TESIS DOCTORAL

MEDICIÓN DE LAS TRES REDES ATENCIONALES EN UN CONTEXTO DE VIGILANCIA Y SU RELACIÓN CON LA CONDUCCIÓN DE VEHÍCULOS

MEASURING THE THREE ATTENTIONAL NETWORKS IN A VIGILANCE CONTEXT AND THEIR RELATIONSHIP WITH DRIVING BEHAVIOUR

DOCTORAL DISSERTATION PRESENTED BY JAVIER ROCA AND SUPERVISED BY CÁNDIDA CASTRO AND SERGIO MORENO-RÍOS

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Lista de Abreviaturas

List of Abbreviations

ACC	Accuracy in the response, generally measured using the percentage of errors
ANT	Attention Networks Test
ANT-R	Attention Networks Test – Revised
ANTI	Attention Networks Test for Interactions
ANTI-V	Attention Networks Test for Interactions and Vigilance
AO	Attentional orienting score
ARDES	Attention–Related Driving Error Scale
ASRS-I	Adult Self–Report Scale – Inattention
ß	Signal Detection Theory index for response bias
BD	Last block minus first block difference in average reaction time or accuracy
BD NTNC	Last block minus first block difference in average reaction time or accuracy, only considering no tone and no cue trials
BP	“Behavioural Prediction” hazardous driving situations
CFQ	Cognitive Failure Questionnaire
Child-ANT	Version for Children of the Attention Networks Test
d'	Signal Detection Theory index for sensitivity
DAPI-DACC	Differential Attention Processes Inventory – Dual Attention Cognitive–Cognitive
DAPI-EFA	Differential Attention Processes Inventory – Extremely Focused Attention
DBQ	Driver Behaviour Questionnaire

DF	"Dividing and Focusing Attention" hazardous driving situations
EC	Executive control score
e.g.	"For example" (*exempli gratia*)
EP	"Environmental Prediction" hazardous driving situations
FA	Percentage of false alarms
fMRI	Functional magnetic resonance imaging
H	Percentage of hits
i.e.	"This is to say" (*id est*)
IOR	Inhibition of return, i.e., a reflexive visual attention mechanism that prevents attention being re–allocated to a recently scanned location or object
NTNC	Average reaction time or accuracy only considering no tone and no cue condition
PC	Personal computer
p.e.	Por ejemplo
PhA	Phasic alertness score
% errors	Percentage of errors
PVT	Psychomotor Vigilance Test
RT	Reaction time
SART	Sustained Attention to Response Task
SD	Sleep deprivation
SDT	Signal Detection Theory
St. Dev.	Standard deviation
UFOV	Useful Field of Vision test
V	Vigilance
VAS	Visual Analogue Scale

RESUMEN EJECUTIVO

EXECUTIVE SUMMARY

Driving a vehicle is a complex multi–tasking activity, in which all the cognitive resources should be applied in a coordinated way to arrive safely at our destination. Among the different cognitive resources, considerable research efforts have been dedicated to understanding the role that the attentional system plays in driving behaviour and accident occurrence. In fact, driver distraction and inattention is considered to be one the main factors explaining road traffic casualties, and its negative influence is expected to increase in forthcoming years as a consequence of the proliferation of some potentially distracting in–vehicle technologies (e.g., Regan, Hallett, & Gordon, 2011).

As the result of more than a decade of neurocognitive research on human attention, a quick and easy computer–based task aiming to measure participants' performance in some basic components of attention has been carefully designed. The original task is known as the Attention Networks Test or ANT (Fan, McCandliss, Fossella, Flombaum, & Posner, 2002) and is based on Michael Posner and his collaborators' neurocognitive model of human attention (i.e., the three attentional networks model; Posner, 1994; Posner & Petersen, 1990). This model proposes the existence of three relatively independent neural networks (alerting, attentional orienting and executive control networks) that are responsible for controlling the different attentional functions. The ANT aims to provide separate measures of the functioning of each attentional network.

This doctoral dissertation analyses the influence of different attentional functions (such as executive control, attentional orienting and both phasic and tonic alertness) on driving behaviour. The starting point is an attempt to modify a laboratory task, the Attention Networks Test, by adding a measure of vigilance performance, since this attentional function may play a crucial role in driving. Further evidence of the validity of the new vigilance score will then be obtained from a sleep deprivation study. Next, the attentional scores obtained in the laboratory will be compared with different driving behaviour outcomes, such as self–report data provided by driver behaviour questionnaires and, finally, participants' performance in a driving simulator.

In **Study 1** (Roca, Castro, López–Ramón, & Lupiáñez, 2011), the Attention Networks Test for Interactions and Vigilance, or ANTI–V, is proposed. This test provides the original ANT with a direct measure of vigilance and the relationship between this measure and other alternative indirect indices is then analysed. The results suggest that the ANTI–V is useful to achieve a direct measure of vigilance and thus could be considered as a new tool available in cognitive, clinical or behavioural research for analysing vigilance in addition to the usual phasic alertness, attentional orienting and executive control scores. Other alternative indices (such as global reaction time and global accuracy averaged across conditions) are only moderately associated with a direct vigilance measure. Thus, although they may be to some extent related to participants' vigilance levels, they cannot be used in isolation as appropriate indices of vigilance. Also discussed is the role played by these global measures, which have been previously associated with some performance measures in applied areas (such as driving performance) in the ANT task .

The main aim of **Study 2** (Roca, Fuentes et al., 2011) is to obtain further evidence of the validity of the vigilance measure from the ANTI–V and also to analyse the influence of sleep deprivation on attentional functioning. To achieve these objectives, the attentional test was applied in a 24–hour sleep deprivation study. Results reveal that sleep deprivation affects both tonic and phasic alertness: vigilance performance deteriorated, while a warning tone was helpful in increasing participants' alertness, resulting in a slightly faster RT and, in particular, fewer errors. Additionally, the reorienting costs of having an invalid spatial cue were reduced after sleep loss. Based on these results and on evidence from previous studies, it is suggested that sleep deprivation may be more detrimental to the endogenous components of attentional orienting while the exogenous components are more resistant. Also, no sleep deprivation effect on the executive control measure was found in the present study, possibly due to the increased demands on cognitive control required by the ANTI–V. Finally, further evidence is provided of the usefulness of the ANTI–V as an attentional task that assesses vigilance together with phasic alertness, attentional orientation and executive control functioning.

In **Study 3** (Roca, Lupiáñez, López–Ramón, & Castro, 2011), the feasibility of the Driver Behaviour Questionnaire (DBQ) to study driver distraction and inattention using the ANTI–V is discussed. The DBQ is one of the tools most widely used to study drivers' attentional lapses and other types of aberrant behaviour. In this study, the relationships between the DBQ and both the ANTI–V and a self–reported measure of cognitive failure (the Cognitive Failures Questionnaire, CFQ) are analysed. Results show that attentional lapses are negatively associated with vigilance and positively associated with cognitive failure. Other types of aberrant behaviour in driving (driving errors, traffic violations and aggressive behaviours) were not found to be related to any attentional performance index (executive control, attentional orienting, phasic or tonic alertness), whereas their relationship with cognitive failure was significant but more moderate (except for DBQ–Errors, which was also highly correlated). Overall, results are consistent with the idea of DBQ–Lapses being related to driving distraction and inattention, and suggest that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour. Further evidence with improved versions of the DBQ or alternative questionnaires would be helpful to clarify whether proneness to attentional lapses while driving may be associated with crashes. Additionally, a higher tendency to make cognitive errors in everyday life has been associated with a higher attentional orienting effect (more reorienting costs) and a worse vigilance performance (lower hits), which is consistent with the suggestion that high–CFQ participants fail to ignore automated actions.

Finally, **Study 4** (Roca, Crundall, Moreno–Ríos, Castro, & Lupiáñez, 2011) aims to assess the influence of individual differences in the functioning of the three attentional networks (alerting, attentional orienting and executive control networks) when drivers have to deal with some common hazardous situations (for example, when an oncoming car or a pedestrian unexpectedly crosses their trajectory). Multiple measures of participants' attentional functioning were obtained from the ANTI–V. These measures were compared to performance in a driving simulator where different types of hazardous situation were presented. Correlation and linear regression analyses revealed significant associations between individual attentional measures and driving performance in specific traffic situations. In particular, a higher attentional orienting score on the ANTI–V was associated with safer driving in situations where a single precursor anticipated the hazard source, whereas in complex situations with multiple potential hazard precursors, higher orienting scores were associated with delayed braking. Additionally, partial evidence of a relationship between crash occurrence and the functioning of both the executive control and the alerting networks was found.

To summarise, this doctoral dissertation presents a series of four studies that will provide additional evidence to discuss the influence of different attentional functions on driving behaviour. A new version of the ANT has been developed including an extra vigilance (tonic alertness) performance score in addition to the usual phasic alertness, attentional orienting and executive control scores (ANTI–V). Once the new vigilance score has been validated in a sleep deprivation study, the multiple attentional measures from the ANTI–V are then compared with different driving behaviour outcomes, such as the Driving Behaviour Questionnaire (DBQ) and participants' performance in a driving simulator presenting common hazardous situations. Thus, this work starts in the laboratory and then takes advantage of different driving behaviour measures to analyse how individual differences in attentional functioning can influence drivers' performance. Accordingly, it is suggested that the current research may provide some insights into the theoretical grounding of the measures of the three attentional networks and may also improve our understanding of the driving task, which would be of interest to both theorists on attention and applied psychologists in the field of driving.

CAPÍTULO 1 CHAPTER

INTRODUCCIÓN

INTRODUCTION

1. JUSTIFICACIÓN E INTERÉS DEL PROYECTO DE TESIS DOCTORAL

Conducir un vehículo es una tarea cotidiana. Muchas personas lo hacen a diario, por ejemplo, para desplazarse de su hogar a su lugar de trabajo, sin que ello les represente ninguna dificultad aparente. Sin embargo, desde un punto de vista evolutivo, la conducción representa todo un desafío para nuestro sistema cognitivo. Pensemos, por ejemplo, que el ser humano se desplaza habitualmente caminando a unos 4–5 km/h. En caso de iniciar una carrera, ésta se producirá a velocidades inferiores a los 38 km/h y no durará demasiado tiempo[1]. Por ello, circular a 80 ó 100 km/h durante un tiempo prolongado representa un reto en la adaptación al entorno de los humanos, esto es, una situación excepcional en la que los conductores deben aplicar todos sus recursos cognitivos de una forma coordinada para completar el trayecto con seguridad.

