamiento en concreto se ve afectada por nuestra manipulación (Luck, 2005).

En las tareas go-nogo, dos potenciales con una distribución fronto-central se han relacionado con la inhibición de respuesta, el N2 y el P3 (Eimer, 1993; Falkenstein et al., 1999). La distribución en regiones frontales del P3 durante la inhibición de respuestas en tareas go-nogo, se conoce como efecto de anteriorización del P3 (Fallgatter et al., 1999). Los potenciales N2 y P3 se han observado en la tarea SART cuando se requiere inhibir la respuesta (Zordan et al., 2008). Los errores de inhibición en la tarea SART se han relacionado con una amplitud atenuada del N2 y P3 (O'Connel et al., 2009). Aunque los potenciales relacionados con etapas más tempranas del procesamiento reciben menos atención, algunos estudios han observado una amplitud más negativa del N1 en regiones posteriores cuando se requiere inhibir una respuesta (Kirmizi-Astan et al., 2006) así como una modulación en su amplitud en función de la dificultad de la tarea, asociándose una amplitud más negativa a un mayor grado de dificultad (Benikos et al., 2013).

Pocos estudios han investigado el efecto del paso del tiempo en tareas go-nogo. Kato y colaboradores (2009) observaron que la amplitud del P3 cuando se requiere inhibir un respuesta es sensible a los efectos del paso del tiempo en una tarea go-nogo espacial. La amplitud del P3 se atenuó con el paso del tiempo en tarea, sugiriendo que la asignación de recursos empeora conforme avanza la tarea (Kato, Endo, & Kizuka, 2009). Smit y colaboradores (2004), aunque no estudiaron la actividad cerebral asociada al efecto del paso del tiempo en tarea, observaron que la tarea SART es sensible al efecto de fatiga. En concreto, un incremento en la actividad theta (relacionado con un nivel más bajo de vigilancia) y en los errores en la tarea SART debido al efecto de fatiga inducido por un periodo de esfuerzo anterior a la ejecución de la tarea (Smit, Eling, & Coenen, 2004).

En este sentido, en la presente tesis estamos interesados en el estudio de los cambios en la actividad electrocortical asociados al efecto del paso del tiempo durante la realización de una tarea que requiere mantener la atención para inhibir la respuesta ante la presentación de estímulos impredecibles e infrecuentes, la SART.

Como conclusión, en esta tesis profundizaremos en el estudio de las fluctuaciones de la capacidad para controlar respuestas inapropiadas a lo largo de una tarea prolongada de vigilancia. Concretamente estamos interesados en conocer si estas fluctuaciones 1) dependen de factores circadianos como la hora del día y el cronotipo de los participantes, y 2) se pueden predecir mediante el registro de índices fisiológicos. Una implicación práctica de esta investigación consiste en poder diseñar horarios óptimos de realización de trabajos prolongados donde la comisión de errores conlleva un riesgo para la salud, ajustados al perfil circadiano del trabajador. En caso de que los horarios laborales no permitan tal flexibilidad, el diseño de dispositivos ergonómicos que monitoricen el estado cognitivo de los trabajadores basados en marcadores fisiológicos como el EEG o la temperatura corporal podría minimizar dicho riesgo.

Capítulo 3: Planteamiento de la Investigación. Objetivos de la Tesis

CAPITULO 3

Como hemos comentado anteriormente, mantener la atención es una función atencional crucial en nuestra vida diaria. El deterioro en la eficiencia de la ejecución con el paso del tiempo en tareas de vigilancia ocupa un lugar central en la investigación sobre vigilancia.

Además del efecto del paso del tiempo en tarea, la vigilancia fluctúa a lo largo del día y existen diferencias individuales de cronotipo que modulan nuestras funciones cognitivas. Sin embargo, normalmente los estudios no tienen en cuenta estas diferencias individuales. La diferencia entre los momentos o picos de máxima eficacia en función del cronotipo se conoce como efecto de sincronía.

Por otra parte, no existe consenso entre la relación entre hora del día, cronotipo y procesos de control frente a automáticos. Algunos estudios sugieren que los procesos de control y no los automáticos se modulan por la hora del día y las diferencias individuales en cronotipo, sin embargo, otros sostienen que este efecto de sincronía también se observa en procesos de carácter automático.

El estudio de la influencia de estos factores circadianos en nuestras funciones cognitivas puede ser de gran utilidad práctica en numerosos contextos, por ejemplo, en el diseño de horarios laborales, evaluaciones neuropsicológicas o en educación, y por tanto conlleva beneficios para la salud y la seguridad en general.

Del mismo modo, anticipar y predecir fallos en vigilancia que puedan acarrear consecuencias graves (por ejemplo accidentes laborales) en contextos naturales es un importante objetivo práctico de la investigación sobre vigilancia, y uno de los principales propósitos de la disciplina conocida como Neuroergonomía. El interés de la

Neuroergonomía reside en el estudio del cerebro humano en relación con situaciones naturales o de la vida diaria, con especial énfasis en su interacción con la tecnología y el trabajo. En Neuroergonomía, el estudio de variables fisiológicas como predictores del estado cognitivo tiene como fin el diseño de dispositivos pórtatiles que permitan una evaluación continua, fiable y sensible.

La presente tesis doctoral consta de dos objetivos principales. En primer lugar, estudiar el efecto del paso del tiempo en tarea en la habilidad para inhibir respuestas dominantes pero inapropiadas e investigar la influencia de la hora del día y las diferencias individuales de cronotipo. En segundo lugar, estudiar marcadores fisiológicos asociados a la eficiencia en la ejecución de la tarea SART. En concreto, la actividad eléctrica del cerebro asociada a la inhibición correcta de respuestas mediante la técnica de potenciales evocados y la temperatura de la piel, una medida portátil, no invasiva, de bajo coste y que permite registros de larga duración.

Objetivo 1. Efecto del paso del tiempo en tarea en la habilidad para inhibir respuestas inapropiadas e influencia de factores circadianos

La tarea de vigilancia SART proporciona un índice de inhibición de respuestas, ya que invierte el patrón característico de las tareas tradicionales de vigilancia (mayor proporción de ensayos go frente a baja proporción de ensayos no go). En esta tarea, para inhibir eficazmente la respuesta, se requiere mantener la atención endógena. La tarea SART es una tarea de corta duración (4.3 minutos aproximadamente). En la presente tesis prolongamos la duración de la tarea SART para estudiar el efecto del paso del tiempo en tarea.

Se ha observado que la habilidad para inhibir respuestas inapropiadas en la tarea SART es modulada por la hora del día. Por el contrario, la velocidad de respuesta, considerada el índice comportamental que refleja el componente automático de la tarea, no mostró variaciones circadianas (Manly, Lewis, Robertson, Watson, & Datta, 2002). Sin embargo, no se ha estudiado la influencia del cronotipo en la ejecución de la tarea SART.

En este primer estudio utilizamos un protocolo de hora del día para estudiar si el efecto del paso del tiempo en tarea en la ejecución de la tarea SART es modulado por la hora del día y las diferencias individuales de cronotipo. Por tanto, evaluamos a los participantes a su hora óptima (mañana para los matutinos y tarde para los vespertinos) y no óptima en función de su cronotipo mientras seguían su horario y actividades habituales. Por otra parte, en función de las instrucciones dadas en los bloques experimentales que componen la tarea, manipulamos la estrategia que debían adoptar los participantes (precisión, rapidez) siguiendo un diseño intrasujeto. En la estrategia de Precisión se priorizaba el control inhibitorio de la respuesta sobre la velocidad, siendo el objetivo principal alcanzar altos niveles de exactitud. De esta manera los participantes adoptan un estilo de respuesta que demanda mayor control ejecutivo. Por el contrario, en la estrategia de Rapidez se prioriza la velocidad sobre la inhibición de respuesta, adoptando un estilo de respuesta más automático.

En primer lugar, esperábamos observar el efecto de sincronía en la estrategia Precisión, es decir, cuando se requiere la participación de procesos de control. Además esperábamos un mayor número de errores de comisión con el paso del tiempo en la hora no óptima de los participantes. Por el contrario, la ejecución en la estrategia Rapidez, no mostraría un efecto del paso del tiempo en tarea ni sería modulada por la hora del día y el cronotipo.

Nuestros resultados mostraron un efecto de sincronía cuando se requeria la participación de procesos de control, en la estrategia Precisión. Los participantes matutinos mostraron una menor en la habilidad exactitud para inhibir respuestas inapropiadas con el paso del tiempo en la sesión de tarde mientras que los vespertinos mostraron un efecto del paso del tiempo más acusado en la sesión de mañana en comparación con la sesión de tarde. Por el contario, la ejecución en la tarea no fue modulada por el cronotipo y la hora del día cuando los participantes adoptaban un estilo de respuesta de carácter automático (estrategia Rapidez).

Puesto que observamos que la habilidad para mantener una respuesta de inhibición eficaz empeora con el paso del tiempo en tarea, nos propusimos replicar este resultado en el Estudio 2 mediante una versión de larga duración de la tarea SART y explorar los cambios en la actividad eléctrica del cerebro asociados al efecto del paso del tiempo en la inhibición de respuestas mediante la técnica de potenciales evocados.

2. Marcadores fisiológicos asociados a la ejecución de la tarea SART: EEG y temperatura de la piel

2.1. Correlatos electrocorticales del efecto del paso del tiempo en la inhibición de respuestas inapropiadas

El objetivo de este estudio fue investigar el curso temporal de los potenciales asociados a procesos de inhibición de respuesta con el fin de establecer un índice neurofisiológico del efecto del paso del tiempo en inhibición de respuesta. En el Estudio 1 observamos que el efecto del paso del tiempo es modulado por la hora del día y el cronotipo. Por tanto, en el Estudio 2, realizamos las sesiones a una hora neutral (11:00 h) para evaluar a participantes principalmente con cronotipo intermedio.

Los estudios con tareas go-nogo sugieren que las ondas N2 y P3, con máxima amplitud en zonas frontocentrales cuando se requiere inhibir una respuesta, son índices del proceso inhibitorio. Zordan y colaboradores (2008) observaron estos potenciales asociados a la inhibición de respuesta en la tarea SART (Zordan, Sarlo, & Stablum, 2008). Asimismo, una mayor amplitud del N2 y P3 en la tarea SART se ha relacionado con una inhibición eficaz (O´Connell, et al., 2009).

En este segundo estudio esperábamos, por una parte, replicar el efecto del paso del tiempo en la habilidad para inhibir respuestas inapropiadas. Por otra parte, esperábamos observar una amplitud atenuada de las ondas N2 y P3 en paralelo con una menor exactitud para inhibir respuestas inapropiadas con el paso del tiempo en tarea. Por otra parte, los potenciales asociados al procesamiento en etapas tempranas, P1 y N1, reciben menos atención en los estudios con tareas go-nogo. En nuestro estudio, analizamos los potenciales P1, N1, N2 y P3 para evaluar si el efecto del paso del tiempo influía específicamente en los procesos relacionados con la selección de respuesta y control cognitivo o también en etapas de procesamiento más tempranas. Además, analizamos la relación entre las medidas fisiológicas y la ejecución en la tarea SART.

El efecto del paso del tiempo en la inhibición de respuestas inapropiadas no fue significativo (aunque análisis posteriores con una mayor muestra mostraron un resultado marginal, más cercano a nuestros resultados del Estudio 1). Las ondas N2 y P3 fueron sensibles al efecto del paso del tiempo en tarea, mostrando una amplitud reducida. Estos resultados sugieren que la amplitud del N2 y el P3 podrían ser índices de la eficiencia inhibitoria con el paso del tiempo en tarea. Por otra parte, la amplitud del N1 fue más negativa, lo que podría reflejar una mayor dificultad de la discriminación perceptiva con el paso del tiempo en tarea. Sin embargo, no observamos una relación entre las medidas comportamentales de la tarea (precisión y velocidad de respuesta) y las medidas neurofisiológicas, posiblemente por el tamaño muestral de este estudio.

En este segundo studio nuestro objetivo fue establecer un marcador neurofisiológico asociado al efecto del paso del tiempo en tarea en la inhibición de respuestas eficaces. En el Estudio 3, nuestro interés residía en el estudio de un indicador autonómico, la temperatura de la piel.

2.2 Temperatura de la piel como índice fisiológico de la ejecución en la tarea SART

El objetivo de esta serie experimental fue investigar si temperatura de la piel podría utilizarse como índice fisiológico de fluctuaciones en el nivel de vigilancia, con la ventaja de ser un método fácil y de bajo coste, portátil y no invasivo.

La relación entre temperatura de la piel y la ejecución en tareas de vigilancia en periodos de tiempo con una duración inferior a los ritmos circadianos (24 horas) es reciente. En una investigación previa se ha sugerido que los valores de temperatura, especialmente proximal, se relacionan con respuestas más lentas y una mayor frecuencia de lapsus atencionales en pruebas de vigilancia psicomotora (Romeijn & Van Someren, 2011). Por otra parte, el estudio de Raymann y colaboradores (2007), donde manipulan la temperatura corporal, apoya este hallazgo. Incrementos en la temperatura proximal aceleran el decremento de vigilancia (Raymann & Van Someren, 2007). Sin embargo, no se ha estudiado si esta relación temperatura-ejecución puede generalizarse a la ejecución de tareas de vigilancia más complejas que requieren control ejecutivo como la tarea SART. Por otra parte, no hay estudios que muestren el curso natural de la temperatura durante tareas de vigilancia y si la temperatura de la piel difiere en función de latarea que se realiza, es decir, si es selectiva a las demandas de la tarea.

Con el propósito de abordar estas cuestiones, se realizaron dos experimentos en los que se registraron la temperatura distal, proximal y el gradiente distal-proximal. Ambos experimentos se diseñaron con el objetivo de evaluar la sensibilidad de la temperatura de la piel como índice fisiológico de variaciones en la ejecución. En el Experimento 1, se establecieron dos condiciones de tarea (Tarea, No Tarea) siguiendo un diseño entregrupo. Los participantes asignados al grupo Tarea realizaron la tarea SART mientras que los participantes asignados al grupo No Tarea (grupo control) recibieron la misma estimulación sensorial pero no tenían que realizar la tarea. En el Experimento 2, se llevó a cabo una manipulación de las demandas de la tarea atencional mediante el paradigma de doble tarea. Los participantes debían realizar dos tareas simultáneamente en la condición dual, laSART y una tarea de conteo, y solo la tarea SART en la condición simple. Por una parte, si la temperatura de la piel era selectiva a las demandas de la tarea, esperábamos observar diferencias en la temperatura de la piel en función de la condición de Tarea (Tarea, No Tarea en el Experimento 1 y Simple, Dual en el Experimento 2). Además, al igual que en los estudios anteriores, esperábamos replicar el efecto del paso del tiempo en control inhibitorio. En el Experimento 2, debido al coste o efecto de interferencia por realizar la tarea dual, la ejecución en la tarea primaria (SART) se vería afectada por las demandas impuestas por la tarea secundaria (tarea de conteo). Por tanto, esperábamos observar una peor ejecución (mayor número de errores de comisión) en la condición dual (SART y tarea de conteo) en comparación con la condición simple (SART). Por otra parte, el efecto del pas del tiempo en la exactitud para inhibir respuestas inapropiadas podría ser menos acusado en la condición simple, donde los recursos atencionales no deben competir por realizar dos tareas simultáneamente.

Nuestros resultados sugieren que la temperatura proximal en particular podría asociarse con la ejecución en tareas de vigilancia más complejas como la tarea SART que requiere inhibición de respuesta. Además, nuestros resultados muestran por primera vez que la temperatura proximal fue sensible a los efectos del paso del tiempo y a las demandas de la tarea. Sin embargo, futuras investigaciones deben esclarecer su relación con la ejecución en tareas cognitivas y su interpretación como índice fisiológico.

CAPITULO 3

Capítulo 4: Estudio 1

CAPITULO 4

Abstract

Time of day modulates our cognitive functions, especially those related to executive control, such as the ability to inhibit inappropriate responses. However, the impact of individual differences in time of day preferences (i.e. morning vs. evening chronotype) had not been considered by most studies. It was also unclear whether the vigilance decrement (impaired performance with time on task) depends on both time of day and chronotype. In this study, morning-type and evening-type participants performed a task measuring vigilance and response inhibition (the Sustained Attention to Response Task, SART) in morning and evening sessions. The results showed that the vigilance decrement in inhibitory performance was accentuated at non-optimal as compared to optimal times of day. In the morning-type group, inhibition performance decreased linearly with time on task only in the evening session, whereas in the morning session it remained more accurate and stable over time. In contrast, inhibition performance in the evening-type group showed a linear vigilance decrement in the morning session, whereas in the evening session the vigilance decrement was attenuated, following a quadratic trend. Our findings imply that the negative effects of time on task in executive control can be prevented by scheduling cognitive tasks at the optimal time of day according to specific circadian profiles of individuals. Therefore, time of day and chronotype influences should be considered in research and clinical studies as well as real-word situations demanding executive control for response inhibition.

CAPITULO 4

Introduction

Maintaining attention to the task at hand over an extended time period (i.e., vigilance) can be crucial in many situations. Research on vigilance has reported a drop-off in performance as time on task increases, the so-called vigilance decrement (Mackworth, 1948). The vigilance decrement has been explained in terms of either reduced arousal or depletion of cognitive resources over time (Parasuraman & Davies, 1977).

The vigilance level of individuals also fluctuates at longer timescales, for example over the course of the day, as shown by research using the Psychomotor Vigilance Test (PVT; Lim & Dinges, 2008). Time of day further influences higher-order cognitive functions, as indexed by behavioural and neural measures related to executive control (Manly, Lewis, Robertson, Watson, & Datta, 2002; Bratzke, Rolke, Ulrich, & Peters, 2007; Vanderwalle, y otros, 2009; Marek, et al., 2010; Schmidt, Collette, Cajochen, & Peigneux, 2007; Blatter & Cajochen, 2007).

Executive control is typically engaged in novel or complex situations to adapt our behaviour for optimal performance (e.g. inhibiting routine responses when they are inappropriate; Norman & Shallice, 1986). The Sustained Attention to Response Task (SART; Robertson I. H., Manly, Andrade, Baddeley, & Yiend, 1997) measures the ability to sustain executive control for response inhibition over a given period of time. The SART requires fast responses to random single digits from 1 to 9 (go digit), except for the '3' stimulus (no-go digit), to which participants must not respond (see Figure 1 for an example). Therefore, successful response inhibition to infrequent no-go trials demands prolonged attention during task (Robertson I. H., Manly, Andrade, Baddeley, & Yiend, 1997).

Grier and colleagues (Grier, et al., 2003) noted that performance on a simulated quality inspection task similar to the SART paradigm (i.e. a vigilance task requiring inhibition of an habitual response) also declines over extended periods. Furthermore, Manly and colleagues (Manly, Lewis, Robertson, Watson, & Datta, 2002) reported a time of day effect on overall response inhibition using the SART, such that accurate inhibition of responses on no-go trials was lower during early morning and night as compared to the afternoon and evening times. In contrast, RTs of go trials, assumed to reflect automatic processing, were not modulated by time of day. These studies together reveal that both time on task and time of day produce important effects on executive control during response inhibition tasks. However, to the best of our knowledge, the joint impact of these factors on inhibitory control had not been studied previously.