En contraste con su aparente sencillez, el análisis de las subtareas requeridas para una conducción segura revela una gran complejidad (véase, por ejemplo, Groeger, 2000; Wickens, Gordon, & Liu, 1998). Mientras conducimos, debemos captar una gran cantidad de información del entorno, principalmente visual pero también auditiva y táctil (por ejemplo, los cambios en la vibración del vehículo). Primero debemos percibir los distintos elementos del tráfico y del vehículo, estimar su posición, valorar sus distancias y considerar su movimiento relativo. También debemos utilizar nuestras funciones atencionales para dar prioridad al procesamiento de determinados estímulos en cada momento (por ejemplo, los peligros potenciales o las señales pertinentes para alcanzar el destino). Toda esta información debe combinarse con nuestros conocimientos y experiencia previa para tomar conciencia de la situación y decidir un curso de acción apropiado. En este punto son aspectos claves la memoria y la capacidad de aprendizaje del conductor, como también sus creencias y actitudes ante la tarea de conducción y la seguridad. Finalmente, las maniobras deben ejecutarse mediante respuestas motoras, utilizando para ello nuestras habilidades perceptivo–motrices.

En general, los humanos somos capaces de ejecutar satisfactoriamente las distintas tareas implicadas en la conducción, al menos cuando éstas se

[1] De acuerdo con la *International Association of Athletics Federations* (2011), el record del mundo actual en 100 metros lisos (Usain Bolt, 2009) es de 9,58 s (37,58 km/h). Para recorrer distancias mayores la velocidad media disminuye. Por ejemplo, el record en la prueba de 1000 metros (Noah Ngeny, 1999) es de 2 m 11,96 s (27,28 km/h).

realizan de forma aislada. Quizá la principal dificultad de la conducción resida en la exigencia de realizar todas estas tareas de forma concurrente y/o consecutiva, de acuerdo a unos requisitos temporales muy estrictos. Mientras se conduce, es preciso atender en el momento apropiado a los estímulos adecuados, los que permitan elegir las respuestas más adaptativas en unas situaciones de tráfico que están cambiando constantemente. En consecuencia, al igual que una buena coreografía de danza depende de la perfecta sincronía con la pieza musical que toca la orquesta, un buen desempeño de la conducción dependerá de la ejecución de las distintas subtareas en un tiempo y modo óptimos (Hancock, 2009).

Dentro de este esquema general, la presente tesis doctoral trata de profundizar en el rol que distintas funciones atencionales (la alerta, la orientación atencional y el control ejecutivo) tienen para explicar el comportamiento del conductor. Por ello, los estudios empíricos que se describen en los capítulos siguientes podrían resultar de interés, en primer lugar, a los investigadores básicos sobre la atención humana, aportando nuevos datos para su definición y caracterización a partir de estudios de laboratorio y también en un contexto real de actividad humana.

Por otro lado, quizá por su enorme complejidad, la tarea de conducción suele entrañar con frecuencia la aparición de errores humanos. Algunos pueden ser menores, sin demasiada importancia, como equivocarse de marcha y corregirla de inmediato. Otros pueden tener consecuencias fatales, como no prestar la debida atención a un motorista e irrumpir en su camino al atravesar una intersección. En verdad, algunos estudios han estimado que el error humano podría contribuir entre el 45 y el 75% de los accidentes de tráfico (por ejemplo, Hankey et al., 1999). Como consecuencia, el estudio del conductor en el tráfico, con un análisis profundo de su funcionamiento cognitivo y de los factores que explican su comportamiento al volante, constituye una de las claves para reducir el número de muertos y heridos en nuestras ciudades y carreteras. Es por ello que la presente tesis doctoral, dirigida al estudio de las relaciones entre el funcionamiento atencional y el comportamiento del conductor, podría tener, en segundo lugar, un interés aplicado, aportando ideas y nuevos conocimientos para el desarrollo de posibles medidas dirigidas a reducir el número de accidentes y víctimas en el tráfico.

Para contextualizar el potencial interés aplicado de la tesis doctoral, se presentan a continuación algunos datos sobre la magnitud del problema de los accidentes de tráfico, destacando el papel que en ellos desempeñan las distracciones y la inatención del conductor.

1.1. Los accidentes de tráfico y la inatención del conductor

En la actualidad los accidentes de tráfico constituyen un grave problema y una enorme carga para la sociedad. De acuerdo con la Organización Mundial de la Salud (2009), cerca de 1,3 millones de personas mueren cada año en accidentes de tráfico (lo que equivaldría a hacer desaparecer toda la población de una ciudad del tamaño de Praga o Milán). Además, entre 20 y 50 millones resultan heridos de distinta gravedad, muchos de ellos sufriendo como consecuencia algún tipo de discapacidad permanente. Estas cifras colocan a los accidentes de tráfico como la novena causa de muerte en todo el mundo, según datos de 2004, y se espera que su impacto aumente progresivamente hasta situarse en la quinta posición en 2030 (Tabla 1.1). La tragedia que representan los accidentes de tráfico se hace todavía más patente cuando comprobamos que la mortalidad por esta causa es especialmente elevada en la población más joven. Las lesiones derivadas en un siniestro de circulación son la principal causa de muerte prematura entre los 15 y 29 años, y aún una de las tres primeras entre los 5 y los 44 años (Tabla 1.1; Organización Mundial de la Salud, 2009).

En España, según datos promedio de los últimos cinco años (Dirección General de Tráfico, 2011a), cerca de 3200 personas mueren cada año en accidentes de circulación y más de 16.600 resultan heridas de cierta gravedad. Si bien es cierto que la situación ha mejorado sensiblemente en los últimos años (habiendo pasado, por ejemplo, de unas 4100 víctimas mortales en 2006 a menos de 2500 en 2010), todavía es demasiado elevado el precio humano que se cobran en nuestro país los accidentes de tráfico. Por último, aunque secundario a todo el dolor humano, se ha estimado que los costes económicos derivados de los siniestros de circulación en nuestro país podrían alcanzar entre 13.000 y 17.600 millones de Euros anuales, un valor próximo al 2% del Producto Interior Bruto (Fundación Instituto Tecnológico para la Seguridad del Automóvil, 2008). Como consecuencia, los accidentes de tráfico no sólo constituyen un grave problema humano, sino también una enorme carga económica que termina pagando toda la sociedad en su conjunto.

	5-14 años	15-29 años	30-44 años	45-69 años	TOTAL (2004)	TOTAL (Estimación para 2030)
1	Infecciones de las vías respiratorias inferiores	**Traumatismos causados por el tránsito**	VIH/SIDA	Cardiopatía isquémica	Enfermedad isquémica del corazón	Enfermedad isquémica del corazón
2	**Traumatismos causados por el tránsito**	VIH/SIDA	Tuberculosis	Enfermedad cerebro-vascular	Enfermedad cerebro-vascular	Enfermedad cerebro-vascular
3	Malaria	Tuberculosis	**Traumatismos causados por el tránsito**	VIH/SIDA	Infecciones de las vías respiratorias inferiores	Enfermedad pulmonar obstructiva crónica
4	Ahogamiento	Violencia interpersonal	Cardiopatía isquémica	Tuberculosis	Enfermedad pulmonar obstructiva crónica	Infecciones de las vías respiratorias inferiores
5	Meningitis	Lesiones autoinfligidas	Lesiones autoinfligidas	Enfermedad pulmonar obstructiva	Enfermedades diarreicas	**Traumatismos causados por el tránsito**
6	Enfermedades diarreicas	Infecciones de las vías respiratorias inferiores	Violencia interpersonal	Cánceres de la tráquea, los bronquios y los pulmones	VIH/SIDA	Cánceres de la tráquea, los bronquios y los pulmones
7	VIH/SIDA	Ahogamiento	Infecciones de las vías respiratorias inferiores	Cirrosis hepática	Tuberculosis	Diabetes mellitus
8	Tuberculosis	Incendios	Enfermedad cerebro-vascular	**Traumatismos causados por el tránsito**	Cánceres de la tráquea, los bronquios y los pulmones	Enfermedad cardíaca hipertensiva
9	Malnutrición proteíno-energética	Guerras y conflictos	Cirrosis hepática	Infecciones de las vías respiratorias inferiores	**Traumatismos causados por el tránsito**	Cáncer del estómago
10	Incendios	Hemorragia materna	Envenenamiento	Diabetes mellitus	Prematuridad y bajo peso al nacer	VIH/SIDA

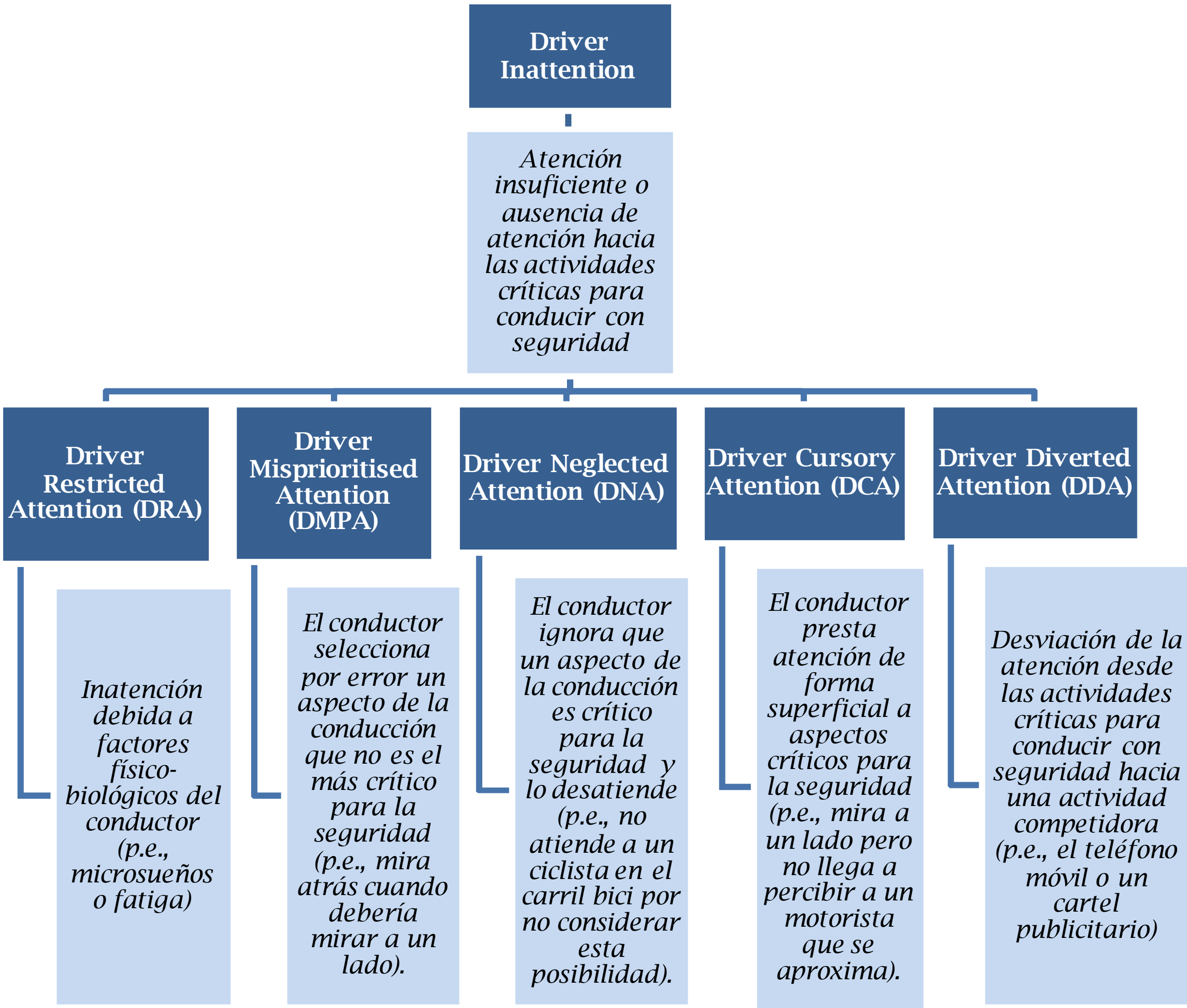
Nota: Tabla adaptada de Organización Mundial de la Salud (2009, pp. ix y 3). Los datos corresponden a 2004 y una estimación realizada para 2030 en Organización Mundial de la Salud (2008).

Tabla 1.1: Principales causas de muerte por grupos de edad en el mundo.

Entre los distintos factores que explican la ocurrencia de los accidentes de tráfico, destacaremos a continuación el caso de las distracciones y la falta de atención del conductor por su especial relación con los objetivos de la presente tesis doctoral. En general, suele aceptarse que detrás de un porcentaje importante de los accidentes se encuentra un conductor distraído o que no estaba prestando suficiente atención a los elementos del tráfico más urgentes para mantener la seguridad. Sin embargo, existen importantes variaciones en los porcentajes estimados, en función de lo que se haya considerado como distracción o inatención y también de las distintas fuentes de datos que se hayan manejado (Regan, Hallet, & Gordon, 2011; Ranney, 2008).

En un trabajo reciente, Regan y sus colaboradores (Regan et al., 2011) revisaron las diferentes definiciones y conceptualizaciones de distracción e inatención del conductor. Tras comprobar cómo estos términos habían sido utilizados en la literatura previa de una forma inconsistente y confusa, propusieron una definición y una nueva taxonomía en la que la distracción constituye un caso particular dentro del concepto más general de inatención (Figura 1.1). De acuerdo con esta propuesta, la inatención del conductor (*Driver Inattention*) es "*la atención insuficiente o la ausencia de atención hacia las actividades críticas para conducir con seguridad*" (p. 1775). Sólo cuando la inatención se produce por una "*desviación de la atención desde las actividades críticas para conducir con seguridad hacia una actividad competidora*" (p. 1776*)*, entonces estaremos hablando propiamente de distracción (*Driver Diverted Attention*). Otras formas de inatención carecen de una actividad competidora (por ejemplo, cuando un conductor somnoliento no reacciona adecuadamente ante un vehículo que frena bruscamente) y, por tanto, no deberían ser consideradas como una distracción. Sin embargo, en muchas de las fuentes de datos sobre accidentes de tráfico, es difícil identificar qué situaciones de tráfico han sido consideradas como distracción, en qué medida una distracción se ha visto potenciada por otros factores de riesgo o si dentro de esta categoría han incluido otras formas de inatención, por lo que la comparación entre las distintas fuentes debe realizarse con cautela.

En España, de acuerdo con datos oficiales de la Dirección General de Tráfico (2011b), la conducción distraída o desatenta aparece como factor concurrente en un 39% de los accidentes ocurridos en 2010, siendo esta cifra mayor en carretera (45%) que en zona urbana (33%). Estas estadísticas se basan



Nota: Figura adaptada de Regan et al. (2011).

Figura 1.1: Taxonomía de la inatención del conductor propuesta por Regan, Hallet y Gordon (2011).

en la valoración de los agentes de policía que intervienen tras la ocurrencia de un accidente con víctimas. En consecuencia, los accidentes más leves, en los que sólo se producen daños materiales, no estarían adecuadamente representados. Además, los partes que se elaboran no se derivan de un estudio exhaustivo de cada accidente, por lo que también pueden ocurrir sesgos como consecuencia de una valoración inadecuada de las causas del accidente.

Ranney (2008) revisa distintas estimaciones basadas en datos policiales (Stutts, Reinfurt, Staplin, & Rodgman, 2001; Stutts et al., 2005) y concluye que la incidencia promedio de la distracción entre los conductores involucrados en un accidente entre 1995 y 2003 en USA fue de un 10,5%. Este dato excluye los accidentes producidos por otras formas de inatención distintas a la distracción. Además, la estimación se basa en el *Crashworthiness Data System*, por el cual investigadores expertos estudian en profundidad unos 5000 accidentes al año, en los que al menos un vehículo tuvo que ser remolcado (independientemente de si se produjeron víctimas o no, lo que ocurrió en un 50% de los casos). Frente a ello, otras estimaciones basadas en estudios naturalistas han encontrado distracciones del conductor en un 33% de los accidentes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). En los estudios naturalistas se recoge una gran cantidad de datos de una muestra amplia de conductores (incluyendo imágenes de vídeo del conductor y el entorno del tráfico) durante largos periodos de tiempo (por ejemplo, un año o más) mientras utilizan con normalidad su vehículo, lo que permite luego identificar y analizar en profundidad factores concurrentes en los accidentes de tráfico observados.

Finalmente, algunos autores han destacado que la influencia negativa de las distracciones y la inatención del conductor podría incrementar sensiblemente en los próximos años, como consecuencia de la proliferación de algunas tecnologías del vehículo potencialmente distractoras, tales como, los teléfonos móviles o los navegadores GPS, entre otras (Regan et al., 2011; Stutts et al., 2001). Estos argumentos muestran, de nuevo, que el estudio de la atención y sus aplicaciones en el ámbito de la conducción constituye una oportunidad esencial y necesaria para el desarrollo de medidas dirigidas a reducir los numerosos accidentes de tráfico que se producen como consecuencia de una distracción o funcionamiento atencional inadecuado.

2. El estudio de la atención en la conducción de vehículos

El análisis y la comprensión del comportamiento del conductor es una tarea que puede abordarse desde distintas disciplinas científicas, tales como la Psicología Cognitiva, la Ergonomía e incluso la Neurociencia del Comportamiento. Por ejemplo, desde el punto de vista de la Psicología Cognitiva, la conducción de vehículos es una tarea claramente atencional en varios aspectos (para una revisión, véase Castro, Durán, & Cantón, 2006). Mientras conducimos vamos recibiendo una gran cantidad de información del entorno de tráfico. Por ello, debemos ser capaces de orientar nuestra atención a las fuentes de información más adecuadas en cada momento y procesar selectivamente aquéllos estímulos más relevantes, ignorando el resto para evitar que nuestro sistema cognitivo se vea desbordado. Pensemos, por ejemplo, en la complejidad de una intersección en zona urbana, donde hay peatones, otros vehículos en varios carriles, semáforos, carteles publicitarios, escaparates, etc. Es importante que vayamos seleccionando de una forma coordinada a cuál de estos elementos debemos prestar atención en cada momento y debemos inhibir temporalmente el procesamiento de los demás para circular con seguridad. Igualmente, es importante que mantengamos un nivel de alerta adecuado durante todo el tiempo de conducción, especialmente por la noche o en entornos monótonos (como las autovías), para poder detectar la ocurrencia de eventos que son infrecuentes pero que constituyen un claro riesgo para la seguridad. Por ejemplo, un conductor fatigado después de haber conducido durante muchas horas por autovía es menos capaz de detectar a tiempo una frenada brusca del vehículo que le precede.

En verdad, las relaciones entre la conducción de vehículos y la Psicología Cognitiva son tan estrechas que los autores que han trabajado en esta disciplina han utilizado frecuentemente la conducción como un símil o una ilustración de sus teorías, aunque no estuvieran especialmente motivados por dar una explicación del comportamiento del conductor (Castro et al., 2006). Por poner sólo un ejemplo, Duncan (1990), para ilustrar su tesis sobre cómo la selección de estímulos y metas controla la conducta humana, afirma: "*Para el conductor de un coche, por ejemplo, puede resultar difícil predecir si el nuevo input que controlará la conducta será una señal de stop, un amigo que le saluda inesperadamente desde la otra acera, o el llanto del niño en el asiento trasero. Sólo seleccionamos estímulos que son relevantes para las metas actuales* (p. 62)".

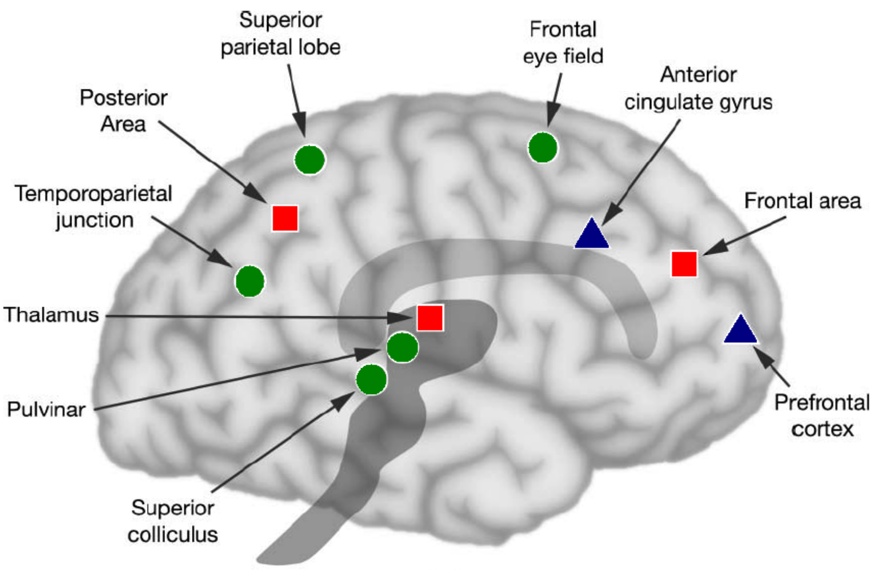
A lo largo de los años, el estudio del comportamiento del conductor se ha enriquecido con aportaciones desde las distintas teorías y conceptualizaciones sobre la atención que se han desarrollado en cada momento. Por ejemplo, el ámbito del tráfico ha sido un campo de estudio aplicado para las teorías basadas en la limitación de recursos atencionales, ya se consideren éstos centrales e inespecíficos (p.e., Kahneman, 1973) o distribuidos y específicos (p.e., Wickens y Hollands, 1992). Por ejemplo, Recarte y Nunes (2002) evaluaron la influencia de varias tareas verbales y de imaginación espacial sobre la búsqueda visual en la conducción y encontraron diferencias cualitativas en función del tipo de procesamiento requerido por las estas tareas. Las tareas de imaginación espacial, a diferencia de las verbales, produjeron un aumento en la duración de las fijaciones oculares, una mayor reducción en el área visual inspeccionada y menos miradas a los espejos retrovisores o al velocímetro. En consecuencia, los resultados fueron interpretados de acuerdo con las teorías de recursos atencionales específicos.