On the other hand, chronotype refers to individual differences regarding both the preferred time of day to perform activities and sleep timing. Chronotype has a genetic basis (Katzenberg, et al., 1998), it affects the temporal organization of physiological functions and behaviours, and can therefore influence cognitive functioning through the day (Schmidt, Collette, Cajochen, & Peigneux, 2007). There are three main circadian typologies or chronotypes: morning-type ('larks'), intermediate-type and evening-type ('owls') (Adan, et al., 2012). With regard to evening-type, morning-type people show a 2–4 h advance in circadian phase in variables like subjective alertness, sleep times, core body temperature (CBT) or distal skin temperature (DST) (Horne & Östberg, 1976; Kerkhof & Van Dongen, 1996; Baehr, Revelle, & Eastman, 2000; Adan, Natale, & Caci, 2008; Kerkhof, 1985).

Given that DST is closely associated to the CBT rhythm (showing an advanced rhythm phase and inverse temporal curve with maximum values within the sleeping period; Kräuchi, 2007), DST has been proposed as a reliable circadian index under free-living conditions (Kolodyazhniy, et al., 2011; Sarabia, Rol, Mendiola, & Madrid, 2008). Additionally, infraclavicular temperature and the difference between distal and proximal temperatures (distal-proximal gradient, DPG) have been related to the vigilance state. Increments in infraclavicular temperature correlate with slower reaction time in the PVT (Romeijn & Van Someren, 2011), and DPG increments correlate with short latency of sleep onset (Kräuchi, 2007; Kräuchi, Cajochen, Werth, & Wirz-Justice, 2000).

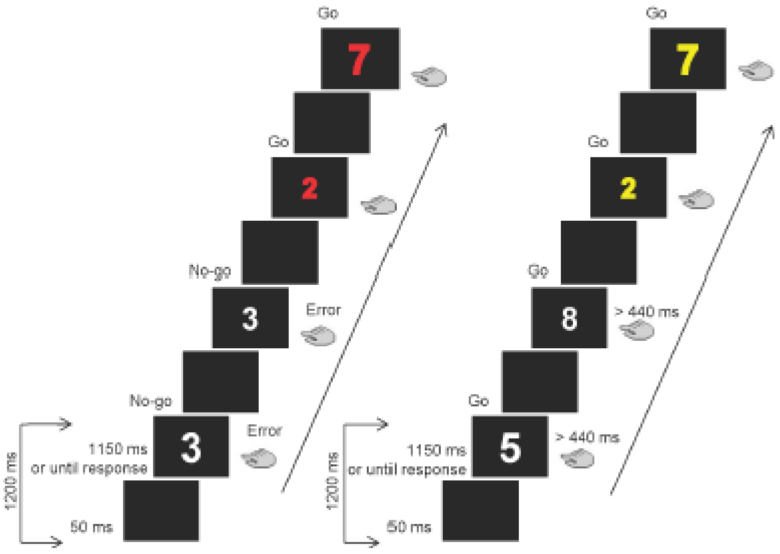

Figure 1. **Sequence of events for both strategy conditions in the modified SART.** The precision strategy condition, on the left, emphasised accurate response inhibition over fast responding. Digits turned red when the average correct response rate in no-go trials was below 0.71. The speed strategy condition, on the right, emphasised fast over correctly inhibited responses. Digits were presented in yellow when the average RT was above 440 ms and accuracy rate in no-go trials was not below 0.45.

Given the differences in circadian rhythmicity between morning and evening chronotypes, it is natural to expect variations in task performance as a function of both chronotype and time of day. The interaction between chronotype and time of day is referred to as the synchrony effect, and involves better performance for optimal (morning for morning-type and evening for evening-type) as compared to non-optimal times of day (Horne, Brass, & Pettitt, 1980; May & Hasher, 1998; Natale & Cicogna,1996; Monk & Leng, 1986). The synchrony effect has been found in a wide range of executive tasks, for example measuring response inhibition (May & Hasher, 1998; May, Hasher, & Foong, 2005; Hahn, et al., 2012), fluid intelligence (Goldstein, Hahn, Hasher, Wiprzycka, & Zelazo, 2007) and set-shifting abilities (Bennet, Petros, Johnson, & Ferraro, 2008; for a review see Schmidt, Collette, Cajochen, & Peigneux, 2007). However, these studies have focused on measures of overall performance (averaged across the whole session), rather than on the evolution of performance across time. Thus, it remained to be tested whether the vigilance decrement during an executive control task is influenced by the synchrony effect.

The aim of the current research was to study the impact of time on task on executive control (vigilance decrement), and to test for the first time whether this decrement changes as a function of time of day and individual differences in chronotype. We used a 20-min long version of the SART task with two response strategy conditions: precision (controlled responding set) vs. speed (auto-matic responding set). According to research suggesting that controlled but not automatic processes are vulnerable to the synchrony effect (May & Hasher, 1998; May, Hasher, & Foong, 2005), we expected the synchrony effect to occur selectively in the precision strategy condition. In contrast, performance in the speed condition inducing an automatic response style should remain relatively stable. Following the cognitive resource theory, we further expected to observe the highest vigilance decrement in the most cognitively demanding condition of the modified SART (i.e., precision strategy), performed at the non-optimal time of day. Finally, we tested whether inhibition performance on SART could be predicted by other measures (RT performance in the PVT and scores in MAAS and ARCES questionnaires; Cheyne, Carriere, & Smilek, 2006) of vigilance.

Method

Ethics Statement

Before the experiment all participants signed a consent form approved by the Ethics Committee of the University of Granada. This study was conducted according to the ethical standards of the 1964 Declaration of Helsinki. After the experiment, participants were rewarded with course credits for their collaboration.

Participants

Forty-four undergraduates from the University of Granada were initially selected to participate according to their score on the reduced scale of Morningness-Eveningness Questionnaire (rMEQ; Adan & Almirall, 1991). A strict selection criterion was used to include in the final sample only participants who confirmed their chronotype after a second administration of the rMEQ at the moment of testing. For this reason, ten undergraduates scoring as intermediate-type (from 12 to 16) in the second administration were not included in the final sample. Scores of selected extremes chronotypes showed a strong consistency between both assessments of circadian typology, r =.88, p<.001. Data from 5 participants who slept less than 5 hours the night prior to the experiment, 1 participant with extremely low accuracy data due to using a wrong response key during most of the experiment and 1 participant who missed the second experimental session, were excluded from analysis. Finally, the sample was constituted by 27 participants, 13 assigned to morning-type group (mean age: 19 years, range: 18–27, SD: 2.4; 12 females; mean score in the rMEQ: 17.85, range: 17–20, SD: 1.14) and 14 to evening-type group (mean age: 19 years, range: 18–23, SD: 1.4; 13 females; mean score in the rMEQ: 9.64, range: 8–11, SD: 0.84).

Apparatus and Stimulus

Questionnaires

Circadian typology was measured by a validated adaptation of the Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976), standardized to the Spanish population: the reduced scale of Morningness-Eveningness Questionnaire (Adan & Almirall, 1991). Scores can range from 4 to 25 in a continuum from low to high morningness. Subjective activation and affect were assessed by a 0–100 visual- analog scale (VAS) developed by Monk (Monk, 1989), where 0 indicated the lowest value (minimum activation/positive mood) and 100 the maximum value for both state indices. The Attentional-Related Cognitive Errors Scale (ARCES; Cheyne, Carriere, & Smilek, 2006) was used to measure susceptibility to cognitive errors in everyday life arising from lapses of attention. Scores can range between 12 (low predisposition to lapses) and 60 (high predisposition). The Spanish version of the Mindful Attention Awareness Scale (MAAS; (Soler, et al., 2012; see also Brown & Ryan, 2003) was used to assess attentional failures, ranging from very frequent (1) up to occasional attention lapses (6). These two questionnaires correlate with SART performance, respectively with the proportion of accurate inhibitions and RT (Cheyne, Carriere, & Smilek, 2006). Trait impulsivity was measured by the adolescent version of the Barratt Impulsivity Scale, appropriate for undergraduate students (BIS 11-A, Fossatti, Barratt, Acquarini, & Di Ceglie, 2002) and translated to Spanish (Cosi, Vigil-Colet, Canals, & Lorenzo-Seva, 2008). Higher scores on the BIS 11-A mean higher impulsivity. We measured impulsivity as it has been related to eveningness (Caci, et al., 2005).

Skin temperature recordings

Body temperature was measured using a temperature sensor (iButton- DS1921H; Maxim, Dallas), which has a temperature range from +15uCto +46uC and 1uC of accuracy with a precision of 0.125 C°. Three sensors were respectively placed at the palmar side of the wrist of the non-dominant hand (with a sport band), infraclavicular area on the right chest and external malleolus area of the right foot (with adhesive tape). The sensors were programmed to sample every minute along the experimental session. Note that the total sample and group sizes differed across the recordings of body temperature for technical reasons. Nineteen participants had wrist temperature recordings (9 morning-type, 10 evening-type), 25 participants had foot temperature recordings (11 morning-type and 14 evening-type) and 26 participants had infraclavicular temperature recording (13 morning-type, 13 evening-type).

Behavioural Tasks

Experimental tasks were performed on a 15-inch screen PC laptop computer. Programming, administration of tasks and behavioural data collection were controlled by E-prime software (Scheneider, Eschman, & Zuccolotto, 2002).

Psychomotor Vigilance Task (PVT)

The *Psychomotor Vigilance Task* (PVT) is a 10-minute simple reaction time task that provides a measure of the overall level of participant's vigilance (Dinges & Powell, 1985). In the current version, a red circumference was presented in every trial at the centre of the screen (9.5 degrees of visual angle at a viewing distance of 60 cm) over a black background. After a random interval, ranging from 2 to 10 seconds, the black circle started to fill up in red and participants had to press as quickly as possible the space bar on the keyboard with the index finger of their dominant hand. After the participant's response, feedback about the RT in that trial was displayed in the screen for a second. Otherwise, a feedback message was provided on missed or anticipated responses. Then, the next trial began. The task lasted 10 minutes, which on average led to 88 trials.

Modified Sustained Attention to Response Task

The *Sustained Attention to Response Task* (SART), as in the original go no-go task developed by Robertson and cols. (Robertson I. H., Manly, Andrade, Baddeley, & Yiend, 1997), requires participants to respond as quickly as possible to single digits randomly ranging between 1 and 9, unless the digit 3 was presented, to which they had to inhibit response (no-go trial). Stimuli appeared in white colour over a black background at the centre of the computer screen in one of five possible font sizes (48, 72, 94, 100 and 120 point, Times New Roman) that changed randomly on every trial (from 1.15º to 2.77º). A blank screen was presented for 50 ms followed by a digit that remained on the screen until the participant's response. If no response was made within 1200 ms, the next trial began. Each experimental block was composed of 200 go trials (5 font sizes x 8 digits x 5 trials) and 40 no-go trials (5 font sizes x 1 digit 6 x trials), leading to a no-go proportion of 0.17.

We used a modified version of the SART, in which the main difference concerned the manipulation of the participant's style of responding (''strategy''), by providing two different instructions across blocks of trials (see Figure 1). In the accuracy strategy condition, participants were instructed to prioritize accurate over fast performance, hence assuring correct response inhibition in no-go trials. In the speed strategy condition participants were instructed to prioritize fast over accurate performance, hence assuring fast responses to go trials. In order to make sure that each strategy condition was followed, the digit colour changed to provide feedback on line when the criteria for speed and accuracy were not met.

These criteria were established on the basis of the results observed in a previous pilot experiment. In the pilot experiment, participants were assigned to precision or speed strategy groups following a median split procedure based on their average accuracy in no-go trials (M = .71). The analyses showed a significant interaction between time of day, chronotype and strategy, F (1, 32) = 4.77, p= .03, only in the precision strategy (n = 18; mean RT: 406 ms, SD: 9.9; mean accuracy: 80%, SD: 0.02) but not in the speed strategy group (n = 18; mean RT: 364 ms, SD: 9.9; mean accuracy: 56%, SD: 0.02; F<1). These findings suggest that the precision strategy group followed a controlled task set to avoid errors while the speed strategy group applied a more automatic response style.

Therefore, in the accuracy strategy digits were presented in red when the average correct response rate in no-go trials was below 0.71. In that case, participants were instructed to take more time to respond more carefully. In the speed strategy, digits appeared in yellow when both the average RT was above 440 ms and accuracy rate in no-go trials was not below 0.45. That is, participants had to increase response speed when the digit turned yellow. Therefore, digits presented in white indicated adequate performance according to the strategy condition of the current block. In addition, the participants were informed about mean RT and accuracy at the end of each block, during the allowed rest. The task was composed of one practice block and 8 experimental blocks. There were 4 blocks for each strategy condition, and they were presented in alternating runs starting with the precision strategy condition. Variations in performance across these four blocks served to study the vigilance decrement.

Procedure

Participants completed the rMEQ and the BIS 11-A before the laboratory sessions. Next, they carried out a 1-hour laboratory session twice, at 08:00 h and 20:30 h, under dim light conditions (<8 lux). The two sessions were separated by one week, in which participants were instructed to follow their habitual schedule. Therefore, in the present study we used a time of day protocol, whereby morning- and evening-type participants were tested at two different times of day (optimal vs. non-optimal). This paradigm is sensitive to fluctuations in high-order cognitive processes (Schmidt, Collette, Cajochen, & Peigneux, 2007; Adan, et al., 2012) and allows testing under ecological, everyday-living conditions (Vanin, et al., 2012). The order of sessions was counterbalanced across participants within each experimental group (7 out of 13 participants of morning-type group and 7 out of 14 participants of evening-type group completed the first session in the morning). When the participant arrived at the laboratory, temperature sensors were placed at three different locations of the body. Then, participants completed the ARCES and the MAAS questionnaires (in the first and second session respectively), and reported about sleep duration, psychiatric and sleep disorders, consumption of stimulants, subjective activation and affect. Afterwards, the PVT was administered to obtain an objective index of vigilance that is sensitive to the synchrony effect. Finally, participants completed the main task, the SART, for 20 minutes approximately.

Design and Statistical Analysis

The rMEQ scores and chronological age were analyzed by one-way analysis of variance (ANOVA) to test for possible differences between morning-type and evening-type chronotype groups. Skin temperature data from each sensor location were analyzed by averaging values within the first 10 minutes (i.e., during the PVT). The distal (wrist) to proximal (infraclavicular) temperature gradient (DPG) was also computed for every participant at each time of day condition.

Body temperature, sleep duration, sleep onset and offset times and time awake before testing, subjective affect, and RT and accuracy in the behavioural tasks, were submitted to separate ANOVAs. We used a mixed-design ANOVA of 2 (Chronotype: Morning-type, Evening-type) x 2 (Time of Day: Morning, Evening), with chronotype as a between participants factor and time of day manipulated within participant. The PVT analysis excluded the first five trials, which were considered as practice, and trials with RTs below 100 ms and longer than 1000 ms (0.09% rejected).

Similarly, the RT analysis of SART excluded trials with RT below 100 or above 1000 ms (0.007% excluded), practice trials (i.e., trials from the practice block and the first five trials of every experimental block, which were considered as warm-up trials) and incorrect trials (i.e., responses in the no-go condition). The accuracy analysis of SART computed the proportion of correct responses in the no-go condition (i.e. responses correctly inhibited). The SART analysis further included Strategy (Accuracy, Speed) and Block (from 1 to 4) as within participants' factors. Mauchley's test showed no violation of sphericity for the main effect of block and interactions with the block factor (all ps > 0.40). To study the role of different response strategies, strategy was manipulated within-participants, so that different blocks emphasized accurate response-inhibition or speeded response style. Moreover, the vigilance decrement in performance was analysed by including block as within-participants factor. When the effect of block was significant, polynomial trend analyses (linear, quadratic and cubic trends) were performed to characterize how executive control evolved along time on task.

Furthermore, simple linear correlations were calculated between self-report questionnaires (ARCES and MAAS), performance on the PVT and inhibitory performance on the precision strategy condition for each participant at both morning and evening sessions.

CAPITULO 4

Results

Demographic Data

The analysis conducted on their MEQ scores confirmed significant differences between our chronotype groups, F (1, 25) = 455.31, p< .01, $\eta p^2 = 0.95$, with higher morningness scores in the morning- vs. evening-type group (see table 1). In contrast, age did not differ between groups, F<1. Sleep duration (the night before experiment) was longer in the evening (M: 7.6 hours, SD: 0.28) than in the morning session (M: 6.1 hours, SD: 0.14), F (1, 25) = 29.53, p< .01, $\eta p^2 = 0.54$. Importantly, however, no differences were observed between morning-type and evening-type groups in sleep duration, F<1, and the interaction between time of day and chronotype was not significant either, F<1, therefore confirming similar sleep duration between groups. In contrast, the analysis of waking duration prior to sessions showed a marginally significant interaction between testing time and chronotype, F (1,25) = 4.16, p =.07, $\eta p^2 = 0.12$. In particular, chronotype groups differed in time awake before the evening session, F (1, 25) = 4.16, p = .05, with more awake hours in morning-type (M = 11.88, SD = 0.41) relative to evening-type group (M = 10.71, SD = 0.40), but no differences were found for the morning session (F<1). The sleep onset time analysis only showed a main effect of time of day, F (1, 23) = 11.55, p<.01, $\eta p^2 = 0.33$, with a latest onset in the evening (M = 1:36, SD: 0.30) than in the morning session (M = 00:22, SD = 1.53). Similarly, sleep offset time showed a significant time of day effect, F (1, 23) = 40.70, p<.01, $\eta p^2 = 0.64$, with earlier waking up time in the morning (M = 6:38, SD = 0.11) than in the evening session (M = 9:02, SD = 0.27). No significant interactions or chronotype effects were found for both sleep onset and offset analysis (all *ps*>0.09).

Furthermore, 2 out of 13 morning-type and 3 out of 14 evening- type participants reported caffeine consumption at least 5 hours before their non-optimal testing time. One morning-type and 2 evening-type participants were smokers.

Analysis of scores in the BIS-11A (n = 19; 8 M-type, 4 of them completed the first session in the morning; 11 evening-type, 5 evening-type assigned to the morning in the first session) revealed higher trait impulsivity in evening-type as compared to the morning-type group, F (1, 17) = 6.50, p= .02, $\eta p^2 = 0.28$ (Table 1).

Thus, the BIS-11A score was later used as a covariate to control for group differences in trait-impulsivity. Analyses on ARCES (n = 25) and MAAS (n = 27) showed no effect of group (all *ps*>.10).

Skin Temperature Recordings

The infraclavicular temperature analysis showed a significant interaction between chronotype and time of day, F (1, 24) = 4.96, p=.03, $\eta p^2 = 0.17$. Planned comparisons revealed that the evening-type group had higher temperature values in the evening (M: 33.81ºC, SD: 0.31ºC) than in the morning (M: 32.69ºC, SD: 0.31ºC) session, F (1, 24) = 8.89, p<.01, while the morning-type group showed no differences (F<1). Wrist temperature only showed a main effect of time of day, F (1, 17) = 4.36, p= .05, $\eta p^2 = 0.20$, with higher temperature in the evening (M: 33.23ºC, SD: 0.23ºC) than in the morning (M: 32.68ºC, SD: 0.35ºC) session. No significant main effects or interactions were observed in the analysis of right foot temperature (all ps>.18).