Por otro lado, muchos autores han recurrido durante las últimas décadas a los conceptos de atención selectiva, dividida, focalizada y/o sostenida para explicar las limitaciones en el procesamiento de la información en determinadas situaciones de tráfico. Por ejemplo, Wickens y Hollands (1992) utilizaron estos conceptos para categorizar los distintos tipos de fallos atencionales, distinguiendo entre "*límites en la atención selectiva*" (cuando se hace una selección inadecuada de los aspectos del entorno que se han de atender), "*límites en la atención dividida*" (cuando es imposible atender adecuadamente a varias fuentes de información) y "*límites en la atención focalizada*" (cuando no resulta posible mantener la atención en una fuente de información y nos distraemos).

Sin duda, los conceptos clásicos de atención selectiva, dividida, focalizada y/o sostenida han sido de gran utilidad para incrementar nuestra comprensión del comportamiento del conductor. Por otra parte, durante los últimos años se ha desarrollado un modelo neurocognitivo de la atención humana capaz de integrar una gran cantidad de datos provenientes de distintas disciplinas, tales como la Psicología Cognitiva, la Neurociencia o la Neuropsicología, y que en la actualidad está siendo utilizado con éxito en diferentes áreas aplicadas. Se trata del modelo propuesto por Michael Posner y sus colaboradores (Posner, 1994; Posner & Petersen, 1990), generalmente conocido como el modelo de las tres redes atencionales. La presente tesis doctoral constituye una nueva aplicación del modelo, en esta ocasión con la finalidad de profundizar en el estudio del comportamiento del conductor.

2.1. El modelo de tres redes atencionales

De acuerdo con el modelo neurocognitivo de la atención humana propuesto por Posner y sus colaboradores (e.g., Posner, 1994; Posner & Petersen, 1990), tres redes neurales relativamente independientes (aunque coordinadas) son responsables del control de las distintas funciones atencionales: la red de alerta, la red de orientación y la red de control ejecutivo (Figura 1.2).



Función Atencional		Principales Estructuras	Modulador
■	**Alerta**	Locus Coeruleus Lóbulo Frontal Derecho Córtex Parietal	Noradrenalina
●	**Orientación**	Lóbulo Parietal Superior Unión Temporo-parietal Campo Ocular Frontal Colículo Superior	Acetilcolina
▲	**Control Ejecutivo**	Córtex Cingulado Anterior Córtex Prefrontal Ventrolateral Ganglios Basales	Dopamina

Nota: Tabla y figura adaptadas de Posner (2007)

Figura 1.2: Resumen de la anatomía y los moduladores químicos implicados en las redes atencionales de alerta, orientación y control ejecutivo.

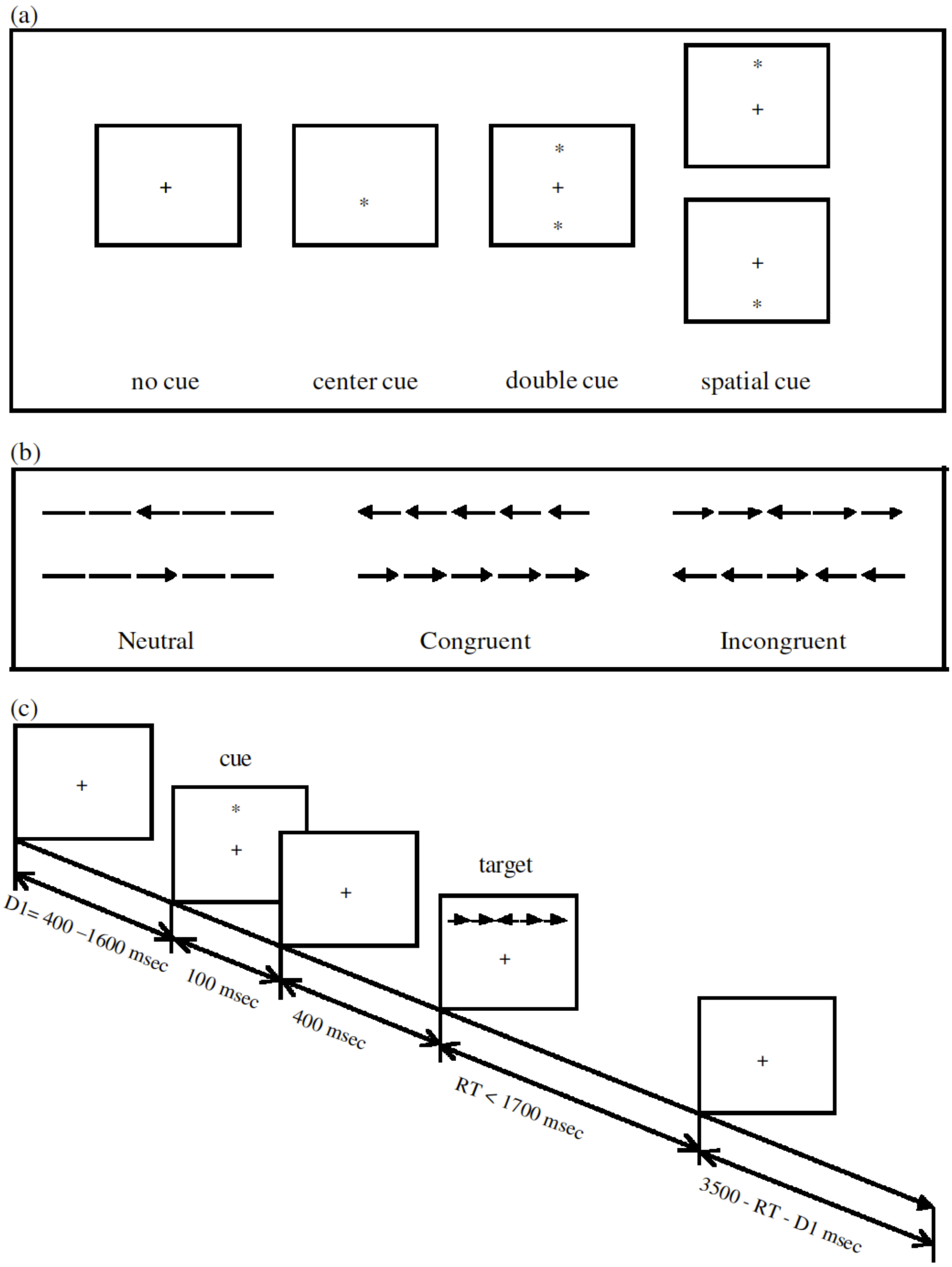
En primer lugar, la red de alerta es necesaria para alcanzar y mantener un estado de alta sensibilidad a la estimulación entrante (Posner, 2008). Incluye regiones frontoparietales del cerebro, principalmente del hemisferio derecho, y también áreas del tronco encefálico como el *locus coeruleus*, donde la noradrenalina es el principal neurotransmisor implicado (Posner 2007). La red de alerta se relaciona con el rendimiento en tareas que requieren alerta fásica y alerta tónica (Posner, 2008; Sturm & Willmess, 2001). La alerta fásica es el incremento en la preparación para responder que ocurre tras una señal de advertencia y suele medirse analizando la influencia de estas señales (por ejemplo, un tono de alerta) sobre el tiempo de reacción y la precisión en la respuesta. Por otro lado, la alerta tónica o vigilancia es la capacidad para mantener la atención durante periodos prolongados de tiempo y puede evaluarse mediante tareas de tiempo de reacción simple en ausencia de una señal de advertencia. Además, una forma habitual de medir la alerta tónica es utilizar una tarea larga y generalmente monótona para evaluar la vigilancia ante estímulos infrecuentes. En este caso, el número de lapsos atencionales (calculados como respuestas muy lentas o también utilizando el número de aciertos y falsas alarmas para estimar la sensibilidad y el sesgo de respuesta de acuerdo con la Teoría de Detección de Señales, TDS) se utiliza como un indicador de vigilancia (por ejemplo, Lim & Dinges, 2008; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; See, Howe, Warm, & Dember, 1995).

En segundo lugar, la red de orientación atencional se encarga de seleccionar la información del *input* sensorial al dirigir el foco atencional hacia áreas u objetos potencialmente relevantes en el campo visual (Posner, 2008). Esta red incluye diferentes áreas del córtex parietal y frontal, siendo la acetilcolina el principal neurotransmisor implicado (Posner, 2007). El funcionamiento de la red de orientación suele evaluarse mediante la presentación de claves visuales espaciales en tareas de tiempo de reacción (p.e., Posner, 1980). Estas claves dirigen el foco atencional hacia el lugar o el objeto donde aparecerá el estímulo objetivo (clave válida), hacia un lugar opuesto (clave inválida) y/o la clave puede ser neutra o estar ausente. Las diferencias en tiempo de reacción y precisión entre algunas de estas condiciones (por ejemplo, entre una clave neutra y una clave válida o entre una clave inválida y una válida) se consideran indicadores del funcionamiento de la red de orientación (p.e., Callejas, Lupiáñez, & Tudela, 2004; Fan, McCandliss, Sommer, Raz, & Posner, 2002).

Por último, la red de control ejecutivo incluye mecanismos para ignorar estímulos distractores y resolver situaciones de conflicto cognitivo (Posner, 2008). Distintas áreas anteriores del lóbulo frontal, tales como el córtex cingulado anterior y el córtex prefrontal, forman parte de esta red, siendo la dopamina el principal neurotransmisor que modula su actividad (Posner, 2007). El funcionamiento de la red de control ejecutivo suele evaluarse en tareas de tipo Stroop, Simon o de flancos (Stroop 1935/1992; Simon & Small, 1969; Eriksen & Eriksen, 1974), donde los participantes deben atender a un estímulo o dimensión estimular *objetivo* mientras tratan de ignorar otros estímulos o dimensiones *distractores* (por ejemplo, deben indicar la dirección de una flecha en el centro de una fila de flechas que apuntan en una dirección opuesta). El efecto de interferencia que generalmente se observa en estas tareas (por ejemplo, el tiempo de reacción es más lento cuando el objetivo y los distractores son incongruentes) se utiliza como un índice del funcionamiento del control ejecutivo (p.e., Callejas et al., 2004; Fan et al., 2002).

2.1.1. El Test de las Redes Atencionales

Tomando como referencia el modelo de las tres redes atencionales, Fan y colaboradores (Fan et al., 2002) desarrollaron una tarea de ordenador dirigida a obtener una medida rápida y sencilla del rendimiento de los participantes en los componentes básicos de la atención. Esta tarea se conoce como el Test de las Redes Atencionales (*Attention Networks Test* o ANT) y es una combinación del paradigma del tiempo de reacción señalado de Posner (1980) y la tarea de flancos de Eriksen y Eriksen (1974). En la ANT, los participantes tienen que identificar tan rápido como les sea posible la dirección (izquierda o derecha) a la que apunta una flecha. La eficiencia de las tres redes atencionales se evalúa midiendo la influencia sobre el rendimiento de señales de alerta, claves espaciales y estímulos distractores (flancos). En la versión original (véase Figura 1.3), la flecha objetivo se presenta en el centro de una serie de cinco flechas (esto es, dos flechas distractoras a cada lado). Las flechas distractoras pueden apuntar en la misma dirección que la flecha central (ensayo congruente) o en la dirección opuesta (ensayo incongruente). También hay una tercera condición en la que se presentan líneas como distractores (ensayo neutro). Además, la serie de flechas viene precedida por una clave espacial que indica el lugar donde aparecerá el estímulo objetivo (un asterisco por encima o por debajo del punto de fijación), por una clave central (un asterisco sobre el punto de fijación), por una clave doble (dos asteriscos señalando ambos lugares), o por una clave ausente (sin asterisco). A partir de estas condiciones experimentales es posible obtener una puntuación del funcionamiento de cada red atencional: efecto de alerta (clave ausente menos clave doble), efecto de orientación (clave central menos clave espacial) y efecto de congruencia o de control ejecutivo (ensayos incongruentes menos ensayos congruentes). La duración aproximada de la tarea es de unos 20 minutos.



Nota: Figura adaptada de Fan et al. (2002).

Figura 1.3: El Test de las Redes Atencionales (*Attention Networks* Test o ANT). (a) Tipos de clave espacial (sin clave, clave central, clave doble, clave espacial). (b) Tipos de estímulos distractores (neutral, congruente, incongruente). (c) Ejemplo de procedimiento.

La resultados obtenidos por distintos autores sugieren que las medidas de la ANT pueden ser consideradas como índices válidos del funcionamiento de las redes atencionales (para revisiones véase Fan & Posner, 2004; Posner, 2008). Por ejemplo, numerosos estudios con datos comportamentales han logrado generar con éxito los efectos de alerta, orientación y congruencia utilizando la ANT (p.e., Fan et al., 2002; Ishigami & Klein, 2009). En un estudio de neuroimagen con fMRI se ha comprobado que la ANT activa por separado tres regiones anatómicas relacionadas los distintos componentes de la atención, siendo estas regiones consistentes con estudios de neuroimagen previos que utilizaron otras tareas atencionales separadas (Fan, McCandliss, Sommer, Raz, & Posner, 2005). Otros autores han evaluado algunas propiedades psicométricas de las puntuaciones atencionales, tales como la estabilidad, la independencia, la robustez, la fiabilidad o los componentes de la varianza (Ishigami & Klein, 2010; Lawrence, Eskes, & Klein, 2009; MacLeod et al., 2010). Además, las puntuaciones de la ANT han permitido comprobar hipótesis específicas sobre las redes atencionales en estudios sobre genética y heredabilidad (Fan, Wu, Fossella, & Posner, 2001; Fossella et al., 2002), sobre el desarrollo de la atención en niños (Rueda et al., 2004) y con distintos tipos de pacientes con alteraciones en los componentes atencionales (p.e., Fernandez et al., 2011; Fuentes et al., 2010; Gruber, Rathgeber, Bräunig, & Gauggel, 2007; Pacheco–Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Wang et al., 2005), tal como se describe más adelante.

Por otro lado, se han identificado también algunas limitaciones en la tarea original. Por ejemplo, Callejas et al. (2004) señalaron que las puntuaciones de alerta y de orientación se obtienen de la misma manipulación experimental (tipo de clave), por lo que las interacciones entre ambas redes no pueden ser analizadas separadamente. Además, las claves espaciales en la ANT original son siempre predictivas de la localización de la flecha objetivo, por lo que la manipulación experimental confunde componentes exógenos y endógenos de la atención (Callejas, Lupiáñez, Funes, & Tudela, 2005). En consecuencia, Callejas y sus colaboradores (Callejas et al., 2004, 2005) propusieron una versión mejorada de la ANT, especialmente diseñada para analizar de forma más independiente el funcionamiento de las redes atencionales y sus interacciones. Esta nueva versión, conocida como ANTI (*Attention Networks Test for Interactions*), incluye un tono de alerta en la mitad de los ensayos para evaluar independientemente la red de alerta (calculando la diferencia en tiempo de reacción y precisión entre los ensayos sin tono y los ensayos con tono). Además, la clave visual espacial sólo es válida en la mitad de los ensayos con clave (33% válidos, 33% inválidos, 33% sin clave), por lo que en la ANTI la clave espacial no es predictiva de la aparición de la flecha objetivo y, en consecuencia, sólo se evalúa la orientación atencional exógena (automática).

Algunos estudios han comparado directamente el funcionamiento y los procesos cognitivos involucrados en la ANT y la ANTI. Por ejemplo, Ishigami y Klein (2009) administraron una de ambas tareas y el Cuestionario de Fallos Cognitivos (Broadbent, Cooper, Fitzgerald, & Parkers, 1982) a una amplia muestra de participantes (200). Tal como se esperaba, la relación entre la frecuencia de fallos cognitivos y el efecto de orientación es cualitativamente distinta en la ANT respecto a la ANTI (al menos con datos de precisión), sugiriendo que estas tareas implican componentes de orientación atencional diferentes (orientación endógena y exógena en la ANT, sólo orientación exógena en la ANTI). Además, el efecto de alerta en la ANTI también aparece relacionado con los fallos cognitivos en dicho estudio, mientras que en la ANT no se observa esta asociación, lo que se explicaría por la forma diferente que tienen ambas tareas de medir la alerta (esto es, mediante un tono de alerta independiente en la ANTI y a partir de claves visuales en la ANT). En otro trabajo de Ishigami y Klein (2010), se evaluó la estabilidad, la independencia, la robustez y la fiabilidad de las medidas obtenidas en la ANT y la ANTI en una muestra de jóvenes adultos que realizaron ambas tareas en 10 sesiones consecutivas. Los datos muestran que ambas tareas son útiles para obtener las puntuaciones atencionales, aunque las medidas de la ANTI pueden ser ligeramente más fiables, especialmente respecto al efecto de alerta. Todos los índices atencionales alcanzan un nivel aceptable de fiabilidad a medida que se agregan datos de más sesiones. Por otro lado, Lawrence, Eskes y Klein (2009) analizaron la fiabilidad de la ANT y la ANTI en población adulta no clínica y también encontraron que la alerta en la ANTI es más fiable que en la ANT. Finalmente, Fan y sus colaboradores (Fan et al., 2009) han propuesto una versión revisada de la tarea (ANT–R) incluyendo claves inválidas, mientras que los efectos de alerta y orientación todavía se obtienen a partir de la misma manipulación experimental.

2.1.2. Aplicaciones de la ANT y sus variantes

En la actualidad, la ANT y sus variantes están siendo utilizadas para evaluar el funcionamiento atencional y comprobar hipótesis específicas en una gran variedad de contextos de investigación. Por ejemplo, Fan et al. (2001) analizaron la heredabilidad de los componentes de la atención en un estudio con gemelos monocigóticos y dicigóticos. El funcionamiento de la red de control ejecutivo mostró un gran heredabilidad, mientras que la evidencia para la red de alerta fue menor. Respecto a la red de orientación, este estudio no mostró indicios de heredabilidad. Además, Fossella et al. (2002) mostraron que el funcionamiento de la red de control ejecutivo se relacionaba con determinadas variaciones en genes relacionados con el sistema dopaminérgico.

Por otro lado, Rueda et al. (2004) diseñaron una versión infantil de la tarea para estudiar el desarrollo de los componentes de la atención en distintas edades (conocida como *Child-ANT*). Las flechas de la ANT fueron sustituidas por peces de color amarillo apuntando a izquierda o derecha sobre un fondo azul y las instrucciones presentaban la tarea como un juego en el que los niños debían alimentar al pez central. Los resultados mostraron que la velocidad y la precisión mejoran desde los 6 años hasta la edad adulta y que cada red atencional sigue un patrón evolutivo diferente (por ejemplo, el efecto de alerta es muy elevado entre los 6 y 9 años y comienza a reducirse antes de los 10 años hasta la edad adulta, el efecto de congruencia se mantiene estable después de los 7 años y no se observaron diferencias en el efecto de orientación en las edades estudiadas).

Otros autores han utilizado variantes de la ANT en estudios con distintos tipos de pacientes neurológicos y psiquiátricos. Por ejemplo, Fuentes et al. (2010) observaron que las interacciones entre las redes atencionales eran diferentes en grupos de pacientes con demencia con cuerpos de Lewy, enfermedad de Alzheimer y controles (por ejemplo, tras un tono de alerta los primeros mostraban una mejora en el funcionamiento de las redes de orientación y control ejecutivo). Además, Fernández et al. (2011) estudiaron a personas con deterioro cognitivo leve y encontraron en ellos un déficit en el funcionamiento de la red de orientación. Por otro lado, Gruber et al. (2007) estudiaron el funcionamiento cognitivo en pacientes con distintos tipos de trastornos del estado de ánimo. Comparados con la depresión mayor, los pacientes con trastorno bipolar en estado maníaco obtuvieron un mayor efecto de orientación y los pacientes con trastorno bipolar en estado depresivo mostraron una peor resolución del conflicto cognitivo (mayor efecto de congruencia) utilizando la ANT. En relación con la esquizofrenia, se han observado déficits en el funcionamiento de la red de control ejecutivo y de orientación en este tipo de pacientes (Wang et al., 2005). Por último, con el uso de la ANT, se ha estudiado cómo la ansiedad modula el funcionamiento de la atención, de forma que una mayor ansiedad–rasgo se asocia con deficiencias en el control ejecutivo mientras que una mayor ansiedad–estado se relaciona con un mayor funcionamiento de las redes de alerta y orientación (Pacheco–Unguetti et al., 2010).