Table 1. Mean and standard deviation (between brackets) for demographic data according to chronotype group

Group Characteristics	**Chronotype Groups**		**p values**
	Morning-type	Evening-type	
Sample size	13	14	
rMEQ	17.85 (0.28)	9.64 (0.27)	0.01
Age	19.23 (0.55)	18.71 (0.53)	0.5
Sleep duration before morning session (in hours)	6.21 (0.21)	5.96 (0.20)	0.4
Sleep duration before evening session (in hours)	7.54 (0.41)	7.68 (0.39)	0.8
Hours awake in morning session	1.41 (0.16)	1.43 (0.16)	0.9
Hours awake in evening session	11.88 (0.41)	10.71 (0.40)	0.05
Sleep onset before morning session (hh:mm)	00:25 (0.27)	00:22 (0.23)	0.9
Sleep onset before evening session (hh:mm)	1:05 (0.45)	2:08 (0.46)	0.13
Sleep offset before morning session (hh:mm)	6:36 (0.19)	6:43 (0.19)	0.7
Sleep offset before evening session (hh:mm)	8:37 (1.22)	9:30 (0.42)	0.16
Smokers	1	2	
Consumption of coffee/tea	3	3	
ARCES	29.18 (2.13)	34.14 (1.89)	0.1
MAAS	4 (0.21)	4 (0.21)	0.9

The DPG analysis showed a significant interaction between time of day and chronotype, F (1, 16) = 4.88, p = .04, indicating a synchrony effect. Morning chronotypes showed the most negative DPG value in the morning (M: 21.47, SD: 0.9) although the difference was not significant with respect to the other conditions (all ps>.10).

Subjective Activation and Mood States

The subjective activation analysis showed a significant interaction between chronotype and time of day, F (1, 25) = 7.20, p= .01, $\eta p^2 = 0.22$. Planned comparisons showed that evening-type participants reported higher activation in the evening (M: 49.28, SD: 4.89) compared to the morning session (M: 35.21, SD: 5.66), F (1, 25) = 5.67, p= .02, while the time of day effect followed an opposite trend for the morning-type group, although it did not approach significance (M: 56.56, SD: 5.87 vs. M: 47.77, SD: 5.07 for morning vs. evening sessions, respectively; F (1, 25) = 2.05, p= .16). In addition, significant differences in self-reported activation between chronotypes were found for the morning session, F (1, 25) = 6.85, p= .01, but not for the evening session (F<1).

Regarding subjective affect, both chronotypes reported more positive affect at their optimal time of day (chronotype x time of day: F (1, 25) = 4.36, p= .05, $\eta p^2 = 0.15$). In particular, the evening-type group showed less positive affect in the morning (M: 66.70, SD: 4.99) than in the evening session (M: 74.71, SD: 4.45), F (1, 25) = 5.24, p= .03, but the morning-type group did not show significant differences between both testing times (F<1; M: 73.52, SD: 5.18 vs. M: 71.00, SD: 4.62 for morning vs. evening sessions, respectively).

Psychomotor Vigilance Task (PVT)

As Figure 2 shows, the RT analysis showed a clear synchrony effect (chronotype6time of day: F (1, 25) = 11.71, p< .01, $\eta p^2 = 0.32$). In the morning-type group, RTs were faster in morning vs. evening sessions, F (1, 25) = 4.63, p= .04. In contrast, the evening-type group showed slower RTs in the morning vs. evening session, F (1, 25) = 7.29, p= .01. Moreover, in the evening session, RTs were faster for evening-type than for morning-type groups, F (1, 25) = 5.17, p=.03. However, no difference was observed in the morning session, F<1.

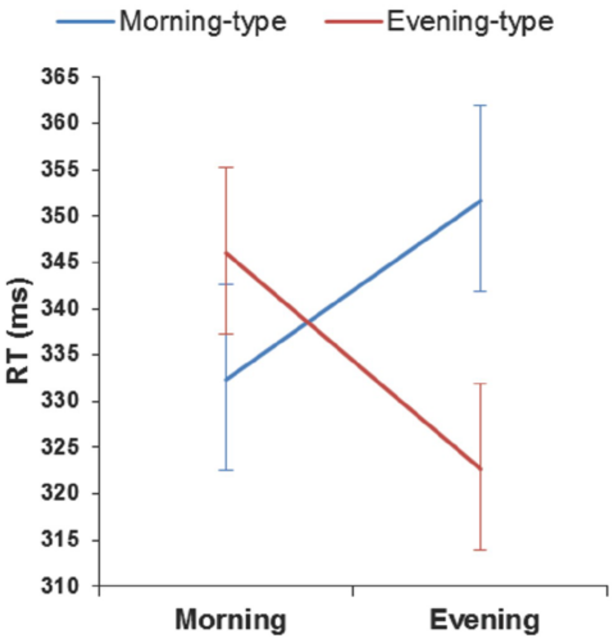

Figure 2. Mean reaction times on the PVT for both chronotypes depending on time of day. Each chronotype responded fastest at their optimal time of day and slowest at their non-optimal testing time. Vertical bars denote +/- standard error of the mean.

Sustained Attention to Response Task (SART)

Reaction Times. The ANOVA on the mean RT showed a significant effect of Strategy, F (1, 25) = 84.33, p<.01, $\eta p^2 = 0.77$, with slower RT in the precision condition (M: 385

ms, SD: 6.86 ms) than in the speed condition (M: 336 ms, SD: 5.56). The remaining main effects and interactions did not reach statistical significance (all ps>.12).

Accuracy. The main effect of strategy was significant, F (1, 25) = 92.50, p<.01, ηp^2 = 0.78, with higher accuracy in the precision strategy (76%) than in the speed strategy condition (57%). The main effect of block, F (3, 75) = 15.04, p< .01, ηp^2 = 0.37, revealed impaired response inhibition with increasing time on task. Further analyses replicated the typical vigilance decrement, which followed a linear trend, F (1, 25) = 34.71, p< .01 (the quadratic trend was not significant, p> .2). Most relevant for the current research, the ANOVA showed a significant interaction between chronotype, time of day and block, F (3, 75) = 2.94, p= .038, ηp^2 = 0.10. This interaction was better qualified by considering the strategy factor, as suggested by a marginally significant interaction between strategy, chronotype, time of day and block, F (3,75) = 2.60, p = .058, ηp^2 = 0.09. Differences between both strategy conditions were tested by hypothesis-driven planned comparisons (Keppel, 1991). As we predicted, the interaction between chronotype, time of day and block (linear trend) was significant only for precision strategy, F (1, 25) = 5.18, p= .03, but not for speed strategy, F<1.

Further analyses of the precision strategy condition revealed that the linear decrement in vigilance was only significant when the groups performed the task at their non-optimal time of day according to chronotype (see Figure 3). That is, in the morning-type group, there was an interaction between time of day and block (linear trend contrast), F (1, 25) = 4.20, p= .05, such that correct response inhibition linearly declined with time on task in the evening session, F (1, 25) = 11.09, p< .01, but not in the morning session (p>.24). In the evening-type group, although the interaction between time of day and the linear trend of block was not significant, F (1, 25) = 1.33, p= .25, further analyses clearly showed a linear decrement on accuracy in the morning session, F (1, 25) = 19.90, p <.01, while the block effect in the evening session was better characterized by a quadratic trend, F (1, 25) = 4.86, p= .04, where accuracy decreased until the third block and then remained stable), rather than a linear trend, F (1, 25) = 3.94, p= .058.

Analysis of covariance in accuracy. Since evening-type showed significantly higher impulsivity than morning-type group (see Demographic Data results), we used BIS-11A scores as a covariate to control for a possible confound of trait-impulsivity in our main manipulation. This covariance analysis confirmed that the interaction between strategy, chronotype, time of day and block remained significant, F (3, 48) = 2.88, p= .04, after controlling for trait-impulsivity, which suggests that our main effects can be attributed to the chronotype manipulation rather than just by differences in impulsivity.

Correlation Analyses

Analysis of simple linear correlations between scores of the MAAS and ARCES scales, RT performance in the PVT and accuracy performance on SART for precision strategy were conducted (the BIS score was not included due to missing data for 8 participants). The main finding was that inhibitory performance on SART was correlated with performance on the PVT (r= -.33, p = .01). Thus, optimal vigilance states were associated with more successful response inhibition (see Figure 4). Accuracy in the SART positively correlated with the MAAS scale (r= .47, p<.01), such that participants reporting more infrequent attentional lapses showed better response inhibition. The ARCES scores did not correlate with performance on SART (all ps>.09).

General Discussion

The main aim of the present study was to investigate the impact of both time of day and circadian typology (i.e., the synchrony effect) on the vigilance decrement in inhibitory control during a modified version of the SART (Robertson I., Manly, Andrade, Baddeley, & Yiend, 1997). Participants completed the task at morning and evening sessions in a counterbalanced order within morning-type and evening-type groups. According to previous research (Manly, Lewis, Robertson, Watson, & Datta, 2002; May & Hasher, 1998), we predicted that controlled processing would be more vulnerable than automatic processing to the influences of time of day and chronotype. The synchrony effect would therefore be most evident in the precision strategy condition demanding a controlled task set. Since the ability to maintain successful response inhibition over time also demands resources of cognitive control (Shaw, et al., 2013), we expected to find the largest vigilance decrement at the non-optimal time of day for each chronotype.

Two findings supported our main prediction. First, the synchrony effect was selectively found in no-go accuracy performance (assumed to index executive control) rather than on go RTs, indexing more automatic processing (Manly, Lewis, Robertson, Watson, & Datta, 2002; Robertson I. H., Manly, Andrade, Baddeley, & Yiend, 1997). Second, the synchrony effect was present in the precision strategy condition, which demanded a controlled response set, but it was absent in the speed strategy condition, which induced an automatic response set. In the precision strategy condition, inhibitory control of the morning-type group decreased gradually over time on task only in the evening, but not in the morning. In contrast, evening-type participants showed a more marked performance decrement in the morning than in the evening session, in which accuracy decreased but remained stable over the final testing period.

Further analyses of the synchrony effect in our objective and subjective measures revealed that response inhibition was most effective when participants performed the SART in their optimal vigilance state. Optimal vigilance was specifically indexed by faster RTs in the PVT (Lim & Dinges, 2008), higher levels of subjective activation (Monk, 1989), and lower DPG (Kräuchi, Cajochen, Werth, & Wirz-Justice, 2000) and infraclavicular temperature (Romeijn & Van Someren, 2011) when the session matched the optimal testing time of each chronotype.

The link between vigilance state and executive control was further supported by a significant negative correlation between RT performance in the PVT and accuracy in the SART, whereby the optimal vigilance state as indexed by fast RTs was related with enhanced inhibitory control. Therefore the PVT could be a useful tool to predict performance on tasks demanding executive control. Furthermore, high MAAS scores (i.e. subjective experience of fewer lapses of attention; Brown & Ryan, 2003) were also found to predict inhibitory performance, which to our knowledge had not been reported previously (Cheyne, Carriere, & Smilek, 2006).

These findings therefore reveal a close interplay between the ability to remain vigilant and the executive control process involved in response inhibition (Robertson & Garavan, 2004). According to conceptions of vigilance as an active, resource-demanding process (Parasuraman & Davies, 1977), (Shaw, et al., 2013; Robertson & O´Connell, 2010; Warm, Parasuraman, & Matthews, 2008) we conclude that performing at non-optimal times of day jeopardizes the engagement of necessary resources to maintain appropriate inhibitory control throughout the task. In contrast, testing at the preferred time of day may mitigate the decline in performance across time on task. Neuropsychological and imaging studies have related SART performance to a right lateralized brain network involved in vigilance and executive control, with emphasis on the right prefrontal cortex (Robertson & Garavan, Vigilant Attention, 2004; Molenberghs, et al., 2009), (Manly, et al., 2003). A recent fMRI study additionally showed a synchrony effect on anterior brain areas involved in executive control as demanded by a Stroop interference task (Schmidt, et al., 2012). Our findings and the above studies hence support the notion that vigilance plays a central role in executive functioning related to inhibitory control.

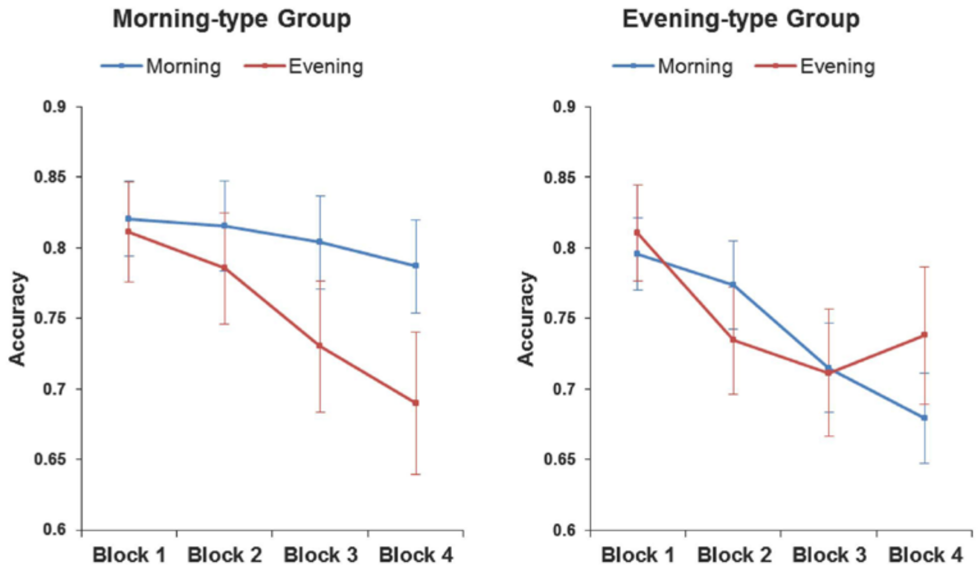

Figure 3. Accurate responses as a function of chronotype, testing time and block for the precision strategy condition. Each chronotype showed marked performance decrements at the non-optimal testing time. Vertical bars denote +/- standard error of the mean.

The current research further highlights the role of individual differences in chronotype regarding the ability to maintain executive control under free-living conditions. Thus, detailed analyses of the synchrony effect in our main measures revealed that time of day effects were less evident in morning-type than evening-type participants. In fact, only the morning-type group was able to prevent completely the vigilance decrement at the optimal time of day. This result is consistent with our previous study on simulated driving, reporting that only the morning-type group showed stable performance over time on task, which was not affected by time of day (Molina, Sanabria, & Correa, 2013). Some authors have interpreted this result in terms of personality factors (Oginska, et al., 2010), associating evening- type participants to low conscientiousness, high impulsivity, higher sensation seeking and reduced vigilance (reviews by Di Milia, et al., 2011; Finomore, Matthews, Shaw, & Warm, 2009). Indeed, differences in impulsivity might have mediated our effects of chronotype (Caci, et al., 2005). However, the analysis including trait impulsivity as covariate suggested that our findings cannot be explained just in terms of impulsivity, but they can be attributed to individual differences in chronotype.

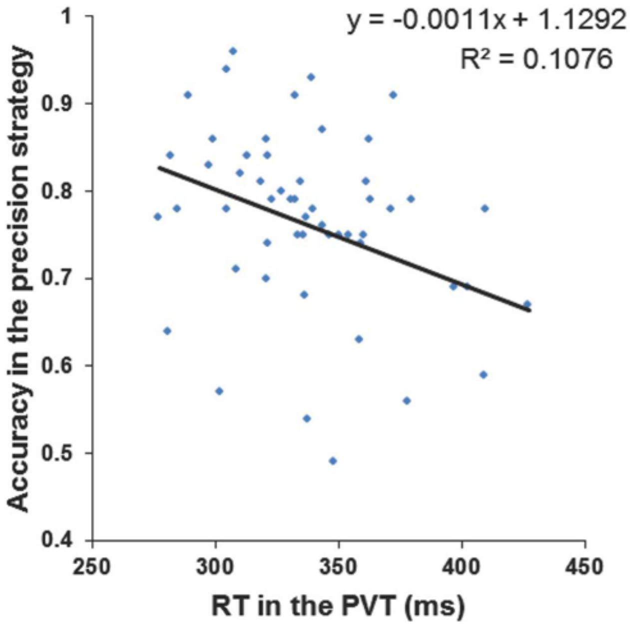

Figure 4. Correlation between RT in the PVT and accuracy on SART for the precision strategy condition.

An alternative explanation considers the difference in sleep homeostatic dynamics between chronotypes. Research relating eveningness with irregular sleep/wake habits and increased need for sleep than morningness, which shows higher sleep efficiency (Lehnkering & Siegmund, 2007; Taillard, Philip, & Bioulac, 1999), can help to explain the robustness of behaviour in morning chronotypes. Although our participants did not report to have sleep problems, further information about sleep quality (e.g., Pittsburgh Sleep Quality Index – PSQI) in our groups should have been recorded to test this hypothesis.

Likewise, the current research presents other limitations that should be addressed in future research. First, this study was designed from a time of day rather than a circadian physiology perspective. Recording of sleep/wake habits by sleep diary and circadian markers (e.g., actimetry) during the week before the experiment would be necessary to warrant interpretation of our time of day effects in terms of pure differences in circadian phase. Although body temperature recorded at the beginning of each session showed a synchrony effect (suggesting that chronotypes were at different circadian phases in the two sessions), we acknowledge that only two time points cannot provide clear information on whether circadian rhythms of our sample were really entrained to our specific testing times.

Moreover, our study focused on cognitive testing under free- living rather than strict laboratory conditions, which involved no restriction of stimulants or careful control of other masking influences such as feeding schedule. In fact, participants followed their natural habits during the course of the study. Since the proportions of smokers and coffee drinkers in our sample were relatively small and matched for morning-type and evening-type groups, it is likely that any masking influence of these factors on performance were balanced and did not preclude the current finding of clear interactions between time of day and chronotype. In future studies it will also be interesting to adapt testing times to individual sleep/awake patterns (Schmidt, Peigneux, Cajochen, & Collete, 2012). In the current study, several participants in both groups slept about six hours, which could be considered as sleep restriction, and evening-type chronotypes were tested earlier than their usual preferences in the morning session. However, both extreme chronotypes recruited in the study reported similar sleep duration, and similar sleep timing before the morning session, so that chronotype effects on the performance during the morning session cannot be just due to restricted sleep duration selective of the evening-type group. As already mentioned, nevertheless, we cannot rule out explanations based on greater sleep need and debt or increased dissipation time of sleep inertia during working days reported in evening-type people (Taillard, Philip, & Bioulac, 1999; Roenneberg, Wirz-Justice, & Merrow, 2003).