Los estudios con aplicaciones de la ANT y sus variantes son numerosos y muy dispares, por lo que una revisión exhaustiva escapa a los objetivos de la presente tesis doctoral. En este apartado se han descrito algunos ejemplos a modo ilustrativo. A continuación, se describen con mayor detalle los estudios existentes en el campo de la Psicología del Tráfico y el Transporte que han utilizado la ANT u otras tareas atencionales para analizar la relación de los componentes de alerta, orientación y control ejecutivo con el comportamiento del conductor.

2.2. El funcionamiento atencional y el comportamiento del conductor

Existen en la literatura científica diversos estudios que, mediante el uso de diferentes tipos de tareas o manipulaciones de la atención, han relacionado el funcionamiento de los componentes atencionales de alerta, orientación y control ejecutivo con el comportamiento del conductor. En este apartado se presentarán brevemente los principales resultados obtenidos en ellos.

2.2.1. Alerta

Tal como se ha descrito anteriormente, la red neural de alerta es responsable del control de dos importantes funciones atencionales: la alerta tónica y la alerta fásica, teniendo ambas un importante papel en la conducción de vehículos. En primer lugar, la alerta tónica o vigilancia es un componente atencional con una gran influencia en el rendimiento del conductor. Los estados de baja vigilancia han sido asociados con un peor rendimiento al volante y una mayor probabilidad de accidente, por ejemplo, tras una privación de sueño, después de una larga jornada de trabajo o durante una conducción prolongada, especialmente por la noche y en situaciones monótonas (véase, por ejemplo, Åkerstedt, Philip, Capelli, & Kecklund, 2011; Campagne, Pebayle, & Muzet, 2004; Lal & Craig, 2001; Larue, Rakotonirainy, & Pettitt, 2011).

Por otro lado, en relación con la alerta fásica, distintos estudios han mostrado la utilidad de algunos dispositivos tecnológicos de advertencia al conductor para evitar accidentes de tráfico, como los sistemas de advertencia ante una eventual salida del carril o ante una posible colisión (para una revisión, véase May & Baldwin, 2009). Por ejemplo, Lee, McGehee, Brown y Reyes (2002) presentaron distintos tipos de señales de advertencia auditivas (advertencia temprana, advertencia tardía y sin advertencia) a un amplio grupo de conductores en un simulador de conducción. En un primer experimento, los conductores debían realizar también una tarea secundaria (contar dígitos en una pantalla próxima al espejo retrovisor) que distraía su atención en distintos momentos y, particularmente, cuando el vehículo de delante comenzaba a frenar bruscamente. En un segundo experimento, los conductores no debían realizar esta tarea secundaria. Los resultados mostraron que presentar señales de advertencia tempranas ayudaba significativamente tanto a conductores distraídos como no distraídos, de forma que sus reacciones eran más rápidas y se evitan más colisiones con el vehículo de delante. Otros autores han comparado la efectividad de advertencias en distintas modalidades sensoriales, como por ejemplo Suzuki y Jansson (2003), quienes encontraron que advertencias hápticas (vibraciones del volante) podían ser más eficaces para evitar que el conductor se salga del carril de circulación, ya que el conductor suele interpretar estas vibraciones como una desviación de su trayectoria. Además, al igual que en el caso de otras intervenciones en seguridad vial, se ha destacado la importancia de considerar las posibles estrategias de adaptación del comportamiento del conductor, ya que éstas podrían modificar o incluso anular la posible eficacia de las tecnologías de advertencia (véase, por ejemplo, Rudin–Brown & Noy, 2002).

2.2.2. Orientación atencional

En relación con al red de orientación atencional, en primer lugar, algunos estudios han mostrado que un test de ordenador sobre atención visual (el *Useful Field of Vision* o UFoV) puede predecir el riesgo de verse involucrado en accidentes de tráfico, particularmente en conductores mayores (e.g., Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ball et al., 2006). El UFoV incluye una tarea de identificación de un estímulo objetivo en el centro del campo visual que debe realizarse en paralelo con una tarea de localización de un estímulo periférico, por lo que proporciona una medida del tamaño del campo de visión útil.

Por otro lado, Bédard y sus colaboradores (Bédard, Leonard, McAuliffe, Weaver, Gibbons, & Dubois, 2006) analizaron la relación entre el rendimiento en la conducción la inhibición de retorno (esto es, un mecanismo reflejo de la atención visual que evita que la atención se oriente hacia un objeto o lugar recientemente atendido; véase, por ejemplo, Klein, 2000, y Lupiáñez, Klein, & Bartolomeo, 2006). Se observó que un mayor efecto de inhibición de retorno estaba asociado con menos errores en una tarea que mide la habilidad de los conductores para inspeccionar el entorno de tráfico.

Además, Underwood, Crundall y Chapman (2011) revisaron distintos estudios de movimientos oculares en situaciones de tráfico en las que la percepción del riesgo era clave para evitar un accidente. Estos autores encontraron evidencia convergente para afirmar que ciertos tipos de peligro se asocian con una reducción general en la amplitud de la búsqueda visual, de forma que en determinadas situaciones los eventos peligrosos provocan fijaciones oculares más largas y una menor inspección del entorno de tráfico. Además, los resultados mostraron que ciertos grupos de conductores (como los noveles) podrían tener una mayor predisposición a dicha captura atencional, lo que sugiere que las diferencias individuales en el funcionamiento de la orientación atencional podrían estar relacionadas con el rendimiento en situaciones de riesgo al volante.

2.2.3. Control ejecutivo

La literatura previa ha mostrado que un bajo rendimiento en tests de función ejecutiva está asociado con un peor rendimiento en la conducción, por ejemplo, utilizando muestras de jóvenes conductores en tareas de conducción simulada (Mäntylä, Karlsson, & Marklund, 2009), grupos de conductores mayores en conducción real (Adrian, Postal, Moessinger, Rascle, & Charles, 2011) y analizando la implicación autoinformada de personas mayores en accidentes de tráfico (Daigneault, Joly, & Frigon, 2002).

Primero, Mäntylä et al. (2009) evaluó diferentes componentes de la función ejecutiva (inhibición de respuesta, actualización de la memoria de trabajo y cambio de set mental) en 50 participantes jóvenes (15–19 años) y comparó su rendimiento en una tarea de conducción simulada (*Lane Change Task*). Los resultados revelaron que los participantes con bajo rendimiento en los tests actualización de la memoria de trabajo cometían más errores en la tarea de conducción simulada, mientras que los tests de inhibición de respuesta, como el Stroop y el *stop signal*, y los de cambio de set mental no resultaron asociados con el rendimiento en la tarea de conducción.

Por otro lado, Adrian et al. (2011) analizó el grado de asociación entre la función ejecutiva y el rendimiento en conducción real en un grupo de conductores mayores de 60 años. En este estudio, se encontraron correlaciones significativas entre un pobre rendimiento al volante y puntuaciones bajas en tests para medir cambio de set mental y actualización de la memoria de trabajo, pero de nuevo la inhibición no aparecía relacionada con el rendimiento en la conducción. De acuerdo con Adrian et al. (2011), una posible explicación de la falta de asociación entre la inhibición y el rendimiento en la tarea de conducción que utilizaron en su estudio es que este componente ejecutivo podría estar particularmente implicado en la ejecución en situaciones de emergencia.

Esta última sugerencia sería consistente con los datos de Daigneault et al. (2002), quienes compararon el funcionamiento ejecutivo en dos grupos de conductores mayores: sin accidentes y con 3 o más accidentes informados en los últimos 5 años. Los resultados mostraron que los conductores que informan accidentes recientes comenten más errores en tareas que indican rigidez mental (errores de perseverancia o problemas de flexibilidad) y tienen menos habilidades para planificar y resolver problemas. En particular, el rendimiento en el test Stroop fue también peor para este grupo, lo que sugiere que una menor habilidad para inhibir respuestas incongruentes se asocia con una mayor probabilidad de accidente.

2.2.4. Estudios con la ANT y sus variantes

Existen pocos estudios antecedentes en los que se ha tratado de relacionar las puntuaciones obtenidas en la ANT por un grupo de conductores y su comportamiento al volante. En primer lugar, Weaver, Bédard, McAuliffe y Parkkari (2009) utilizaron la versión original de la ANT, el *Useful Field of Vision* (UFoV) y el *Manitoba Road Test* en una tarea de conducción simulada y también en entorno real. Como ya se ha descrito con anterioridad, el UFoV (Ball et al., 1993) es un test destinado a obtener una medida del tamaño del campo de visión útil. Este test incluye una tarea de identificación de un estímulo objetivo en el centro del campo visual que debe realizarse en paralelo con una tarea de localización de un estímulo periférico. Respecto al *Manitoba Road Test* (Weaver et al., 2009), se trata de un sistema de puntos deméritos que proporciona una medida global del rendimiento en la conducción. Durante un recorrido en coche, los conductores acumulan puntos por la comisión de ciertos errores o infracciones, tales como el exceso de velocidad, realizar giros no permitidos o incumplir las indicaciones de las señales de tráfico.

De acuerdo con los resultados de Weaver et al. (2009), el promedio del tiempo de reacción y de la precisión en la ANT son buenos predictores de la puntuación en el UFoV y el rendimiento global en el simulador de conducción. Sin embargo, no se encontró ninguna asociación entre las puntuaciones atencionales (alerta, orientación o control ejecutivo) y el rendimiento en la conducción. Los propios autores calificaron estos resultados como sorprendentes, debido a que se considera que estas funciones atencionales desempeñan un papel muy importante durante la conducción. En relación con ello, quizá el UFoV y, especialmente, el *Manitoba Road Test* hayan sido medidas poco apropiadas para capturar los diferentes aspectos de la atención (por ejemplo, en la mayoría de casos un exceso de velocidad no es debido a una distracción, sino a comportamiento deliberado del conductor), por lo que se ha recomendado que otros estudios busquen posibles relaciones utilizando situaciones de conducción diferentes y otras medidas del comportamiento del conductor. La presente tesis doctoral trata de recoger estas recomendaciones, tal como se describe más adelante, con la finalidad de obtener nuevos datos para analizar las relaciones entre el funcionamiento atencional y el rendimiento en la conducción.

Por otro lado, López–Ramón, Castro, Roca, Ledesma y Lupiáñez (2011) siguieron una estrategia diferente a la de Weaver y sus colaboradores. Aplicaron la ANTI (Callejas et al., 2004) y un cuestionario de autoinforme para medir errores atencionales durante la conducción (*Attention-Related Driving Errors Scale*, ARDES) a una muestra de 55 conductores en Argentina. El ARDES (Ledesma, Montes, Poó, & López–Ramón, 2010) es una escala de 19 ítems que evalúa la propensión a cometer fallos atencionales durante la conducción (por ejemplo, un ítem sería “al llegar a una intersección, no darme cuenta de que un peatón está cruzando la calle”). Los datos mostraron que el grupo de conductores con mayor propensión a los fallos atencionales obtenía un tiempo de reacción más lento y una mayor puntuación de alerta fásica en la ANTI (esto es, una mayor ventaja en tiempo de reacción por la presentación de una señal de advertencia). De acuerdo con los autores, los resultados sugieren que estos participantes muestran una reducción general en su rendimiento y una menor preparación endógena para señales de alerta de alta prioridad, posiblemente por una menor vigilancia. De este modo, como consecuencia de su menor preparación previa, los participantes obtienen un mayor beneficio de la presentación de una señal de advertencia que les indica la inminente aparición del estímulo objetivo en la ANTI. Además, López–Ramón et al. (2011) también encontraron que los conductores más propensos a cometer fallos atencionales durante la conducción obtenían un menor efecto de congruencia (por tanto, una mejor resolución del conflicto cognitivo), pero únicamente después de la presentación de claves espaciales válidas. En consecuencia, se podría afirmar que estos conductores pueden también compensar su menor preparación endógena cuando una clave espacial les ayuda a orientar su atención al lugar correcto. No obstante, la ANTI carece de una medida directa de alerta tónica o vigilancia, por lo que se ha recomendado que futuros estudios con la ANT incluyan medidas específicas para evaluar este componente de la atención y su posible modulación sobre otras funciones atencionales, tal como se realiza en la presente tesis doctoral.

3. OBJETIVOS DE LA TESIS DOCTORAL

La presente tesis doctoral se plantea dos objetivos generales. En primer lugar, se desarrollará una nueva variante de la ANT con la finalidad de obtener una medida directa de vigilancia, junto con las puntuaciones de alerta fásica, orientación atencional y control ejecutivo habituales en estudios anteriores. En segundo lugar, una vez se obtengan pruebas de la validez de la nueva tarea atencional, ésta se utilizará en estudios dirigidos a analizar la influencia de las diferentes funciones atencionales (incluyendo la vigilancia) sobre el comportamiento del conductor.

A continuación se describen y se justifican teóricamente estos dos objetivos generales, distinguiendo además objetivos más específicos para los cuatro estudios empíricos que componen la tesis doctoral (Figura 1.4).

3.1. Midiendo vigilancia junto a las demás funciones atencionales (Estudios 1 y 2)

Aunque es posible encontrar diferentes versiones de la ANT en la literatura científica (por ejemplo, la ANTI de Callejas et al., 2004; la ANT–R de Fan et al., 2009 la *Child*–ANT de Rueda et al., 2004), todas ellas utilizan un único indicador de alerta fásica para evaluar el funcionamiento de la red de alerta (esto es, comparando el rendimiento del participante con y sin una señal de advertencia). Sin embargo, algunos autores han subrayado la importancia de obtener una medida de alerta tónica o vigilancia cuando se evalúa el funcionamiento de las redes atencionales. Por ejemplo, varios estudios con la ANT han encontrado mayores puntuaciones de alerta fásica en determinados grupos de participantes, tales como pacientes con fibromialgia (Miró et al., 2011), participantes con cronotipo matutino evaluados por la tarde (Matchock & Mordkoff, 2009) y conductores propensos a cometer fallos atencionales (López Ramón et al., 2011). Estas mayores puntuaciones en alerta fásica han sido interpretadas, bien como un mejor funcionamiento de la red de alerta, bien como una vigilancia reducida (de modo que la señal de alerta les permite compensar su menor preparación). Dado que la ANT carece de una medida

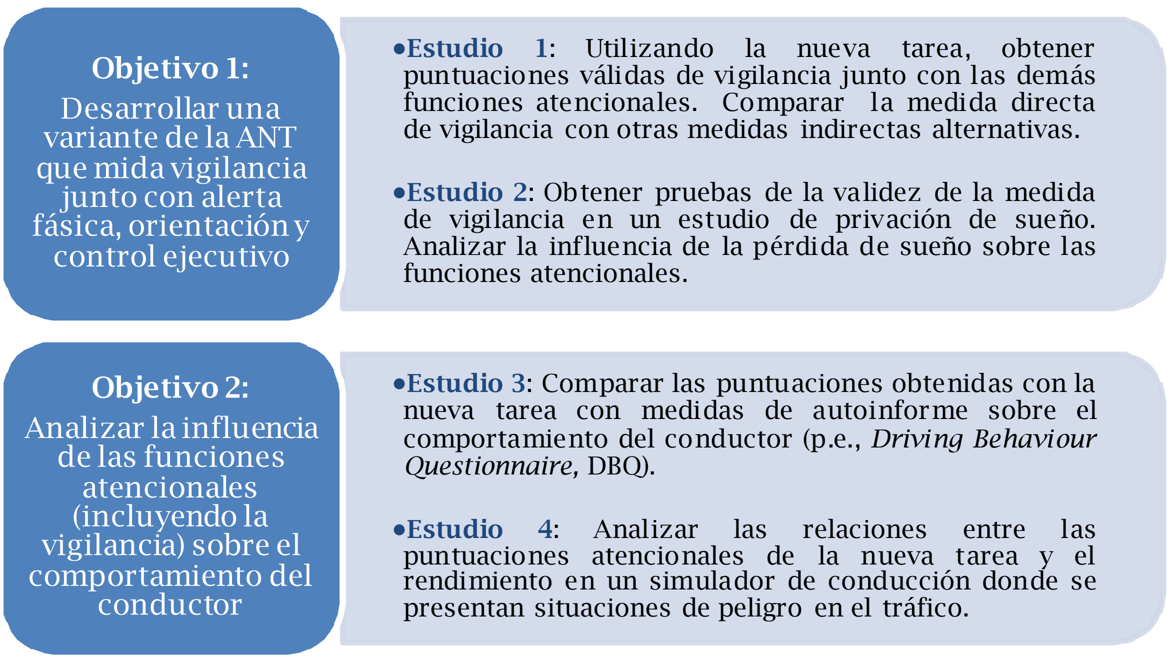


Figura 1.4: Objetivos generales de la tesis doctoral y objetivos específicos para los cuatro estudios empíricos que la componen.

directa de vigilancia, resulta difícil interpretar las diferencias individuales en alerta fásica en estudios como los anteriores.

Por otro lado, algunos modelos teóricos enfatizan la importancia de la vigilancia sobre los demás aspectos de la cognición (Lim & Dinges, 2008), llegando a afirmar que muchos de los déficits cognitivos que se observan, por ejemplo, después de una privación de sueño, pueden ser parcialmente atribuidos a una capacidad reducida para mantener la atención. Además, en el caso concreto de los estudios sobre Psicología del Tráfico y el Transporte, el estudio de la vigilancia tiene una especial relevancia para comprender y prevenir la ocurrencia de determinados tipos de accidente (p.e., Campagne et al., 2004). En consecuencia, incorporar una medida de alerta tónica o vigilancia a la ANT puede ayudar a observar relaciones más claras entre el comportamiento del conductor y el funcionamiento de las redes atencionales, especialmente en la red de alerta.

Aunque no existe todavía una versión de la ANT que incluya una medida directa de alerta tónica o vigilancia, algunos indicadores indirectos han sido propuestos en la literatura. Por ejemplo, Posner (2008) argumentó que, en los ensayos sin clave espacial de la ANT, las respuestas de los participantes se basan en su propia alerta endógena, por lo que el tiempo de reacción en esta condición podría reflejar los aspectos tónicos de la alerta. Además, otros autores (Sparkes, citado en Ishigami & Klein, 2009) han sugerido que la diferencia en el tiempo de reacción promedio entre el último y el primer bloque experimental de la ANT podría ser útil para evaluar el cambio en vigilancia. Finalmente, dado que la alerta tónica se ha medido tradicionalmente en tareas de tiempo de reacción simple (por ejemplo, Lim & Dinges, 2008; Sturm & Willmes, 2001), quizá el tiempo de reacción global en la ANT también se muestre relacionado con la vigilancia. Alguno estos indicadores indirectos podría constituir una aproximación aceptable para estimar la vigilancia de los participantes. Sin embargo, todavía es necesario un estudio que compare su funcionamiento con una medida directa de vigilancia. Por ello, los resultados basados en estos indicadores deberían considerarse con cautela.

Como consecuencia a los motivos aducidos en este apartado, el primer objetivo de la tesis doctoral será el de desarrollar una nueva variante de la ANT capaz de obtener una medida directa de vigilancia, además de las puntuaciones habituales de alerta fásica, orientación atencional y control ejecutivo. A esta nueva tarea nos referiremos como *Attention Networks Test for*

Interactions and Vigilance o ANTI–V. En un primer experimento (Estudio 1), se utilizará esta nueva versión de la ANT y se espera encontrar puntuaciones válidas para las distintas funciones atencionales, incluyendo la vigilancia. Además, se compararán las medidas directas e indirectas de vigilancia para valorar si alguna de las propuestas alternativas es también adecuada para obtener una estimación de la alerta tónica en futuros estudios. A continuación, en un segundo experimento (Estudio 2), se obtendrán datos complementarios acerca de la validez de la nueva tarea atencional. Si la medida directa de vigilancia en la ANTI–V es adecuada, entonces sus puntuaciones deberían ser sensibles a una manipulación del nivel de vigilancia de los participantes, lo que puede realizarse utilizando un paradigma de privación de sueño (p.e., Killgore, 2010; Lim & Dinges, 2008). Además, este segundo estudio puede proporcionar nueva información para estudiar la influencia de la pérdida de sueño sobre el funcionamiento atencional en los distintos componentes de alerta, orientación y control ejecutivo.

3.2. Influencia de las funciones atencionales en el comportamiento del conductor (Estudios 3 y 4)

Una vez completado el objetivo anterior y se tengan, por tanto, pruebas de la validez de la nueva tarea, se desarrollarán estudios dirigidos analizar la influencia sobre el comportamiento del conductor de las diferentes funciones atencionales, incluyendo la vigilancia. Primero, siguiendo la estrategia utilizada por López–Ramón et al. (2011), se buscarán relaciones entre la ANTI–V y cuestionarios de autoinforme dirigidos a medir distintas dimensiones del comportamiento del conductor (por ejemplo, el *Driving Behaviour Questionnaire* o DBQ). A continuación, se buscarán pruebas que sugieran asociaciones particulares entre los componentes de la atención y el rendimiento en un simulador de conducción. Sin embargo, a diferencia del estudio de Weaver et al. (2009), donde se utilizó una medida de conducción quizá demasiado general e inespecífica para la atención, en la presente tesis doctoral se presentará a los participantes una tarea de conducción simulada con situaciones peligrosas en las que un funcionamiento atencional inadecuado representaría una colisión.