Addressing the abovementioned limitations will surely improve our current understanding of the neurophysiological mechanisms underlying our main behavioural result. Our findings observed under free-living conditions are consistent with previous research using more controlled protocols (constant routine or forced- desynchrony) and reporting circadian rhythmicity of executive functions (Bratzke, Rolke, Ulrich, & Peters, 2007; Bratzke, Rolke, Steinborn, & Ulrich, 2009; but see Bratzke, Steinborn, Rolke, & Ulrich, 2012). However, the previous research did not address the vigilance decrement in cognitive performance.

Research on decrements in vigilance during everyday tasks demanding executive control is crucial for ergonomics, since it can lead to serious consequences for safety in transport and work. The current study provides, for the first time, empirical evidence indicating that the vigilance decrement of executive functioning depends on the interaction between circadian typology and time of day factors. The amount of necessary cognitive resources to maintain adequate executive function over time on task could be regulated by a complex interplay between circadian and homeostatic influences underlying time of day and chronotype effects. The current study provides implications concerning the importance of considering chronotype and time of day when scheduling tasks demanding sustained executive control, not only in clinical and research contexts of cognitive testing, but also in everyday and work-related situations where optimal cognitive functioning can be critical.

CAPITULO 4

Capítulo 5: Estudio 2

CAPITULO 5

Introduction

The aim of the present study was to investigate the electrophysiological correlates of inhibitory performance over time during the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) using event-related potentials (ERPs). Findings from Study 1 showed that the ability to maintain successful inhibition of dominant responses worsened over time on task. Therefore, we aimed to replicate this time on task effect in inhibitory performance using a long version of the Go/No-go SART and to explore ERPs underlying this impaired response inhibition over time.

Electroencephalography (EEG) is a non-invasive neuroimaging technique that can be used to objectively assess vigilance and sleepiness levels with high temporal resolution (Oken, Salinsky, & Elsas, 2006). The ERPs are time-locked brain electrical responses that reflect the time course of information processing stages and can be used as indices of sensory and cognitive processing (Key, Dove, & Maguire, 2005).

Late ERPs components, such as the P3, show decreases in amplitude that parallel declines in detection efficiency over time during vigilance tasks (Parasuraman, Warm, & See, 1998). The P3 is a positive wave with parieto-central maximum amplitude within a latency range of 300-450 ms. Its amplitude is hypothesised to be an index of the amount of resources allocated to process relevant task information (Polich, 2007). Using a vigilance task with light flashes as signals, Koelega and colleagues (1992) found that the P3 amplitude showed an inverse relation over time with response speed, suggesting a decline in resources allocation in response to task demands (Koelega, et al., 1992).

On the other hand, the N2 is a negativity that appears maximal at fronto-central sites with peak latency at around 200 ms and is typically evoked during tasks that tax inhibition of responses, such as the Go/No-go or the stop signal tasks. Usually, the N2 is followed by the P3 when responses must be inhibited (No-go condition), a sequence known as the N2/P3 complex. Overall, both N2 and P3 showed the largest amplitudes over anterior brain regions in the No-go condition (Bokura, Yamaguchi, & Kobayashi, 2001). When withholding a response is required, the No-go P3 usually shows a more fronto-central topography relative to the posterior Go P3, an ERP effect known as the No-go P3 anteriorization (Fallgatter & Strik, 1999).

These two No-go related potentials, the No-go N2 and the No-go P3, have been interpreted as indices of efficiency of inhibition. For example, Falkenstein and colleagues (1999) found enhanced No-go N2 amplitudes in good relative to poor inhibitory performance (Falkenstein, Hoormann, & Hohnsbein, 1999).

Regarding the time on task effect, Kato and colleagues (2009) reported ERP modulations using a spatial Go/No-go procedure. In particular, they found slower speed of responses and reduced No-go P3 amplitude as a function of time on task. Accordingly, the authors suggested that sustaining an optimal allocation of resources became increasingly difficult over time (Kato, Endo, & Kizuka, 2009).

Only a few studies have focused on the ERP correlates of SART performance using the original random version (unpredictable randomized sequence of digits), which is the focus of the current thesis. Zordan and colleagues (2008) found that the No-go N2 was maximal at central sites. They also observed the No-go anteriorization effect (i.e. larger frontal P3 amplitude for No-go condition; Zordan, Sarlo, & Stablum, 2008). The same pattern of results was found by O'Connell and colleagues (2009). Moreover, the

N2/P3 complex was attenuated when individuals committed an error vs. a correct inhibition in No-go trials (O'Connell, et al., 2009). Nevertheless, these studies did not addressed whether these potentials change as a function of time on task.

Therefore, in the current study we analysed, for the first time, the ERP changes associated with successful inhibitory performance as a function of time on task, during a long-version (83 minutes) of the SART. First, we expected to replicate our Study 1, by finding lower accuracy for response inhibition over time. This time on task would be evident as attenuated amplitudes for both the No-go N2 and No-go P3 as time on task progresses. In addition, we tested whether early perceptual processing (indexed by the P1 and the N1, first positivity and negativity respectively, peaking around 100 ms over posterior regions) also varied with time on task. The idea was to test whether the time on task effect is specific to late processes related to response selection and cognitive control (N2, P3), or it also influences stimulus processing at early stages (P1, N1).

In contrast to inhibition-related N2 and P3 waves, far less emphasis has been placed on early potentials in Go/No-go paradigms. However, some studies found inhibition-related modulations on initial processing stages. For example, the N1 has shown larger amplitudes (i.e. more negative) in the No-go compared to the Go condition over posterior locations whilst the P1 did not differ (Kirmizi-Astan et al., 2006). The N1 amplitude has also shown to be sensitive to variations in the task difficulty level (manipulated through a deadline for responding), with larger N1 amplitudes over posterior locations for No-go trials in the highest difficulty condition (Benikos et al., 2013). Regarding the SART, early ERP waves had not been investigated when inhibition is required during the random SART as a function of time on task.

A secondary aim of our study was to explore autonomic markers for predicting variations in the attentional level associated with SART performance. Therefore, we also recorded wrist skin temperature while participants performed the task. Previous studies on circadian rhythms of performance noted that high core body temperature is associated with better vigilance performance and subjective alertness (e.g. Wright, Hull, & Czeisler, 2002). We were interested in studying reliable and ecologically valid predictors of vigilance levels over shorter periods of time. In this regard, non-invasive monitoring of distal skin temperature using wireless sensors has been proposed as an accurate method for assessing the body temperature under normal living conditions (van Marken Lichtenbelt et al., 2006; Sarabia et al., 2008; Kolodyazhniy et al., 2011). Recently, distal (wrist) temperature has been positively related to attentional lapse rate on a modified PVT where participants performed speeded perceptual discriminations (Romeijn & Van Someren, 2011). However, to our knowledge, no study has reported the time course of distal temperature along a vigilance task, or tested whether higher wrist temperature is related to worse performance in a vigilance task involving executive control. We predicted increased wrist temperature over time on task and worse inhibitory performance on the SART with higher distal temperatures.

Method

Ethics Statement

All participants signed a written consent form approved by the Ethics Committee of the University of Granada (Ref.:17/CEIH/2015). This study was conducted according to the ethical standards of the 1964 Declaration of Helsinki. After the experiment, participants were rewarded with course credits for their collaboration.

Participants

Nineteen undergraduate students from the University of Granada took part in this study. The inclusion criterion was having an intermediate chronotype: scores between 12-16 on the reduced scale of Morningness-Eveningness Questionnaire (rMEQ; Adan & Almirall, 1991). Furthermore, participants should sleep no less than 5 hours the night prior the experiment. Data from four participants with excessive noise in the EEG recordings and 1 participant who failed to follow task instructions were excluded from analyses. Finally, the sample was constituted by 14 participants (mean age: 20 years, range: 18-32, SD: 3.81; 7 females). All participants reported normal or corrected-to-normal vision.

Apparatus and stimulus

Questionnaires

The questionnaires used in this study were the same as in our previous one (see Chapter 4).

Tasks

Programming, administration and behavioural data collection were controlled by E-prime software (Schneider, Eschman, & Zuccolotto, 2002) and run on an Intel Core 2 Duo personal computer with a 17” LCD monitor. For the main task, the SART, the EEG data were recorded using EGI’s Net Station software on a Macintosh computer with Power PC G5.

As in Study I, we used the PVT and the SART. Two main modifications were made with respect to the original SART. First, instructions emphasized accurate response inhibition over fast responses (see Study I for further details). Second, we lengthened the duration of the task (83 minutes) to test the time on task effect on performance and to obtain sufficient observations per condition in the EEG analyses. The task was composed of one practice block and 6 experimental blocks. Each experimental block lasted 13 minutes. Participants were informed about their mean RT and accuracy during obligatory one-minute rest intervals between blocks.

Skin temperature recording

Wrist temperature was measured in the same way as in Study I. A second sensor recorded room temperature during the session. For technical reasons, one participant did not have temperature recordings and the sample for wrist temperature was composed of 13 participants.

EEG recording and preprocessing

EEG data were collected using a 128-channel Geodesic Sensor Net and the signal was amplified with a high-input impedance (200 MΩ) Net Amps (Electrical Geodesics Inc., -EGI- Eugene, Oregon; Tucker, Liotti, Potts, Russell, & Posner, 1994). Amplified analog voltages (filtered online at 0.1-100 Hz bandpass) were digitized at 250 Hz. Sensors were adjusted until impedances were less than 50 kΩ. The recording reference was the vertex channel.

Prior to ERPs analysis, we used independent component analysis (ICA) to identify and remove blink artifacts from filtered (1-40 Hz) EEG recordings. The mean number of components removed was 1.78 (range 1-5). Then, EEG data were segmented separately for each individual into stimulus-locked epochs using a time window ranging from -50 ms to 700 ms after the target onset in the No-go condition. Only ERPs for correct No-go trials (i.e. responses successfully inhibited) were analyzed. The epochs were grouped into 3 categories or block conditions (blocks 1 + 2, blocks 3 + 4 and blocks 5 + 6, respectively) in order to obtain a larger number of segments per block and optimize signal to noise ratio. The minimum number of epochs per condition for including a subject in the analysis was 30 artifact-free trials. Epochs were marked as bad if they contained ocular artefacts (electro-oculagram channel differences greater than 55 µV) or with more than 10 bad channels (voltage drifts of more than 70 µV in any channel). Single channels marked as bad were replaced using a spherical interpolation algorithm (Perrin, Pernier, Bertrand, & Echallier, 1989). Since the number of free-artifacts epochs was unequal across blocks, we randomly matched them to the minimum number of good epochs obtained in one of the 3 blocks after artifact detection, in order to obtained comparable ERPs across conditions. These epochs were then averaged for each participant and category (block) and referenced off-line to the average of all of the channels. The epochs were baseline corrected for each subject using the 50 ms pre-stimulus period. Finally, we calculated grand average ERP waveforms for each condition by averaging across participants.

ERP analyses were focused on the P1, N1, N2 and P3 potentials. According to previous literature and the visual inspection of the grand average waveforms and the voltage distribution over the scalp (topographic maps), we selected electrodes and time periods for analyses of amplitudes. Amplitude was calculated as the mean voltage in the time window symmetrically selected around the peak of interest.

The P1 and N1 potentials were measured using a cluster of 11 electrodes (59, 65, 66, 71, 72, 76, 77, 84, 85, 91, and 92) over posterior sites. The temporal windows for determining the amplitude of both P1 and N1 were 89-141 ms and 217-273 ms, respectively. The N2 was analyzed over fronto-central electrodes (11, 12, 13, 5, 6, 7, 107, and 113) between 301 and 353 ms. The P3 had a broad scalp distribution and was measured over fronto-centro-parietal regions (6, 7, 13, 31, 32, 37, 38, 43, 53, 54, 55, 61, 62, 68, 79, 80, 81, 87, 88, 94, 105, 106, 107, and 113) between 421 and 521 ms.

Procedure

Each participant completed a session of 2 hours and 45 minutes in an electrically isolated room. The session began at 11:00h. This testing time was selected to avoid circadian variations related to both individual differences in chronotype and time of day on performance and physiological measures (Polich and Kok, 1995). The rMEQ was again administered at the moment of testing to confirm that participants had intermediate chronotype. First, temperature sensors were placed at the wrist to record a baseline of at least 30 minutes, during which participants completed the rMEQ, the ARCES, the MAAS, the BIS 11-A and the Monk's activation-affect scale. They also reported about sleep duration, psychiatric and sleep disorders and consumption of stimulants. Then, the PVT was administered. After the PVT, a sensor net was placed over the participant's scalp for EEG recording and participants performed the SART. Finally, they completed the Monk's scale again.

Design and statistical analysis

All participants scored on the second administration of the rMEQ as intermediate type, except for three participants who scored as moderate morning-type, 1 participant as extreme morning-type and one participant as moderate evening-type. They were nevertheless included in the analyses because experiment was not performed at a non-optimal time of day.

Temperature data were baseline corrected by subtracting the minute immediately preceding the beginning of the task from each of the 78 minutes of SART.

Subjective activation and mood states were analyzed using separate repeated measures analysis of variance (ANOVA) with Time (pre-test vs. post-test) as a within participants factor. Temperature data from each sensor, RT and accuracy performance in the SART and mean amplitude for each ERP component (P1, N1, N2, and P3) were also submitted to separate repeated measures ANOVAs with Block (1, 2, 3) as a within-subject factor. When the effect of Block was significant, planned comparisons were performed to test for differences between blocks. In the SART, the RT analyses excluded trials with RT below 100 and above 1000 ms, and incorrect trials (i.e. responses in the no-go condition). The accuracy analysis computed the proportion of responses correctly inhibited to the no-go stimulus. All analyses excluded practice trials (i.e. trials from the practice block and five first trials of every experimental block, considered as warm-up trials).. Simple linear correlations were calculated between self-reported questionnaires (MAAS and ARCES), performance on the PVT (mean RTs) and behavioral indices of the SART (mean RTs and accuracy). Correlation analyses between ERP measures and SART performance were also performed using the slope of the linear trend of data.

Results

Demographic data

Information about group characteristics is detailed in Table 1. The table also includes information about mean room temperature and mean RTs on the PVT.

Table 1. Mean and standard deviation (between brackets) for demographic data, mean RTs on the PVT and room temperature for the sample of Study II

Group characteristics	
Sample size	14
Age	20 (3.81)
Gender	7 females
Chronotype	14.86 (3.11)
MAAS	4.16 (0.72)
ARCES	29.85 (7.13) (1)
BIS 11-A	66.07 (6.85)
Duration of sleep (in hours)	7.75 (1.19)
Wake time (in hours)	2.61(1.00)
Last ingestion of food (in hours)	1.72 (0.79) (2)
Coffee/Tea intake	2 (2)
Smokers	2 (2)
PVT performance (ms)	307.08 (25) (1)
Room temperature (°C)	22.22 (1.66) (1)

(1) The mean and standard deviation for n= 13. One participant did not complete correctly the ARCES scale and one participant did not have room temperature recording. One participant did not report time awake before testing.

The mean and standard deviation for n= 12. Two participants did not have PVT data and the sample was composed of 12 participants.

(2) Ten out fourteen participants ate breakfast before session. Two participants reported caffeine consumption between one and three hours before the session. Two participants were smokers, one of them smoked 1 hour before the session and the other participant 10 hours prior to the session.

Subjective activation and mood states

The Time (pre-test vs. post-test) ANOVA on subjective activation showed a significant main effect, F (1, 13) = 23.37, $p < .01$, ηp^2= 0.64, with participants reporting higher subjective activation before (M: 61.07, SD: 4.39) than after the test (M: 34.07, SD: 4.37). The subjective affect analysis also showed a significant difference, F (1, 13) = 5.68, $p = .03$, ηp^2= 0.30, showing less positive affect after the test (M: 62.48, SD: 5.66) in comparison to pre-test assessment (M: 74.45, SD: 3.54).

Wrist temperature data

The ANOVA revealed a significant effect of Block on wrist temperature, *F* (2, 24) = 112.50, $p < .01$, $\eta p^2 = 0.90$, showing a decrease in wrist temperature from baseline over time on task (see Figure 4.1).

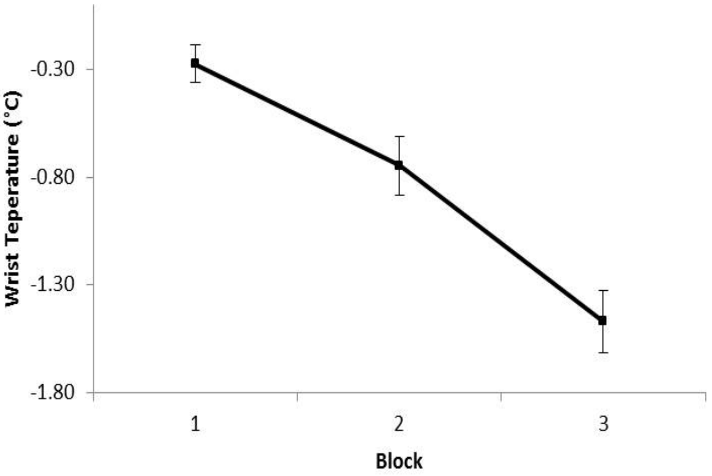

Figure 4.1. Decrement in wrist temperature (variation from baseline) as a function of time on task.

Sustained Attention to Response Task (SART)

Accuracy. The main effect of block did not approach significance, *F* (2, 26) = 1.64, p = .21. We performed further comparisons between blocks based on the results of Study I, which revealed that Block 1 was not significantly different from Block 3 (*F* (1, 13) = 2.76, p = .12) and Block 2 (*F* <1; see Figure 4.2).

Reaction Times. The effect of Block was far from significant (F < 1).

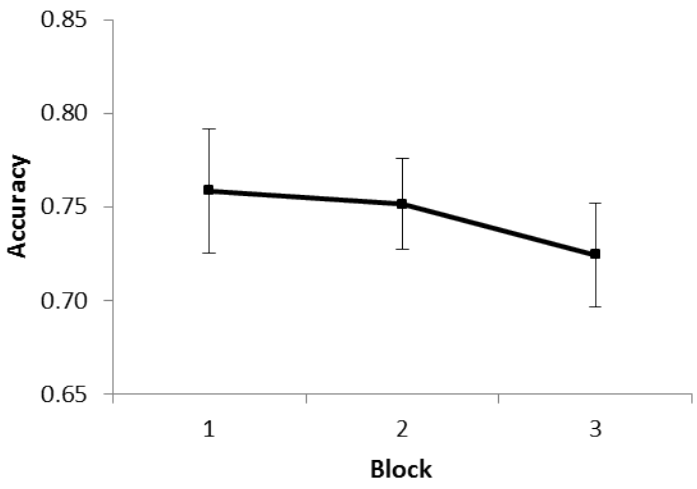

Figure 4.2. Mean proportion of accurately inhibited responses in the no go condition as a function of time on task.

Event-related potentials

P1

The P1 mean amplitude did not differ significantly over time on task (p = .14).

N1

The main effect of Block was significant, F (2, 26) = 3.98, p = .03, ηp^2= 0.23, showing that N1 amplitude increased over time. Planned comparisons showed the smallest amplitude in Block1 (M: -2.08, SD: 0.45) relative to Block 3 (M: -2.65, SD: 0.56; F (1, 13) = 4.71, p = .05) and also a significant difference between Block 1 and Block 2 (M: -2.63, SD: 0.56; F (1, 13) = 5.24, p = .04).

N2

The ANOVA showed a significant effect of Block, F (2, 26) = 4.15, p = .03, ηp^2= 0.03, such that N2 amplitude was larger in Block 1 (M: -1.00, SD: 0.49) than Block 3 (M: -0.27, SD: 0.53). Further analyses confirmed this trend, F (1, 13) = 5.37, p = .04. The difference between Block 1 and Block 2 (M: -0.53, SD: 0.39) was also significant, *F* (1, 13) = 5.28, *p* = .04.

P3

The P3 ANOVA revealed a significant main effect of Block, *F* (2, 26) = 7.81, *p* < .01, ηp^2= 0.37, showing that amplitude decreased over time. In particular, Block 1 (M: 3.67 SD: 0.51) showed larger amplitude than Block 2 (M: 3.00, SD: 0.37), *F* (1, 13) = 8.71, *p* = .01, and Block 3 (M: 2.79, SD: 0.48), *F* (1, 13) = 9.20, *p* < .01.

Correlational analyses

The linear trend across blocks of ERP amplitudes did not show a significant association with inhibition performance on SART (all *ps* >.19). No significant correlations were found either between SART performance and self-report measures (all *ps* > .09) or between behavioural indices of the SART and RT performance in the PVT (*p* = .21).

Discussion

The main aim of the current study was to assess the effect of time on task on inhibitory control and to explore electrophysiological markers of impaired inhibitory performance over time. Subjective reports confirmed that participants were vulnerable to the effect of time on task, as they reported both lower activation and more negative affect after than before the long vigilance task. However, our behavioural results did not provide strong evidence of a clear time on task effect. We observed a 3 % decrement in inhibitory performance at the end of the task. Because the sample size was relatively small (n = 14), our attempt to replicate the time on task effect on inhibitory performance may be compromised. In fact, an analysis including participants with noisy recordings in the EEG (total n= 18) revealed marginal effects (*p* = .06), a result more consistent with findings from Study 1.

We clearly observed the two characteristic potentials showed by ERP studies using Go/Nogo paradigms when inhibition is required, the No-go N2 and the No-go P3. Both inhibition-related potentials showed reduced mean amplitude over time, suggesting that they were sensitive to the time on task effect. Regarding early ERPs, only the N1 showed enhanced amplitude (more negative) with increasing time on task. Contrary to what we expected, however, we did not observe significant correlations between behavioural and ERP measures, which may be attributed to the small sample size tested in the present study.

Our main finding of decreased amplitudes of the No-go N2 and No-go P3 over time is in line with Kato and colleagues (2009), who reported reduced No-go P3 amplitude over time during a spatial Go/Nogo task. This decrement was interpreted to reflect attenuated attentional resources over time. This interpretation also fits well with studies relating impaired inhibitory performance with reduced No-go N2 and No-go P3 amplitudes (Falkenstein, Hoormann, & Hohnsbein, 1999; O'Connell et al., 2009).

In a similar vein, previous ERP studies using the random SART found the N2/P3 inhibitory complex (Zordan, Sarlo, & Stablum, 2008; O`Connell et al., 2009). In the present study, we also observed both the fronto-central No-go N2 and the No-go P3 with a broader distribution. O'Connell and colleagues (2009) found that both the No-go N2 and the No-go P3 were attenuated for unsuccessful responses (i.e. failures of inhibition) in the random SART (O'Connell et al., 2009). We predicted that if amplitude of both inhibition-related waves were associated to successful performance in the random SART, a decline in accuracy might be coupled with attenuated No-go N2 and

No-go P3 amplitudes over time. Although our ERP data did not clearly parallel the accuracy data, our results of amplitude decrements in N2/P3 with time on task may reflect increasing difficulty to perform the task because of the continuous demand of sustained top-down attention for successful inhibition (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). These results fit with previous behavioural and EEG studies noting that the SART or SART-like vigilance tasks (i.e. requiring the inhibition of responses) are resource-demanding (Grier, et al., 2003) or negatively influenced by manipulations of the level of mental fatigue prior to perform the SART (Smit, Eling, & Coenen, 2004). Therefore, our results suggest that both No-go N2 and No-go P3 amplitudes can potentially be indices of processing efficiency or resource allocation underlying inhibitory functioning over time.

Furthermore, we observed increased N1 amplitude along time on task. The N1 had been proposed as an index of perceptual discrimination (Vogel & Luck, 2000; Luck, 1995). The No-go N1 amplitudes have shown to be enhanced with high levels of task difficulty. Accordingly, this N1 modulation may reflect a greater allocation of visual resources to inhibitory processing as a function of task difficulty (Benikos et al., 2013). The trend toward enhanced No-go N1 amplitude over time in the present study could thus reflect a greater difficulty for perceptual discrimination as time on task progresses.

Finally, we tested whether skin temperature could be a sensitive predictor of performance during high-demand tasks. The results showed that wrist temperature declined as time on task increased. At first, this finding could suggest wrist temperature as an index of the vigilance decrement, in accordance with the resource theory of the vigilance decrement (Warm, Parasuraman, & Matthews, 2008). However, an alternative explanation emerged according to the literature on circadian thermoregulation. Heat production exceeds heat loss during morning hours, and temperature at distal skin regions normally decreases (Kräuchi, 2007). Note that our participants were tested at 11:00. Therefore, the current experiment was not designed to clarify whether the decline in distal temperature was reflecting either the natural circadian rhythm or a time on task effect caused by cognitive task demands. With this aim, we carried out a further experimental series, which will be detailed in the next chapter.

CAPITULO 5

Capítulo 6: Estudio 3

CAPITULO 6

CAPITULO 6

Introduction

Vigilance refers to our ability to stay alert and focused on a task over time (Warm et al., 2008). An important finding from vigilance research is the performance decline as time on task increases, known as the vigilance decrement (Mackworth, 1948; Davies and Parasuraman, 1982). Neuroergonomic approaches aim at identifying neurophysiological indices associated with performance in natural and working environments. Vigilance performance relies on a right frontoparietal network and is modulated by the subcortical noradrenergic system known to regulate arousal level (Posner and Petersen 1990; Posner, 2008).

A study by Paus and colleagues (1997) measuring regional cerebral blood flow (Positron Emission Tomography –PET-) and electroencephalogram (EEG) showed reduced activity over time in both right frontal and parietal regions associated to vigilance and subcortical arousal areas during a vigilance task (Paus et al., 1997). Moreover, using arterial spin labeling (ASL) perfusion-based functional magnetic resonance imaging (fMRI), it has been observed that changes in frontoparietal cerebral blood flow (CBF) after the task relative to a baseline (rest) period can be a successful index to measure cognitive workload, and CBF levels before the task in the right middle frontal gyrus and thalamus can predict performance decrements (Lim et al., 2010).

Most neuroimaging techniques (such as perfusion positron emission tomography –PET- or functional magnetic resonance imaging –fMRI-), however, require for instance that individuals stay still within the scanner and are not appropriate for real-world settings. Alternative neuroimaging tools for use in real life situations are functional near infrared spectroscopy (fNIRS) and Transcranial Doppler (TCD) sonography (Mehta and Parasuraman, 2013). Using TCD, it has been found that decrements in performance efficiency over time are coupled with declines in CBF velocity on the right hemisphere (Warm and Parasuraman 2007; see also Warm, Matthews and Parasuraman 2009).

As for autonomic measurements, skin temperature could be a promising candidate due to the recent development of low cost, wireless and easy-to-use portable devices that can reliably measure skin temperature under normal living conditions for several days (van Marken Lichtenbelt, et al., 2006; Sarabia, Rol, Mendiola, & Madrid, 2008; Ortiz-Tudela, Martinez-Nicolas, Campos, Rol, & Madrid, 2010; Kolodyazhniy, et al., 2011).

It is known that optimal performance in simple reaction time (RT) tasks is coupled with the highest values reached during the circadian rhythm (a roughly 24-hour cycle) of core body temperature (CBT); that is, RT is lowest when central temperature is highest (Kleitman & Jackson 1950; Wright, Hull & Czeisler 2002; reviewed by Blatter & Cajochen 2007). Moreover, heat loss via distal skin regions promotes decrements in CBT, and is positively associated with high sleepiness and earlier sleep onset latency (Kräuchi, Cajochen, Werth, & Wirz-Justice, 1999; Kräuchi, Cajochen, Werth, & Wirz-Justice, 2000; Kräuchi, 2007). Heat loss is usually measured by the gradient between body temperature at proximal and distal skin sites ("distal to proximal gradient", DPG) as an index of peripheral vasoconstriction (Rubinstein & Sessler, 1990).

Proximal skin temperature (measured at the infraclavicular area on the chest) exhibits a similar time course as core body temperature, whereas distal skin temperature oscillates in opposite phase throughout the day. Core body temperature progressively increases during daytime until it reaches its maximum (acrophase) at evening and then it continues to fall throughout the night. In contrast, distal skin temperature (measured at the palmar side of the wrist) begins to rise at evening and reaches its acrophase during the sleep period (Kräuchi, 2007; Sarabia, Rol, Mendiola, & Madrid, 2008). In general, the moment when core temperature is at minimum, and distal temperature is at maximum (between 3 and 5 am), is closely associated with the lowest level of alertness as reported by subjects and indexed by reaction time tasks, such as the Psychomotor Vigilance Task (PVT; Wright, Hull & Czeisler 2002; Gradisar & Lack 2004), and is related to increased rates of accidents (Folkard, 1997).

Although most studies had usually focused on measuring the course of the vigilance state and body temperature across the circadian cycle, only a few studies have recently analysed temperature fluctuations over shorter monitoring periods. Ramautar and colleagues (2013), using a modified PVT of 19 minute long where participants performed speeded perceptual discriminations, found that DPG temperature was negatively associated with levels of beta activity after a sleep night deprivation (indicating a decrease in compensatory efforts to maintain vigilance) and also positively with the peak latency of the P3 (13.5 ± 6.4 ms per 1 ºC increase in DPG, indicating a slower speed of processing associated to low vigilance) particularly after a normal night of sleep (Ramautar et al., 2013). Moreover, Romeijn and Van Someren (2011) used the same task and found that high proximal (chest) temperature was associated with longer response times. The same relationship was found for distal temperature and the gradient between skin temperatures (Romeijn & Van Someren 2011). For example, they found that an increment in 1 ºC is related to slower responses by 27 ms. Therefore, these indices could be used as markers of the vigilance state during cognitive task performance.

This finding opens important questions for applied contexts. Thus, to the best of our knowledge, no study had reported whether the temporal course of skin temperature changes as a function of time on task during vigilance tasks. It is unclear whether skin temperatures are task dependent, that is, if they are selectively influenced by cognitive demands. Furthermore, it had not been addressed whether body skin temperature can be related to behavioural performance in other than simple RT tasks, such as tasks demanding executive control.

Therefore the current research had three aims:

1) Testing whether skin temperature is sensitive to the time on task effect.

2) Testing whether skin temperature is sensitive to different loads in cognitive demands.

3) Testing whether skin temperature can be used to predict task performance.

We compared which of our three main measures of skin temperature (distal, proximal or DPG) showed the highest sensitivity to our experimental manipulations. In two experiments, we used a task demanding sustained attention for successful response inhibition, the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Most studies using the SART have focused on overall failures of inhibition as a result of momentary lapses of attention(Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Manly, Lewis, Robertson, Watson, & Datta, 2002), but the SART further allows testing how response inhibition evolves over time, that is, the vigilance decrement (Lara, Madrid & Correa, 2014).

In Experiment 1, a group of participants completed the SART whereas the control group did not. The control group allowed measuring the change of skin temperatures without an active cognitive engagement in the task and, therefore, accounting for task unspecific changes, for example, produced by the strong effect of circadian rhythms of temperature.

In Experiment 2, all participants performed single-task (SART) and dual-task (SART and a counting task) conditions. We manipulated the cognitive load imposed by the task (single, dual) in a within-subject basis to test whether skin temperature was sensitive to differential levels of attention demands. If skin temperature was a reliable index of vigilance and generalizable to high-level cognitive tasks, it should be sensitive to variations in inhibitory performance and attentional demands on the SART.

Method

Ethics Statement

All participants first signed a consent form approved by the Ethics Committee of the University of Granada. Participants in both Experiment 1 and Experiment 2 were paid for their collaboration. This study was conducted according to the ethical standards of the 1964 Declaration of Helsinki.

Experiment 1

Experiment 1 tested whether skin temperature could be a sensitive physiological index of attentional level during a vigilance task involving executive control, the SART. We also tested, for the first time, whether changes in skin temperature depend on task demands by including a control condition (No Task group) where participants received the same sensory stimulation but did not perform the task (see Shaw et al., 2009, for a similar approach using transcranial Doppler sonography –TCD-).

Performance in vigilance tasks has been associated to a sympathetic release of norepinephrine and epinephrine because of induced stress by task demands (Warm, Parasuraman, & Matthews, 2008). That is, if task demands increases sympathetic arousal, the Task group would show lower wrist temperature during the test session than the No Task group. In the Task group, we also expected to find less correctly inhibited responses with higher skin temperatures (i.e., wrist, proximal and DPG; Romeijn & Van Someren, 2011).

Participants

Twenty-three students from the University of Granada participated in Experiment 1. Participants were required to sleep for at least 5 hours the night prior to the experiment. One participant with hyperthyroidism and 1 participant who was taking antihistamines, were excluded from analyses. The sample was constituted by 21 participants, 10 randomly assigned to the Task Condition (all females) and 11 assigned to the No Task Condition (7 females; see Table 5.1 for further details).

Apparatus and Stimuli

Questionnaires

The Spanish version of the reduced Morningness-Eveningness Questionnaire (rMEQ; Adan & Almirall 1991) was first administered to assess chronotype. Subjective indices of activation and affective states were measured by using a visual analog scale (VAS) ranging from 0 (minimum activation/positive mood) to 100 (maximum activation/positive mood) (Monk, 1989). Differential demands between task conditions were checked by asking participants to rate their mental effort perceived during the test session using a visual analogue scale ranging from 0 ("nothing at all") to 100 ("too much") on 4 items: strain, concentration, fatigue and motivation (Maire, et al. 2014). The Attentional-Related Cognitive Errors Scale (ARCES; Cheyne, Carriere & Smilek 2006) measured individuals' proneness to everyday cognitive errors arising from attentional lapses. ARCES scores can range from 12 (low susceptibility to lapses) to 60 (high susceptibility to lapses). The Mindful Attention Awareness Scale (MAAS; Brown & Ryan 2003), in its Spanish version (Soler, et al. 2012) was used to measure attention failures. Scores can range between 15 (very frequent attentional lapses) and 90 (fewer attentional lapses). The Barratt Impulsiveness Scale for undergraduate students (BIS 11A; Fossatti, et al. 2002) translated into Spanish (Cosi, et al. 2008) measured trait impulsivity.

Skin temperature recordings

Skin temperature was monitored using temperature data loggers (Thermochron iButton- DS1921H, Maxim, Dallas; temperature range: +15°C to +46°C, with 1 °C of accuracy and a precision of 0.125°C). The sensors recorded one sample per minute. The wrist temperature sensor was placed at the palmar side of the non-dominant hand and attached with a sport band. Proximal temperature was recorded using a sensor fixed with adhesive tape to the infraclavicular skin region on the right chest. Two participants from the No Task condition reported unintentional removal of chest sensor and then their proximal temperature data were not reliable and excluded from analyses (i.e. n= 9 for chest and DPG analyses). A third sensor recorded ambient room temperature.

Behavioural tasks

Experimental tasks were performed on a personal computer (Intel Core i7 3770) connected to a 23” LCD monitor. Programming, administration of tasks and behavioural data recording were controlled by E-prime software (Scheneider, Eschman, & Zuccolotto, 2002). To objectively assess the level of participant’s vigilance, we administered the 10-min *Psychomotor Vigilance Task* (PVT, Dinges & Powell, 1985). We used a modified version of the *Sustained Attention to Response Task*, which duration was much longer (83 minutes) than the original version (4 minutes). Participants had to respond as quickly as possible to every digit (go trials) but withhold the response when the no-go target trial (“3”) appeared. Stimulus was presented at a viewing distance of 60 cm and subtended a visual angle ranging from 0.95° to 2.86°. They were informed about their mean RT and accuracy at the end of each experimental block during an obligatory rest interval of 30 seconds. Digits turned red when the average correct response rate in no-go trials was below 0.71 (for further details see Chapter 4). The task was composed of one practice block and 6 experimental blocks. Each experimental block lasted 13 minutes.

Procedure

All participants completed a 2-hour session at 11:00 h under dim light conditions (< 8 lux). First, temperature sensors were placed at the wrist and chest to record the baseline period (with a minimum duration of 30 minutes) when the participants arrived at the laboratory. During the baseline period, participants reported about sleep duration, psychiatric and sleep disorders and consumption of stimulants. Next, they completed different scales (MEQ, ARCES, MAAS, BIS and activation-affect). Participants performed the PVT after completion of the questionnaires. Afterwards, participants assigned to the Task condition completed the SART while participants assigned to the No Task condition received the same sensorial stimulation but must remain as observers.

Design and statistical analysis

Separate one-way ANOVAs with Task Condition (Task, No Task) as a between subject factor were performed to test for differences in self-report scales (rMEQ, ARCES, MAAS, BIS), subjective effort, mean RTs on the PVT, room temperature and age. The PVT analysis excluded warm-up trials (first five trials) and RTs below 100 ms or above 1000 ms (3.10 % rejected). Scores on subjective activation and affect were analyzed using a mixed ANOVAs of 2 (Time: pre-test, post-test) x 2 (Task condition:

Task, No Task), with Time as a within-subject factor and Task as a between subject factor.

In skin temperature analyses, the DPG was calculated for each one-minute sample by subtracting proximal (infraclavicular area) from distal (wrist) temperature. Temperature data included the values recorded at one-minute intervals during performance across the 78 minutes of the SART. The minute previous to the start of the task was used as baseline. SART performance in the Task group and skin temperatures data were averaged on the subject level across 3 blocks, 26 minutes on each (these 3 blocks corresponding to the time period of block 1 + block 2, block 3 + block 4, block 5 + block 6 of the SART). The blocks were grouped in order to obtain an appropriate number of observations per block for permutations tests.

In the SART, the accuracy analysis computed the percentage of responses correctly inhibited to the no-go stimulus. Trials with RT either below 100 ms or above 1000 ms (2.60%) and incorrect trials (i.e. responses in the no-go condition) were excluded from the analysis. Both analyses excluded practice trials (i.e. trials from the practice block and five first trials of every experimental block considered as warm-up trials). The RTs were inversed transformed (1000/RT) before analyses and termed as speed. Likewise, mean RTs in the PVT were analyzed.

SART performance in the Task group as well as the group differences in skin temperatures over time on task were tested using non-parametric permutation tests (10000 times). Permutation tests are exact, unbiased and do not require meet parametric assumption requiring data fit the normal distribution (Ernst, 2004; Pesarin & Salmaso, 2010). Temperature data were analyzed using a design with the between-subject variable of Task Condition (Task, No Task) and the within-subject variable Block

(Block 1, Block 2 and Block 3).SART performance (speed and accuracy) was a one-factor (Block) design with 3 levels (Block from 1 to 3). Significant main effects and interactions were explored by using post hoc and pairwise comparisons. 95% confidence intervals (CI) are reported.

We further analysed the relationship between SART performance (accuracy and speed) and skin temperatures by linear mixed-effects analysis. Linear Mixed Models (LMMs) account for non-independence among the continuous observations from repeated measures designs, heteroscedastic and missing data. The model included Temperature and Minute as fixed effects factors. Intercepts for each subject and by subject slope were added as random effects. The analyses were performed over all trials for speed and accuracy (data filtering was the same as in permutation analyses). The permutation tests, CIs and mixed-effects model were performed using Matlab R2015b (MathWorks, Inc.).

Results

Demographic data

Analyses confirmed that Task and No Task groups were matched in chronotype, age, impulsivity, attentional trait measured by MAAS, duration of sleep prior to the experiment and the wake time before the beginning of the experimental session (see Table 5.1), except for ARCES scores, *F* (1, 19) = 5.69, *p* = .28, $\eta p^2 = 0.23$, indicating higher susceptibility to lapses in the Task group (M: 34.5, SD: 1.45) than in the No Task group (M: 29.72, SD: 1.38). In addition to these group characteristics, information about RT performance in the PVT, room temperature, ingestion of food and consumption of stimulants for each group are detailed in Table 5.1.

Table 5.1. Mean and deviation (between brackets) for demographic data for the sample of Experiment 1

	p- values	*Task Group*	*No Task Group*
Sample size		10	11
Gender		10 females	7 females
Age	.27	21 (1.01)	23 (0.96)
rMEQ	.84	13.67 (0.96)	13.40 (0.91)
MAAS	.77	4.41 (0.19)	4.33 (0.18)
ARCES	.03	34.50 (1.45)	29.73 (1.38)
BIS-11A	.64	63.40 (2.70)	61.64 (2.58)
Motivation (VAS)	.02	64.30 (7.95) (3)	35.00 (7.95)
Fatigue (VAS)	.59	72.20 (5.92)	67.60 (5.92)
Strain (VAS)	.40	37.30 (8.87)	48.00 (8.87)
Concentration (VAS)	.09	66.00 (8.48)	44.20 (8.48)
Duration of sleep (in hours)	.21	6.62 (0.36)	7.27 (0.35)
Wake time (in hours)	.31	2.85 (0.31)	2.41 (0.29)
RT performance in the PVT (ms)	.23	337.47 (6.44) (3)	326.61 (5.83)
Room temperature (baseline corrected)	.67	0.89 (0.05)	0.92 (0.05)
Ingestion of food		8 (1)	9 (2)
Coffee/Tea intake		5 (1)	4 (2)
Smokers		2 (1)	3 (2)

(1) For the Task group, 8 out 10 participants ate breakfast before session. Five participants reported caffeine consumption between one and a half and four hours before the experiment. Two participants smoked between half and one hour before the session.

(2) Nine participants ate breakfast before session and 4 of them reported caffeine consumption between one and two hours. Three participants smoked between half an hour and sixteen hours.

(3) One participant from the Task group did not have PVT data (n = 9). One participant from the No Task group did not complete correctly the VAS scales for effort (n = 10).

Self-report measures of activation and affect

The Task Condition (Task, No Task) x Time (pre-test, post-test) ANOVA showed a statistically significant difference between pre-test and post-test activation scores, *F* (1, 18) = 14.55, *p* < .01, ηp^2= 0.45. Participants reported subjective activation before (M: 53.84, SD: 2.65) than after the test (M: 39.87, SD: 4.07).The main effect of Task condition (p = .29) and the interaction between Task condition and Time (F < 1) did not reach significance.

Similarly, the analyses on affect scores showed a significant main effect of Time, *F* (1, 18) = 19.86, *p* < .01, ηp^2= 0.52, showing that participants reported less positive affect after (M: 59.96, SD: 3.18) than before the test (M: 75.82, SD: 3.54). The remaining effects did not reach significance (Fs < 1)

Regarding perceived effort, participants from the Task group reported higher motivation (M: 64.30, SD: 7.95) than the No Task (M: 35.00, SD: 7.95) during the test. The strain, fatigue and motivation scores did not show significant differences between groups (all ps = .09; see Table 5.1 for further details).

Behavioural Tasks

Psychomotor Vigilance Task (PVT)

PVT performance did not differ between groups, *F* (1, 18) = 1.56, *p* = .23, suggesting that they were balanced in terms of their vigilance level before prior to starting the test (see Table 5.1).

Sustained Attention to Response Task (SART)

Accuracy

In the SART, the effect of Block on accuracy (i.e. responses correctly inhibited to the no-go stimulus) was significant (p < .01). Post hoc test showed higher accuracy for Block 1 (M: 0.82; 95% CI [0.80, 0.84]) with respect to both Block 2 (M: 0.76; 95% CI [0.74, 0.78]; p < .01) and Block 3 (M: 0.77; 95% CI [0.75, 0.79]; p < .01) but not between the last two blocks (p = .47; see Figure 5.1).

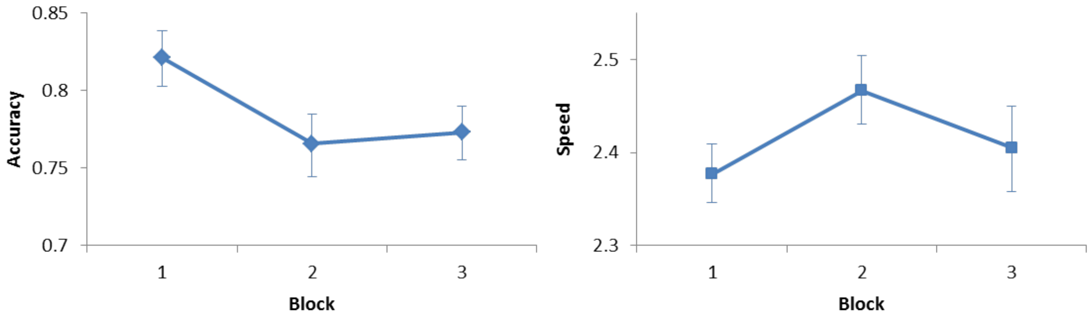

Figure 5.1. Accurate responses (proportion of correctly inhibited responses in the no-go condition) and speed (1000/Reaction Time) as a function of time on task. Vertical bars denote CIs of the mean

Speed

The speed analysis showed a significant main effect of Block (p < .01). Further post hoc test showed that speed of response was faster in Block 2 (M: 2.47; 95% CI [2.43, 2.50]) in comparison to Block 1 (M: 2.38; 95% CI [2.35, 2.41]; p < .01) and Block 3 (M: 2.40; 95% CI [2.36, 2.45]; p < .01). There was no difference between Block 1 and Block 3 (p = .55; see Figure 5.1).

Skin Temperatures

The chest temperature results showed both significant main effect of Block and Task condition (ps < .01; see Table 5.2). The interaction between both factors was only marginally significant (p = .08). Separate main effects showed that chest temperature in both Task and No Task groups showed a time on task effect (ps < .01). Furthermore, pairwise comparisons showed that groups differed at all blocks (all ps < .01). In particular, the Task group showed higher chest temperature than the No Task group (see Figure 5.2).

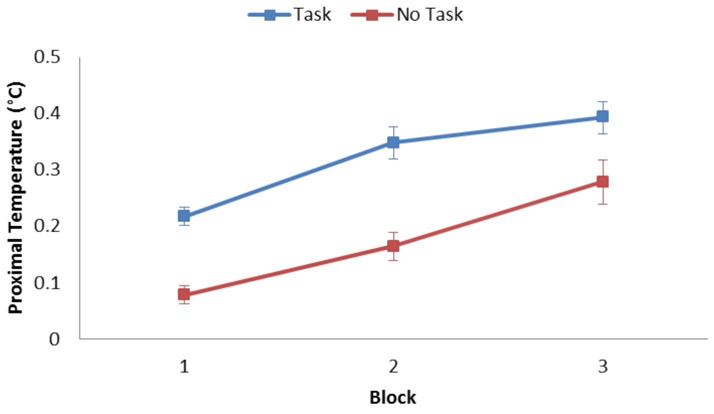

Figure 5.2. Chest temperature over time as a function of Task condition

The wrist temperature analyses showed a significant main effect of Block (p < .01). Post hoc test revealed that temperature in Block 3 was lower than in Block 2 and Block 1 (ps <.01, see Table 5.2.). This was also true for DPG (all ps < .01). On the other hand, DPG temperature was lower in Task vs No Task groups (p = .01, Table 5.2).

Table 5.2. Results of the permutation tests (p-values) and the mean temperature values [95% CIs] for both Task groups and each Block.

	Distal	**Proximal**	**DPG**
Main effect of Task	p = .72	p < .01	p = .01
Task	0.004 [-0.04, 0.05]	0.32 [0.31, 0.33]	-0.31 [-0.36, -0.26]
No Task	0.02 [-0.03, 0.07]	0.17 [0.15, 0.19]	-0.22 [-0.29, -0.16]
Main effect of Block	p < .01	p < .01	p < .01
Block 1	0.14 [0.10, 0.17]	0.15 [0.14, 0.16]	-0.03 [-0.07, 0.005]
Block 2	0.12 [0.06, 0.18]	0.26 [0.24, 0.28]	-0.16 (-0.23, -0.10]
Block 3	-0.22 [-0.30, -0.15]	0.34 [0.32, 0.36]	-0.61 [-0.70, -0.53]
Interaction Task x Block	p = .80	p = .08	p = .76
Task group		p < 0.01	
Block 1	0.13 [0.08, 0.17]	0.22 [0.21, 0.24]	-0.09 [-0.13, -0.05]
Block 2	0.13 [0.05, 0.20]	0.35 [0.32, 0.38]	-0.22 [-0.30, -0.15]
Block 3	-0.24 [-0.36, -0.13]	0.39 [0.36, 0.42]	-0.64 [-0.74, -0.54]
No Task group		p < 0.01	
Block 1	0.14 [0.09, 0.19]	0.08 [0.06, 0.10]	0.03 [-0.04, 0.10]
Block 2	0.11 [0.02, 0.19]	0.16 [0.14, 0.18]	-0.10 [-0.21, 0.01]
Block 3	-0.20 [-0.31, -0.10]	0.28 [0.24, 0.32]	-0.58 [-0.72, -0.45]

Relationship between skin temperatures and SART performance

Linear mixed-effects model for accuracy and speed failed to show a significant effect of skin temperature (all ps > 0.13; see Table 5.3).

Table 5.3. Results of the linear mixed-effect analyses indicating effects of temperature fluctuations as regressor for fluctuations in responses correctly inhibited and speed of response per degree-Celsius change in temperature. The regression model was: Behavioural index ~ 1 + Minute + Temperature + (1 + Minute + Temperature | Subject)

	Accuracy		**Speed**	
	Effect ± SE	**p**	**Effect ± SE**	**p**
Distal	0.106±0.06	0.13	-0.004±0.01	0.79
Proximal	-0.003±0.05	0.92	0.008±0.01	0.67
DPG	0.085±0.06	0.22	-0.005±0.01	0.74

Discussion

Experiment 1 replicated the time on task effect on inhibitory control, such that participants' ability to inhibit inappropriate responses declined over time (in a more pronounced manner during the first half-hour). Moreover, speed of response fluctuated over time on task. Participants responded faster in the second half-hour of the task but then speed of response slowed during the last half-hour.

Regarding our first aim, we found strong time on task effects on all temperatures. However, this effect was mainly task unspecific, as it appeared in both task groups. Increments in proximal and decrements in wrist and DPG temperatures fit well with the typical circadian rhythm at 11 am and with the literature on circadian thermoregulatory processes showing that heat production exceeds body's heat loss during morning hours (Krauchi, 2007). Overall, chest temperature increased and heat loss measurements (distal temperature and DPG) decreased over the session. It may be concluded that the circadian rhythm exerted a strong influence on temperatures, thus masking a clear effect of task demands. In fact, only the proximal temperature differed between task groups, and it only showed a marginally significant interaction with the time on task effect. Therefore, our manipulation of task demands may have not been sufficiently robust. In fact, subjective reports of activation, mood and perceived effort (fatigue, strain, motivation and concentration) did not differ significantly between groups. For instance, it is possible that the control condition, where participants had to maintain visual attention passively (without a challenge or task engagement for responding), was more demanding than we expected (Grier, et al. 2003).

Therefore, Experiment 2 was designed to optimise the sensitivity of temperatures to differential task demands on the basis of two main changes:

1) We used a stronger manipulation of cognitive workload by using a dual-task methodology.

2) To minimise the robust influence of circadian rhythms, we tested over different times of day, so that different trends as a function of time of day would cancel each other. Moreover, using different times of day would enhance the generality of our findings.

Experiment 2

Experiment 2 tested whether skin temperatures (distal, proximal and DPG) were task-selective by using a dual-task methodology (Pashler, 1994), in which participants performed the SART together with another task simultaneously. Skin temperatures were recorded during the performance of single-task (SART) vs dual (SART and a counting task) task conditions. In Experiment 2 all participants were tested under each of the two task conditions at the same time of day, either in the morning (9:00, 11:00, or 13:00) or in the afternoon (16:00, 18:00 or 20:00h), to assess different skin temperature dynamics over the course of the day. We also tested a larger sample size than in Experiment 1.

We expected less accurate inhibition in the dual-task condition (SART and counting task) than when the SART was performed alone (single-task condition). Moreover, the greater vigilance decrement should be observed in the dual-task condition, according to the higher demands of cognitive resources when performing two tasks simultaneously (Davies and Parasuraman, 1982; Warm et al., 2008).

According to Experiment 1, proximal temperature should differ over time on task as a function of task condition (i.e. Task x Block interaction). Overall, skin temperatures could be affected by the time on task effect with independence of the circadian trend associated with a fixed testing time. On the other hand, according to Romeijn and colleagues (2011), we expected to find that higher skin temperature correlated with lower accuracy response inhibition, in particular in the proximal temperature.

Participants

Inclusion criteria for participating were having slept a minimum of 5 hours the night prior to sessions and not taking antihistamines. Forty-two students from the University of Granada took part in Experiment 2 (26 females; see Table 5.4, for further details).

Apparatus and Stimuli

Questionnaires

All self-reported scales were the same as those used in Experiment 1 except for the Pittsburgh Sleep Quality Index (PSQI; Royuela and Macías, 1997), which was included to assess subjective aspect of sleep quality.

Skin temperature recordings

Skin temperature measurements were recorded in the same manner as described in Experiment 1.

Behavioural tasks

In Experiment 2, participants did not perform the PVT. On the other hand, we used a 55-min version of the SART. Participants completed one practice block and 4 experimental blocks (13 minutes each). Trials began with the 100 ms presentation of a central fixation cross (yellow or blue-coloured) followed by a digit displayed for 1100 ms or until response (see Figure 5.3).

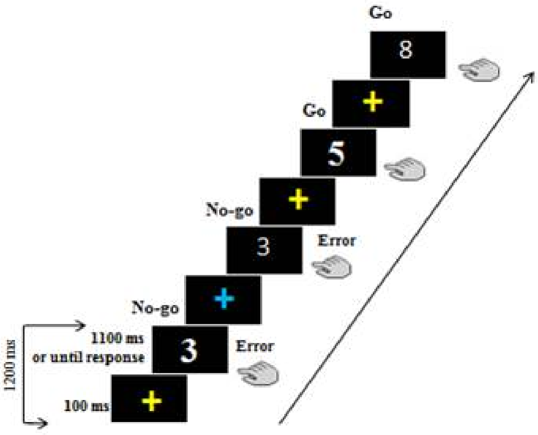

Figure 5.3. Sequence of events for both single-task and dual-task conditions in the SART.

Each colour was randomly presented and there was a low proportion of blue (ranging from 0.06 to 0.12 according to two different occurrence probabilities) in comparison to yellow crosses (from 0.94 to 0.87). The two probabilities of blue crosses were presented in alternating order across blocks and this sequence order was counterbalanced across subjects, so that half of the participants first did a block with the low proportion of blue crosses and the other half a block with the high proportion. The crosses were presented with unequal probabilities to ensure that participants did not generate expectations about the occurrence of blue crosses across blocks. In the dual-task condition, participants were instructed to perform the SART while at the same time performing a counting task: they had to count and remember how many times the blue fixation cross appeared. They reported the number of blue crosses presented when that block ended. At the end of each block, participants were informed about their mean RT, accuracy and the number of blue crosses presented during an obligatory one-minute rest interval. In the single-task condition, coloured crosses (blue and yellow) also appeared but participants performed only the SART. Since we used coloured crosses for the dual task manipulation, in contrast to Experiment 1, the digit colour did not change to red to provide feedback online in this experiment.

Procedure

All participants carried out a 90-minute laboratory session twice on two consecutive days, at the same time of day, with a lighting level of 97.9 lux. Experimental sessions were carried out at one of the following testing times: 9:00, 11:00, 13:00, 16:00, 18:00 or 20:00 h. The order of task condition (single, dual) was counterbalanced across participants. In one of the two sessions, they were asked to fill out the rMEQ and PSQI questionnaires while in the other they completed the MAAS, ARCES and BIS 11A scales. The Monk' scale activation and affect scales, the VAS scale for self-perceived effort, and questionnaires about sleep duration, time awaking, ingestion of food and consumption of stimulants were administered as in Experiment 1. Finally, participants performed the SART as single task or the SART simultaneously with the counting task.

Design and statistical analysis

The average duration of sleep the night prior to the test, the time awake before each session, and scores on the VAS scales for effort were analyzed by repeated measures ANOVAs to test for possible differences between sessions. Subjective measurements of activation and affect were analyzed with Time (pre-test, post-test) as a within-subject factor. For measures of the secondary task performance we also computed a repeated measure ANOVA with Block (Block 1, Block 2) as within participant's factor. Responses in the counting task were recorded at the end of each block. We computed the percent deviation of responses with respect to the number of crosses presented in the block.

As in Experiment 1, blocks in the SART were grouped (Block 1 + Block 2, Block 3 + Block 4) in order to obtain an appropriate number of observations per block for permutations tests.

For skin temperature analyses, we performed a visual inspection of temperature plots to detect artifacts and noise during the recordings. In the chest temperature data, we observed changes equal to or greater than 0.5 C from one minute to the next (similar to changes in skin temperature recordings of subject from Experiment 1 who reported unintentional removal of sensor). It is unlikely that such abrupt changes reflected physiological fluctuations in skin temperature, so data from 6 participants were excluded from analyses. On the other hand, for technical reasons, 1 participant did not have wrist temperature recording and another participant did not have chest temperature recording. In addition, one participant reported he responded with the non-dominant hand and data were excluded from analyses on distal skin temperature to avoid influences on sensitivity to show temperature changes due to continuous motor responses required to perform the task. The final sample for wrist, chest and their gradient were constituted by 39, 35, and 34 participants, respectively.

Skin temperatures (distal, proximal and their gradient) and SART performance data of both single and dual-task conditions (accuracy and inverse transformed RTs –

speed-) were analysed using non-parametric permutation tests as in Experiment 1 but with Task Condition (single, dual) as a within-subject factor. Likewise, LMMs were used to test the relationship between skin temperatures and SART performance as in Experiment 1.

Results

Demographic data

There was no difference between the average duration of sleep the night prior to the test between Task conditions (F < 1). Similarly, the time awake before each session did not differ (p = .21) between conditions. Information about sleep duration and hours awake and consumption of stimulants are also reported in Table 5.4.

Self-report measures of activation, affect and effort

The ANOVA on pre-post measures of subjective activation showed a significant effect of Time, F (1, 39) = 14.07, p < .01, $\eta p^2 = 0.26$, with greater activation before (M: 51.98, SD: 2.80) than after the task (M: 41.20, SD: 3.52). Other effects did not reach significance (all ps > .27).

Similarly, subjective affect was less positive affect after the test (M: 62.81, SD: 3.34) than before (M: 72.01, SD: 3.02), F (1, 39) = 29.65, p < .01, $\eta p^2 = 0.43$. Other effects were not significant (ps = .31).

Self-rating of effort did not differ between Task conditions (see Table 5.4 for further details).

Table 5.4. Information about self-report measurements of Experiment 2

Mean (deviation) and scores range		
	Mean (SD)	***Range***
rMEQ	12.78 (3.28)	5-24
MAAS	4.03 (0.73)	1.73-5.73
ARCES	36.11 (7.21)	26-54
BIS 11A	65.41 (9.44)	41-85
PSQI	8.05 (3.38)	3-19

Mean and deviation (between brackets) for single-task and dual-task conditions			
	p- values	***Single-task***	***Dual-task***
Activation pre-test	.16	49.91 (2.33)	54.05 (2.55)
Activation post-test	.94	41.11 (2.78)	41.29 (2.79)
Affect pre-test	.91	71.88 (2.35)	72.13 (2.47)
Affect post-test	.15	61.56 (2.42)	64.07 (2.61)
Motivation (VAS effort)	.09	58.42 (3.48)	63.37 (3.39)
Fatigue (VAS effort)	.82	63.87 (3.22)	64.70 (3.27)
Strain (VAS effort)	.10	47.10 (4.31)	53.25 (4.42)
Concentration (VAS effort)	.82	64.80 (2.79)	69.52 (3.39)
Duration of sleep (in hours)	.43	7.60 (0.22)	7.40 (0.17)
Wake time (in hours)	.21	5.17 (0.56)	5.61 (0.58)
Room temperature (baseline corrected)	0.23	0.37 (008)	0.47 (0.02)
Ingestion of food		38 (1)	41 (2)
Coffee/Tea intake		22 (1)	21 (2)
Smokers		12 (1)	12 (2)

(1) For the single-task session, 38 out 42 participants ate breakfast before session. 22 participants reported caffeine consumption between half an hour and ten hours before the experiment. 12 participants smoked between one quarter of an hour and thirteen hour before the session.

(2) Forty-one participants ate breakfast before session and 21 of them reported caffeine consumption between half an hour and twenty hours. Twelve participants smoked between one quarter of an hour and fourteen hours.

Sustained Attention to Response Task (SART)

Accuracy

The permutation test on accuracy revealed a significant main effect of Task ($p < .01$), showing higher accuracy in the simple than in the dual-task condition (see Figure 5.4). However, neither the Block ($p = .38$) effect nor the interaction between Task and block factors ($p = .76$) reached significance.

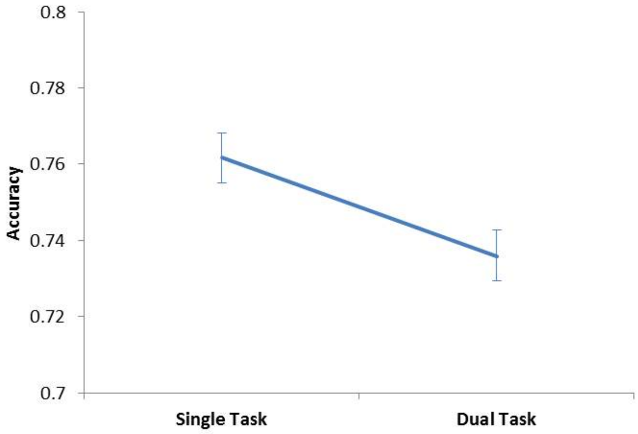

Figure 5.4. Accurate responses in the single-task and dual-task conditions

Speed

The analyses on speed showed significant main effects of Task condition and Block ($ps < .01$), and their interaction ($p < .01$). Further analyses showed a significant effect of Block in both the single-task ($p = .01$) and the dual-task condition ($p < .01$), being the effect larger in the dual task (Figure 5.5). Pairwise comparisons further revealed that speed of response differed between tasks in both Block 1 and Block 2 ($ps < .01$; see Figure 5.5).

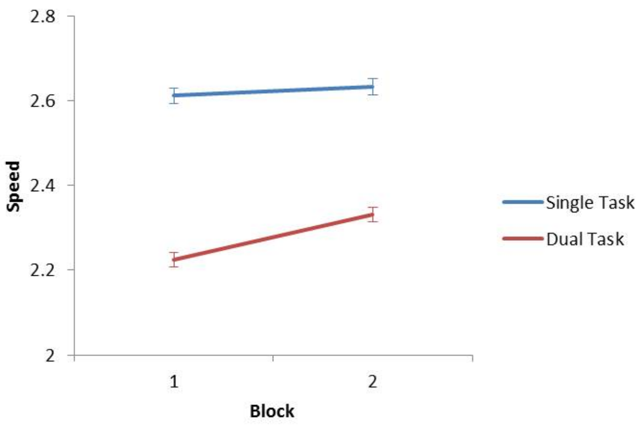

Figure 5.5. Speed in the single-task and dual-task conditions as a function of time on task

Secondary task

Performance on the secondary task was high, indicating that participants were engaged in dual task, did not change over time (F < 1). Although not statistically significant, the participants' response was more accurate during the first part of the task (percent deviation = 0.34) than during the last period (percent deviation = 4.23).

Skin Temperatures

The analyses on chest temperature revealed both significant main effects of Task condition and Block (ps < .01), and their interaction (p < .01). Further analyses showed that both single-task and dual-task condition showed a significant Block effect (ps < .01), so that chest temperature increased over time on task. Pairwise comparisons revealed that both tasks did not differ in Block 1 (p= .11) but they did so in Block 2 (p < .01; Figure 5.6).

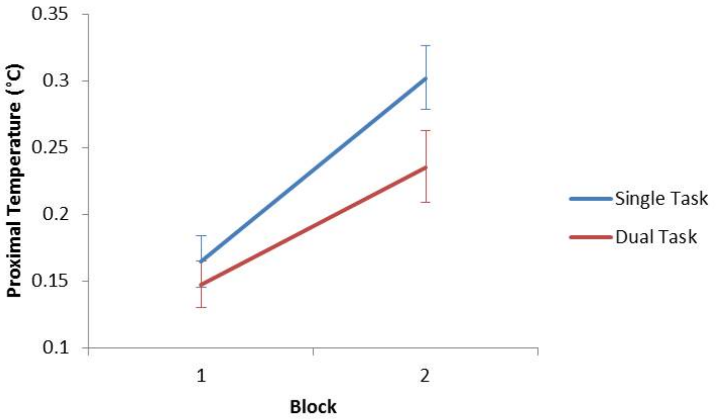

Figure 5.6. Temporal course of chest temperature (baseline corrected) over time on task as a function of Task condition. Vertical bars denote CIs of the mean

The permutation tests on wrist temperature showed significant effects of Block and Task (ps < .01). In contrast to Experiment 1, wrist temperature increased from Block 1 (M: 0.11; 95% CIs [0.09, 0.13]) to Block 2 (M: 0.16; 95% CIs [0.15, 0.21]). Moreover, the single-task showed a lower wrist temperature (M: 0.09; 95% CIs [0.06, 0.12]) in comparison to the dual-task condition (M: 0.18; 95% CIs [0.15, 0.21]; see Table 5.5). However, the interaction between Task condition and Block did not reach significance (p = .64).

The DPG temperature also showed both significant main effects of Block and Task (ps < .01). The DPG dropped with increasing time-on-task and became more negative in the last task period (M: -0.12; 95% CIs [-0.18, -0.08]) in comparison to the first period (M: -0.05; 95% CIs [-0.08, -0.02]). In addition, the single-task showed the more negative DPG value (M: -0.14; 95% CIs [-0.18, -0.10]) relative to the dual- task (M: -0.03; 95% CIs [-0.07, 0.004]). The Task condition and Block factors, however, did not interact significantly (p = .95).

Table 5.5. Results of the permutation tests (p-values) for main effects of Block and Task and their interaction. The mean temperature values and 95% CIs are provided.

	Distal	**Proximal**	**DPG**
Main effect of Task	p < .01	p < .01	p < .01
Single task	0.09 [0.06, 0.12]	0.23 [0.22, 0.25]	-0.14 [-0.18, -0.10]
Dual task	0.18 [0.15, 0.21]	0.19 [0.17, 0.21]	-0.03 [-0.07, 0.004]
Main effect of Block	p < .01	p < 0.01	p < 0.01
Block 1	0.11 [0.09, 0.13]	0.16 [0.14, 0.17]	-0.05 [-0.08, -0.02]
Block 2	0.16 [0.12, 0.19]	0.27 [0.25, 0.29]	-0.12 [-0.18, -0.08]
Interaction Task x Block	p = .64	p < .01	p = .95
Single task			
Block 1	0.07 [0.04, 0.10]	0.16 [0.14, 0.18]	-0.10 [-0.14, -0.07]
Block 2	0.11 [0.06, 0.16]	0.30 [0.28, 0.33]	-0.18 [-0.25, -0.11]
Dual task			
Block 1	0.15 [0.12, 0.18]	0.14 [0.13, 0.16]	0.004 [-0.03, 0.04]
Block 2	0.21 [0.15, 0.27]	0.23 [0.21, 0.26]	-0.07 [-0.14, -0.002]

Relationship between skin temperatures and SART performance

Linear mixed-effects models for accuracy and speed revealed a relationship between both proximal and DPG temperatures and SART performance, mainly in the single-task condition. In the dual-task condition, only the DPG was associated with accuracy for response inhibition (see Table 5.6).

Single Task

The fixed effect of proximal temperature was significant for accuracy and speed models ($p < 0.01$ and $p = 0.05$, respectively). In particular, accuracy for response inhibition increased by about 0.069 (6.9%) and speed of response slowed by about 0.012 (2.46 milliseconds) per degree Celsius that chest temperature increased (see Table

5.6). Moreover, the DPG was also related to inhibition of responses. In particular, for every degree Celsius that DPG increased, accuracy for response inhibition decreased by about 0.03 (3%).

Dual Task

Only the fixed effect of DPG temperature was significant for accuracy performance. Similarly to the Single task analysis, accuracy for response inhibition declined by about 0.03 (3%) per degree Celsius that DPG increased.

Table 5.6. Results of the linear mixed-effect analyses indicating effects of temperature fluctuations as regressor for fluctuations in responses correctly inhibited and speed of response per degree-Celsius change in temperature. The regression model was: Behavioural index ~ 1 + Minute + Temperature + (1 + Minute + Temperature | Subject)

	Single Task			
	Accuracy		**Speed**	
	Effect ± SE	**p**	**Effect ± SE**	**p**
Distal	-0.009±0.013	.46	-0.000±0.002	.78
Proximal	0.069±0.016	<.001	-0.012±0.005	.05
DPG	-0.034±0.013	.01	0.003±0.002	.25
	Dual task			
	Accuracy		**Speed**	
	Effect ± SE	**p**	**Effect ± SE**	**p**
Distal	-0.018 ± 0.015	.40	-0.004±0.004	.35
Proximal	0.022 ± 0.035	.56	-0.014±0.009	.15
DPG	-0.034 ± 0.15	.03	0.003±0.002	.88

General Discussion

Our behavioural findings from Experiment 2 showed that overall inhibitory performance was affected by dual-task load, as reflected by lower inhibition accuracy and longer response latency. This dual-task cost can reflect greater investment of cognitive processing resources when the SART was concurrently performed together with a secondary task.

Regarding the time on task effect, in Experiment 1 we found a decline in accuracy for response inhibition with increasing time on task when participants without strong morning or evening preferences were tested at a neutral testing time (11:00 h). In Experiment 2, we predicted that performance on the dual-task should be more challenging and, therefore, the decrement in inhibitory performance could be clearer. The secondary (counting) task required memory updating, which is considered an executive process (Miyake, 2000). According to the resource theory (Warm et al., 2008), the two concurrent tasks compete for limited cognitive resources during dual-task performance and, therefore, the vigilance decrement should be intensified (Helton & Russell, 2011). Several studies support that secondary memory tasks affect negatively vigilance performance over time (e.g. Caggiano & Parasuraman, 2004; Helton & Russell, 2011). In contrast to our prediction, the time on task effect in accuracy was not observed in either single-task or dual-task conditions.

However, responses became faster over time on task, replicating Experiment 1. In the SART, the go condition is expected to induce an automatic response tendency (Robertson et al., 1997). Therefore, in Experiment 1, speed of response increased in Block 2 in parallel to a decline in accurate inhibitory responses, suggesting that the automatic tendency to respond dominated over inhibitory control along time on task. In Experiment 2, responses also became faster with time, especially in dual task, but accuracy did not change. Note that speed is much slower under dual task, suggesting a controlled response style that prevented accuracy drops. As the secondary task gets practiced with time, this could be reflected as faster responses along blocks.

The main results on skin temperatures from Experiment 2 are summarized in the following paragraphs, according to three objectives of this study:

1. Sensitivity of skin temperatures to task demands

In Experiment 2, the proximal temperature was lower in the dual task, when participants performed the SART and the counting task. In Experiment 1, the No Task group showed the lower proximal temperature.

The wrist temperature was higher in the dual task, showing also selectivity to task demands.

The DPG was higher in the dual task (Experiment 2) and the No Task group (Experiment 1).

2. *Skin temperatures as index of time on task effect:*

Proximal temperature increased over time on task in both Experiment 1 and Experiment 2.

The wrist temperature decreased in Experiment 1, particularly in the last part of the task. In contrast, wrist temperature increased over time on task in Experiment 2.

The DPG decreased with time on task. This effect was consistently found in both experiments.

3. Skin temperatures as predictor of behavioural performance on the SART

In the single-task condition of Experiment 2, we found that, increments in proximal temperature were related to higher accuracy for response inhibition and slower speed of responses, suggesting a more controlled responding set with high proximal temperature.

Furthermore, increments in the DPG were related to lower accuracy for response inhibition. The same was found for the dual-task condition and accuracy performance.

Taking into account our results as a whole, proximal temperature seems to be the most sensitive measure to predict variations in SART performance. Proximal temperature increased with time on task and differed between single (higher) and dual task (lower) in the last task period. An increment in proximal temperature was related to a controlled task set (higher accuracy and lower speed of response) in the single task. Furthermore, the DPG decreased with time on task and was higher in the dual task although its temporal course did not differ between tasks. An increment in the DPG was related to poor inhibitory performance. The wrist temperature increased with time on task in Experiment 2 (unlike in the case of Experiment 1) and was higher in the dual relative to the single task. However, it did not predict SART performance.

In sum, our results suggest that wrist temperature may not be a reliable predictor of performance in the SART. Romeijn and colleagues (2011) reported that wrist temperature showed a smaller predictive value of lapses (but not for speed of response) relative to proximal temperature. This could be due to artifacts during the recording. For example, motor responses might influence dynamics of skin blood flow, leading to changes from resting to continuous movement of the hand, or might yield worse recordings due to unstable contact with skin surface.

Proximal and DPG yielded more reliable results and could be used to predict inhibitory performance. Given that recording of proximal temperature is simpler than DPG (which requires wrist recording) and according to Romeijn's study (2011), this could be the measure of election for a device monitoring the individual's cognitive state non-invasively in vigilance tasks.

The circadian profile of proximal temperature is analogous to central temperature, so high values could be related to states of high vigilance, which fits with the relation of good inhibitory performance in the single task condition, where proximal temperature is higher. However, the interpretation of high proximal temperature as a marker of optimal vigilance can hardly explain our finding of higher proximal temperature with time on task. Two complementary explanations might be provided. First, it is possible that circadian rhythm during daytime was not fully prevented in Experiment 2, so the time on task effect was reflecting the normal temporal course of proximal temperature during vigil. Second, given that accuracy was not impaired with time on task in Experiment 2, the increment with time on task in proximal temperature might reflect the "effort" to maintain an optimal level of vigilance to keep proper inhibition over time. Although these explanations remain highly speculative so far, it invites further research to clarify the sensitivity of this index to different experimental manipulations affecting the individual's psychological state.

To conclude, our research goes beyond previous findings by showing that skin temperature can be associated not only with performance in a simple RT task (Romeijn et al., 2011) but also with performance in more complex vigilance tasks requiring inhibition of responses. Furthermore, the current research shows for the first time that the recording of proximal temperature is sensitive to the effects of time on task and to variations of mental workload. Skin temperature monitoring of vigilance therefore features many advantages of neuroergonomic methods (Parasuraman and Rizzo, 2007), such as being easy to use, non-invasive, wearable, comfortable and cheap. In addition, it allows measurements over long periods of time. Further research should address sensitivity and selectivity of skin temperatures to monitor attention fluctuations over periods shorter than 24h in natural settings and to clarify the functional interpretation of these indices.

Capítulo 7: Discusión General

CAPITULO 7

Discusión General

En la presente tesis doctoral nos planteamos dos objetivos principales. En primer lugar, estudiar las fluctuaciones del nivel de vigilancia en función de tres importantes factores inherentes a cualquier situación que requiere mantener la atención: el paso del tiempo en tarea, la hora del día y las diferencias individuales de cronotipo. En segundo lugar, estudiar marcadores fisiológicos asociados a la ejecución de la tarea SART. Por ello, por una parte, exploramos la evolución de los correlatos electrocorticales del control inhibitorio de respuestas inapropiadas con el paso del tiempo en tarea mediante la técnica de potenciales evocados. Por otra parte, estudiamos la sensibilidad de la temperatura de la piel como índice fisiológico de las variaciones en el nivel de vigilancia en la tarea SART.

1. *Efecto del paso del tiempo en una tarea de vigilancia e inhibición de respuesta e influencia de factores circadianos*

La literatura sobre vigilancia, así como nuestra propia experiencia, nos muestra que conforme pasa el tiempo en una tarea que requiere mantener la atención, nuestra eficiencia para llevarla a cabo normalmente empeora.

La tarea SART está diseñada especialmente para evaluar la vigilancia mediante índices de ejecución globales. La medida principal son los fallos en inhibición, considerados índices de fluctuaciones transitorias de la atención o lapsos (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Por tanto, la tarea SART mide la habilidad para mantener la atención para una inhibición eficaz de respuestas inapropiadas. En la presente tesis, prolongamos la duración de la tarea SART para investigar el efecto del paso del tiempo en tarea.

Como hemos comentado anteriormente, nuestro nivel de vigilancia fluctúa a lo largo del día. Cabe esperar, por tanto, que las diferencias individuales en cronotipo modulen también nuestra ejecución en tareas cognitivas. Sin embargo, normalmente los estudios no tienen en cuenta estas diferencias individuales.

Nuestro objetivo en el Estudio 1 fue investigar cómo la hora del día y el cronotipo modulan el efecto del paso del tiempo en tarea en la inhibición de respuestas inapropiadas.

En cuanto a la relación entre hora del día, cronotipo y procesos de control frente a automáticos, no existe consenso en la literatura (ej. Natale et al., 2003; May et al., 2005; Bennet et al., 2008). Esta relación la estudiamos mediante una manipulación de las instrucciones de la tarea, asegurando que la ejecución requería un procesamiento de tipo controlado (estrategia Precisión) frente a automático (estrategia Rapidez). En la estrategia de primar la precisión se observaron respuestas más lentas y una mayor exactitud para inhibir respuestas inapropiadas mientras que en la estrategia de primar la rapidez se observaron respuestas más rápidas y una menor exactitud.

Nuestra manipulación de la hora del día y las diferencias individuales en cronotipo mostró que el efecto del paso del tiempo en tarea en la inhibición de respuestas inapropiadas es modulado por la hora del día y la tipología circadiana cuando intervienen procesos controlados. Es decir, observamos el efecto de sincronía en la estrategia Precisión. Sin embargo, no se observó en la estrategia Rapidez que inducía un procesamiento de carácter más automático.

En concreto, observamos que la habilidad para inhibir respuestas en los participantes matutinos decreció (12 %) con el paso del tiempo en tarea en la sesión de tarde (20:00 h) pero no encontramos un deterioro significativo en la inhibición de respuestas (3 %) con el paso del tiempo en tarea en la sesión de mañana (8:00 h). Aunque no se observó un claro efecto de sincronía para los participantes vespertinos, el deterioro en la habilidad para inhibir respuestas con el paso del tiempo en tarea fue más acusado en su hora no óptima (11 %) en comparación con su hora óptima (7 %).

Robertson y Garavan (2004) sugieren que la eficiencia para inhibir respuestas inapropiadas se relaciona con la habilidad para mantener la atención durante la tarea. Según estos autores, la red frontoparietal de vigilancia se encargaría de regular los niveles de arousal, especialmente cuando es necesario un control atencional endógeno, y esta comunicación entre el sistema de vigilancia y el sistema de arousal podría estar mediada por el cíngulo anterior (Robertson y Garavan, 2004). En esta línea, nuestros resultados del Estudio 1 sugieren que la habilidad para mantener la atención juega un importante papel en la inhibición de respuestas inapropiadas.

Por otra parte, nuestro estudio resalta la importancia de considerar no solo el impacto de la hora del día en la habilidad para inhibir respuestas inapropiadas sino también de las diferencias individuales de cronotipo. Esta influencia de factores circadianos es especialmente relevante si tenemos en cuenta la naturaleza de la tarea, observándose en tareas que requieren la participación de procesos de control.

En los Estudios 2 y 3 nuestro interés residía en el estudio de marcadores fisiológicos, y continuamos investigando el efecto del paso del tiempo en inhibición de respuestas inapropiadas con el objetivo de replicar el resultado del Estudio 1. Puesto que observamos que la hora del día y el cronotipo modulan la ejecución en la tarea SART, en el Estudio 2 y en el Estudio 3 (Experimento 1) las sesiones experimentales se realizaron a una hora neutra (11:00 h) y principalmente con participantes con puntuaciones intermedias en el cuestionario de Matutinidad-Vespertinidad. Por otra parte, las sesiones experimentales se realizaron a distintas horas en el Experimento 2 del Estudio 3. Teniendo en cuenta los distintos estudios de la presente tesis, podemos observar que el efecto del paso del tiempo en tarea en la inhibición de respuestas inapropiadas no fue consistente entre ellos. A continuación, se resumen los resultados obtenidos en los Estudios 2 y 3 sobre el efecto del paso del tiempo en tarea en la inhibición de respuestas inapropiadas y velocidad de respuesta.

Exactitud para inhibir respuestas inapropiadas

En el Estudio 2 observamos una tendencia a una menor habilidad para inhibir respuestas inapropiadas (3%) con el paso del tiempo en tarea, sin embargo, este resultado no fue significativo debido probablemente al tamaño de la muestra.

En el Experimento 1 del Estudio 3 observamos que la habilidad para inhibir respuestas dominantes decrece con el paso del tiempo en tarea. En concreto, la eficiencia para inhibir respuestas inapropiadas decreció (6%) durante la primera media hora de tarea aproximadamente y después se mantuvo estable.

Por el contrario, cuando estudiamos el efecto del paso del tiempo en tarea evaluando a los participantes a distintas horas del día (Experimento 2 del Estudio 3), la habilidad para inhibir respuestas automáticas no decreció a lo largo de la tarea.

Velocidad de respuesta

Con respecto a la velocidad de respuesta, en la tarea SART los tiempos de reacción más lentos no indican una peor ejecución como en las tareas de vigilancia tradicionales. La necesidad de mantener la atención durante la tarea implica que los participantes adopten una respuesta de carácter más controlado en los ensayos go para evitar fallos de inhibición. Como observamos en el Estudio 1, la estrategia Precisión se caracteriza por una mayor exactitud para inhibir respuestas inapropiadas junto con tiempos de reacción más lentos en comparación con la estrategia Rapidez, que se caracteriza por un estilo de respuesta de carácter más automatico, con tiempos de reacción más rápidos y una menor exactitud para inhibir respuestas.

En los Estudios 2 y 3 las instrucciones de la tarea priorizan la inhibición de respuesta sobre la velocidad de respuesta. Es decir, utilizamos las instrucciones dadas a los participantes en la estrategia Precisión del Estudio 1. En este sentido, cabe esperar que una inhibición de respuestas más eficaz se acompañe de respuestas más lentas. Con el paso del tiempo en tarea, una mayor dificultad para mantener la atención endógena se reflejaría en respuestas más rápidas y una menor exactitud para inhibir respuestas.

En el Estudio 2, no observamos un efecto del paso del tiempo en la velocidad de respuesta y, como hemos comentado, la inhibición de respuestas inapropiadas no mostró un efecto del paso del tiempo significativo.

En el Experimento 1 del Estudio 3, observamos que las respuestas se aceleran en el segundo bloque en comparación con la primera y última media hora de la tarea, donde las respuestas son más lentas. Asimismo, observamos una menor exactitud para inhibir respuestas dominantes en el bloque 2. Esta aceleración en las respuestas puede reflejar una tendencia automática, asociada con una menor exactitud.

Por el contrario, en el Experimento 2 del Estudio 3, las respuestas en los ensayos go son más rápidas mientras que la exactitud para inhibir respuestas inapropiadas no muestra un efecto del paso del tiempo. En la condición dual, la eficiencia en la tarea secundaria fue relativamente estable (el porcentaje de desviación de la respuesta dada por los sujetos fue 0.34 y 4.23 para los bloques 1 y 2 respectivamente). La aceleración de las respuestas en la condición dual podría deberse a un efecto de práctica en la tarea secundaria.

Por una parte, los resultados del Estudio 1 sugieren que la ejecución en la tarea se relaciona con el nivel de vigilancia. El efecto negativo del paso del tiempo en tarea se atenúa a la hora óptima de los participantes, coincidiendo con su nivel óptimo de vigilancia, en comparación con su hora no óptima. Sin embargo, la eficiencia en la ejecución de la tarea SART no depende exclusivamente del nivel de vigilancia. La habilidad para inhibir respuestas inapropiadas decrece debido a la dificultad para aplicar un control atencional continuo durante la tarea, de acuerdo con la teoría de los Recursos. En esta línea, también observamos un coste en la ejecución global de la tarea SART en una situación de doble tarea (Experimento 2 del Estudio 3).

2. *Índices electrocorticales relacionados con el efecto del paso del tiempo en tarea en la inhibición de respuestas inapropiadas.*

En nuestro segundo estudio investigamos el curso temporal de la actividad electrocortical relacionada con la inhibición de respuestas correctas. En concreto, analizamos los potenciales P1, N1, N2 y P3. Nuestro interés residía en evaluar si el efecto del paso del tiempo en tarea influía específicamente en los procesos relacionados con la selección de respuesta y control cognitivo o también en etapas de procesamiento más tempranas.

Cuando se requiere inhibir una respuesta, las ondas N2 y P3 muestran su máxima amplitud en la región anterior del cerebro (Eimer et al., 1993; Bokura et al., 2001; Fallgater et al., 1999). Los potenciales N2 y P3 se han interpretado como índices de eficiencia de la inhibición (Falkenstein et al., 1999).

Con el paso del tiempo en tarea, se ha observado que la amplitud del P3 decrece en tareas de vigilancia en paralelo con un deterioro en la detección de señales (Parasuraman, Warm & See, 1998). En una tarea go-nogo espacial, Kato y colaboradores (2009) también observaron una amplitud atenuada de la onda P3, sugiriendo que mantener una asignación óptima de recursos en la tarea es difícil con el paso del tiempo (Kato et al., 2009).

Pocos estudios han investigado las ondas electrofisiológicas asociadas a la ejecución en la tarea SART original. Zordan y colaboradores (2008) observaron una mayor amplitud en N2 y P3 en áreas centrales y frontales en los ensayos nogo (Zordan et al., 2008). O'Connell y colaboradores observaron además una amplitud reducida de las ondas N2 y P3 cuando se comete un error en comparación con respuestas correctamente inhibidas (O'Connell et al., 2009). Sin embargo, estos autores no investigaron el efecto del paso del tiempo en la habilidad para inhibir respuestas inapropiadas.

De acuerdo con nuestras predicciones en función de estudios previos (Zordan, Sarlo, & Stablum, 2008; O´Connell, et al., 2009), la amplitud de las ondas N2 y P3 fue sensible al efecto del paso del tiempo en tarea, mostrando una amplitud reducida. Aunque los índices comportamentales no mostraron un efecto claro del paso del tiempo en tarea como comentábamos anteriormente, nuestros resultados podrían reflejar una mayor dificultad para realizar la tarea con el paso del tiempo. Además, observamos un incremento en la amplitud del N1. Benikos y colaboradores (2013) manipularon la dificultad de la tarea en una tarea go-nogo reduciendo el tiempo permitido para responder y observaron una amplitud del N1 más negativa en la condición de mayor dificultad. Estos autores sugieren que una amplitud del N1 más negativa podría reflejar una mayor distribución de recursos visuales para el procesamiento inhibitorio (Benikos, Johnstone, & Rooddenrys, 2013). Nuestro resultado podría reflejar una mayor dificultad en la discriminación perceptiva con el paso del tiempo en tarea.

3. *Temperatura de la piel como índice fisiológico de fluctuaciones de la vigilancia en una tarea de vigilancia e inhibición de respuesta*

El registro de temperatura de la piel podría ser un índice fisiológico apropiado para medir fluctuaciones del nivel de vigilancia debido a que es una medida no invasiva, de bajo coste, de fácil aplicación y portátil, que permite además registros de larga duración.

La temperatura proximal se ha relacionado recientemente con tiempos de reacción más lentos y un mayor número de lapsus atencionales en una tarea de tiempo de reacción simple (Romeijn & Van Someren, 2011). Esta relación es más débil para la temperatura distal y el gradiente distal-proximal. La temperatura proximal, por tanto, se ha propuesto como marcador fisiológico de fluctuaciones en vigilancia durante tareas de tiempo de reacción simple. Por otra parte, estudios que manipulan la temperatura corporal han observado que los incrementos en la temperatura proximal se relacionan con un decremento de vigilancia más acusado (Raymann & Van Someren, 2007).

En el Estudio 3, nuestro interés residía en estudiar la relación entre fluctuaciones en la temperatura de la piel y variaciones del nivel de vigilancia durante la tarea SART. Es concreto, si su relación con la ejecución en tareas de tiempo de reacción simple podría generalizarse a tareas más complejas como la tarea SART, que requiere inhibir la respuesta. Para ello, llevamos a cabo el Experimento 1 (Tarea vs No Tarea) y el Experimento 2 (condición simple y dual).

El efecto del paso del tiempo en tarea se observó en todas las temperaturas de la piel: la temperatura proximal incrementó, el gradiente distal-proximal decreció y la temperatura distal mostró un patrón temporal distinto en el Experimento 1 (decremento) y en el Experimento 2 (incremento). La temperatura proximal difirió entre la condición simple y dual, siendo más alta en la simple en el último periodo de la tarea. El gradiente distal-proximal fue mayor en la tarea dual pero su curso temporal no fue difirió entre tareas. Por otra parte, en el Experimento 2 observamos una relación entre temperatura proximal y el gradiente distal-proximal con la precisión para inhibir respuestas inapropiadas. En particular, incrementos en la temperatura proximal se relacionaron con una mayor precisión para inhibir respuestas y respuestas más lentas en la condición simple mientras que el gradiente distal-proximal mostró una relación negativa con la inhibición de respuesta en la condición simple y dual.

En la presente tesis, hemos estudiado el efecto del paso del tiempo en una importante función ejecutiva, la inhibición de respuesta, y la influencia de la hora del día y el cronotipo. A pesar de la importancia del efecto del paso del tiempo en tarea y de la influencia de las diferencias individuales de cronotipo, son pocos los estudios que tienen en cuenta como interactúan modulando nuestra eficiencia en tareas que requieren control ejecutivo como la SART. Nuestros resultados muestran que el efecto del paso del tiempo en tarea en la habilidad para inhibir respuestas inapropiadas se atenúa a la hora óptima de los participantes. En futuros estudios, sería interesante realizar las sesiones a horas más extremas (especialmente las sesiones de tarde) y teniendo en cuenta participantes con cronotipo matutino, vespertino e intermedio (puesto que se considera el cronotipo más representativo de la población) para estudiar con más detalle el efecto de la hora del día en función de estas diferencias individuales.

Por otra parte, estudios previos con la tarea SART original no han estudiado los cambios en la actividad electrocortical relacionados con la habilidad para inhibir respuestas inapropiadas en funcion del paso del tiempo en tarea. En el Estudio 2, observamos que cuando se requiere inhibir una respuesta las ondas N1, N2 y P3 son moduladas por el efecto del paso del tiempo en tarea. Nuestro estudio aporta información sobre el curso temporal de la actividad electrocortical en distintas etapas de procesamiento. En futuros estudios, sería interesante explorar la actividad electrocortical asociada al efecto del paso del tiempo en la inhibición de respuestas a distintas horas del día y con participantes matutinos, intermedios y vespertinos para estudiar con más detalle la relación entre cambios en la actividad electrocortical y eficiencia en inhibición de respuestas con el paso del tiempo.

Por último, recientemente se ha observado una relacion entre temperatura de la piel y la ejecucion en una tarea de tiempo de reaccion simple, siendo la temperatura proximal la medida más prometedora para predecir fluctuaciones en vigilancia. En el Estudio 3, hemos investigado si esta relación puede generalizarse a tareas de vigilancia que requieren inhibir la respuesta. Por otra parte, no existe evidencia sobre si las fluctuaciones en temperatura de la piel se asocian selectivamente con las demandas de la tarea que se realiza y no se han estudiado los cambios en el curso temporal de la temperatura de la piel durante la realizacion de la tarea. Nuestros resultados sugieren que la temperatura proximal es la medida más sensible para predecir variaciones en la ejecución de la tarea SART. Puesto que la habilidad para inhibir respuestas inapropiadas no deteriora en el Experimento 2, el incremento en la temperatura proximal podría reflejar un esfuerzo por mantener un nivel de vigilancia óptimo para una inhibición de respuestas eficaz con el paso del tiempo en tarea. En futuros estudios, sería interesante continuar estudiando esta relación en función de las demandas de la tarea.

El registro de la actividad eléctrica del cerebro mediante electroencefalografía puede considerarse un método no invasivo con una alta resolución temporal que proporciona una medida en tiempo real del estado cognitivo. Esta medida requiere el desarrollo de algoritmos para reducir la contaminación de artefactos como movimientos, parpadeos o la interferencia de otras señales fisiológicas (Mehta y Parasuraman, 2013). Aunque se ha avanzado en este sentido, la temperatura de la piel tiene la ventaja de ser una medida más ergonómica.

La medida de la temperatura de la piel es un método de bajo coste, no invasivo, de fácil aplicación, pórtatil y cómodo, que permite un registro continuo y de larga duración en contextos naturales sin interrumpir la actividad diaria (Sarabia et al., 2008; Hasselberg et al., 2013). Aunque la temperatura de la piel permite un registro seguro mediante, por ejemplo, el uso de adhesivos médicos, en ocasiones podría registrar valores de temperatura inexactos debido a una pérdida de contacto del sensor con la piel. Sin embargo, este problema podría solventarse mediante un registro múltiple, con más de un sensor, de la temperatura de la piel (Hasselberg et al., 2013).

Conclusiones

La hora del día y las diferencias individuales en cronotipo modulan la ejecución en tareas cognitivas que requieren la participación de procesos controlados.

El efecto del paso del tiempo en tarea en la habilidad para inhibir respuestas inapropiadas es modulado por estos factores circadianos. Teniendo en cuenta su influencia podemos mejorar la eficiencia asi como atenuar el efecto negativo del paso del tiempo en situaciones de la vida diaria. Por tanto, su estudio es de especial relevancia por ejemplo para la evaluación y rehabilitación neuropsicológica, el diseño de horarios laborales y académicos para un rendimiento adecuado, y en general para la realización de actividades que demandan control e implican un riesgo para la salud.

El curso temporal de la actividad eléctrica del cerebro podría considerarse un índice neurofisiológico del efecto del paso del tiempo en tareas de vigilancia que requieren inhibición de respuesta. Nuestra exploración de los correlatos electrofisiológicos del efecto del paso del tiempo en tarea en inhibición de respuesta sugiere que es importante considerar la dinámica temporal de los potenciales relacionados con procesos de selección de la respuesta y control cognitivo y asociados a etapas más tempranas del procesamiento de la información. Los cambios en la amplitud con el paso del tiempo podrían reflejar una mayor dificultad podrían ser un índice de la eficiencia del procesamiento o la asignación de recursos con el paso del tiempo en tarea.

La temperatura de la piel, en particular la temperatura proximal, ofrece ventajas como método para monitorizar fluctuaciones en vigilancia. La temperatura proximal es la medida con mayor sensibilidad al efecto del paso del tiempo, selectividad a las demandas de la tarea y valor predictivo, lo que sugiere que podría ser utilizada para la evaluación del estado cognitivo en situaciones de vigilancia.

La relación de la temperatura proximal con la ejecución en la tarea SART sugiere además que podría considerarse un potencial índice fisiológico de variaciones en vigilancia no solo en tareas de tiempo de reacción simple sino también en tareas de vigilancia que requieren inhibición de respuesta. Por tanto, la investigación sobre su sensibilidad y fiabilidad como predictor de fluctuaciones en vigilancia es interesante debido a las posibles implicaciones prácticas en la salud y la seguridad en contextos de la vida diaria.

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