3.2.1. Estudio 3: Medidas de autoinforme

En el tercer estudio empírico de la presente tesis doctoral (Estudio 3), las puntuaciones obtenidas con la ANTI–V por un grupo amplio de participantes serán comparadas con las puntuaciones en el *Driving Behaviour Questionnaire* (DBQ). El DBQ (Reason, Manstead, Stradling, Baxter, & Campbell, 1990) es una escala de auto–informe muy extendida en el campo de la psicología del tráfico y el transporte, dirigida a obtener una medición del comportamiento aberrante del conductor. De acuerdo con una revisión meta–analítica reciente (Winter & Dodou, 2010), el DBQ ha sido utilizado hasta la fecha en al menos 174 estudios, incluyendo comparaciones interculturales y el análisis de las diferencias individuales en distintos grupos de conductores (profesionales, motoristas, infractores, mayores, etc.). Además, dicho meta–análisis ha permitido confirmar el poder predictivo del DBQ sobre el número de accidentes informados por los participantes (la correlación promedio fue de 0,10 y 0,13, para los factores de errores e infracciones respectivamente).

El DBQ se diseñó inicialmente para distinguir entre dos tipos de comportamiento aberrante: errores involuntarios durante la conducción e infracciones deliberadas de la norma, con la finalidad de demostrar que estos factores están influidos por procesos psicológicos diferentes. Sin embargo, en el trabajo inicial de Reason et al. (1990), un análisis factorial mostró la existencia de un tercer factor de lapsos atencionales, que incluiría algunos pequeños *despistes* o fallos en la atención del conductor. Además, una modificación posterior de la escala incorporó nuevos ítems dirigidos a medir comportamientos agresivos durante la conducción (Lawton, Parker, Manstead, & Stradling, 1997). Por ello, actualmente suelen distinguirse cuatro factores en el cuestionario (errores, lapsos, infracciones y comportamientos agresivos).

No obstante lo anterior, la relevancia del factor de lapsos atencionales ha sido cuestionada en la literatura sobre el DBQ, principalmente por dos motivos. En primer lugar, los lapsos atencionales fueron considerados como fallos meramente triviales (Reason et al., 1990) y algunos estudios iniciales no pudieron relacionar este factor con la accidentalidad informada por los conductores (e.g., Parker, Reason, Manstead, & Stradling, 1995). En segundo lugar, los análisis de la estructura factorial del DBQ no siempre han encontrado que los lapsos atencionales constituyan un factor distinto del factor de errores del conductor (Özkan, Lajunen, & Summala, 2006; Lajunen, Parker, & Summala, 2004). Por ejemplo, Ökan et al. (2006) revisaron las distintas adaptaciones del cuestionario y encontraron que, pese a existir soluciones factoriales que van desde los dos a los seis factores, la versión original de cuatro factores (errores, lapsos, infracciones y comportamientos agresivos) ha sido frecuentemente replicada. Por otro lado, Lajunen et al. (2004) encontraron que la solución de cuatro factores era estable en las versiones británica, finesa y holandesa del cuestionario. Sin embargo, al realizar un análisis factorial de segundo orden sobre los cuatro factores iniciales, entonces aparecía una solución factorial de dos factores (errores e infracciones), por lo que considerar una taxonomía jerárquica de comportamientos aberrantes puede ayudar a solucionar la discusión.

En general, podría afirmarse que hay evidencia suficiente sobre el DBQ para utilizar tanto una solución de dos factores (errores e infracciones) como de cuatro factores (errores, lapsos, infracciones y comportamientos agresivos). A este respecto se ha sugerido (Lajunen et al., 2004) que la solución de cuatro subescalas podría resultar más informativa e útil para las personas que trabajan en el campo aplicado de la seguridad vial. Esto también podría ser cierto para los investigadores particularmente interesados en estudiar, por ejemplo, los lapsos atencionales o los comportamientos agresivos. Por ello, sería útil obtener datos adicionales que apoyen la validez de cada factor para complementar los estudios con análisis factorial (por ejemplo, analizando la validez convergente o discriminante con otras medidas potencialmente relacionadas).

Como consecuencia, en la presente tesis doctoral se analizan las relaciones entre las cuatro subescalas del DBQ (errores, lapsos, infracciones y comportamientos agresivos) y el funcionamiento de las redes atencionales medido por la ANTI–V. Los datos obtenidos podrían contribuir al debate sobre la validez de las distintas estructuras factoriales propuestas para el DBQ, utilizando otras pruebas complementarias a los estudios con análisis factorial. En particular, los resultados podrían establecer una relación entre la medida de lapsos atencionales del DBQ y el funcionamiento atencional de los participantes, aportando nuevos datos para discutir la adecuación del DBQ para estudiar la inatención del conductor.

Por otro lado, de forma complementaria, también se analiza la relación entre los factores del DBQ y el Cuestionario de Fallos Cognitivos (CFQ; Broadbent et al., 1982). Esta escala proporciona una medida de autoinforme de la tendencia del participante a cometer pequeños errores en la ejecución de actividades cotidianas. La literatura previa ha mostrado una correlación positiva (r = 0,66) entre la puntuación total del CFQ y el factor de lapsos atencionales del DBQ (Van de Sande, 2008). Sin embargo, este estudio no informó acerca de la relación entre el CFQ y otros factores del DBQ (errores, infracciones y comportamientos agresivos), por lo que se desconoce si esta relación es específica para los lapsos atencionales o es común con otras dimensiones de la conducción aberrante. Por último, respecto a las relaciones entre la ANTI–V y el CFQ, los datos del Estudio 3 podrían ampliar los resultados obtenidos con la ANTI por Ishigami y Klein (2009), quienes observaron correlaciones positivas entre el CFQ y las puntuaciones de orientación y alerta fásica.

3.2.2. Estudio 4: Simulador de conducción

En el último estudio de la presente tesis doctoral (Estudio 4), se analizan las relaciones entre las diferencias individuales en el funcionamiento de las tres redes atencionales y el rendimiento de los participantes en un simulador de conducción donde se les presentan situaciones de peligro en el tráfico.

Weaver et al. (2009) encontraron que las puntuaciones globales de la ANT (tiempo de reacción y precisión) están relacionadas con el rendimiento al volante, pero no se encontraron relaciones entre funciones atencionales específicas (alerta, orientación y control ejecutivo) y situaciones de tráfico concretas. Entre los posibles motivos para explicar este resultado, se podría considerar que las diferencias individuales en el funcionamiento atencional no eran un factor determinante en las situaciones de conducción que se utilizaron en dicho estudio. Weaver et al. (2009) obtuvieron un índice global basado en la comisión de errores e infracciones para valorar el rendimiento general en un itinerario de conducción sin incidentes. Frente a ello, en la presente tesis doctoral los participantes encontrarán situaciones de tráfico en un simulador de conducción, en las que el correcto funcionamiento de la atención es clave para evitar una colisión. De este modo, el rendimiento global del conductor en estas situaciones podría ser más adecuado para establecer relaciones específicas con los distintos componentes atencionales.

Por otro lado, a partir de los datos del simulador se obtendrán medidas globales del rendimiento de los participantes, pero también se considerarán distintos tipos específicos de situaciones de riesgo. En particular, de acuerdo con Crundall y sus colaboradores (Crundall, Andrews, van Loon, & Chapman, 2010; Crundall et al., in press), existen al menos tres categorías de situaciones de riesgo: *Predicción del Comportamiento*, *Predicción del Entorno* y *Atención Focalizada y Dividida*. Primero, las situaciones de *Predicción del Comportamiento* pueden evitarse si el conductor anticipa el comportamiento de otro usuario de la vía (p.e., un peatón u otro conductor) antes de que se convierta en un peligro real. Un ejemplo de esta categoría sería un vehículo que espera en una intersección pero que acelera repentinamente cuando el conductor participante se aproxima, cortando su trayectoria. Segundo, en las situaciones de *Predicción del Entorno* la fuente del peligro está oculta por un elemento del entorno hasta que el conductor se aproxima a ella. En estas situaciones, el riesgo puede evitarse si dicho elemento del entorno se utiliza como precursor del peligro. Por ejemplo, un camión aparcado puede esconder un peatón que se dispone a cruzar. Finalmente, las situaciones de *Atención Focalizada y Dividida* son situaciones de tráfico más complejas en las que hay varios peligros posibles, antes de que uno de ellos se convierta en un peligro real. Un ejemplo de este tipo de situaciones podría ser una intersección en la que hay varios vehículos aproximándose por ambos lados, pero sólo uno de ellos se cruza finalmente en el camino del conductor. Esta taxonomía de situaciones de peligro ha demostrado ser eficaz, por ejemplo, para discriminar el comportamiento de conductores expertos y conductores novatos (Crundall et al., 2010, in press).

El objetivo de incluir la taxonomía anterior en el cuarto estudio de la presente tesis doctoral es explorar la existencia de posibles diferencias cualitativas en la relación de los componentes atencionales con el rendimiento en la conducción en distintas situaciones de tráfico. Por ejemplo, mientras se conduce, focalizar toda la atención en el vehículo de delante (y, por tanto, ignorar parcialmente el entorno de tráfico) podría ser de ayuda cuando este vehículo frena bruscamente, pero el mismo comportamiento atencional podría ser arriesgado si un peatón cruza repentinamente desde el borde de la vía. Por ello, el funcionamiento de un determinado componente atencional podría estar asociado a un mejor o un peor rendimiento en la conducción dependiendo del tipo de situación de tráfico que se haya considerado.

En definitiva, la presente tesis doctoral describe una serie de cuatro estudios que proporcionará nuevos datos para analizar la influencia de las distintas funciones atencionales sobre el comportamiento del conductor. Para ello, primero se desarrolla una versión del *Attention Network Test*, incluyendo una medida adicional de vigilancia junto a las puntuaciones de alerta fásica, orientación y control ejecutivo. Una vez se tengan pruebas de la validez de esta nueva tarea en un estudio de privación de sueño, entonces las puntuaciones atencionales de la ANTI–V se comparan con distintas medidas del comportamiento del conductor, tales como el *Driving Behaviour Questionnaire* (DBQ) y el rendimiento de los participantes en un simulador de conducción que presenta situaciones de riesgo en el tráfico. En consecuencia, los estudios descritos a continuación podrían resultar de interés a los investigadores básicos sobre la atención humana, al aportar resultados con datos de laboratorio y en entorno real; y también podrían tener un interés aplicado, contribuyendo con ideas y nuevos conocimientos al desarrollo de posibles medidas dirigidas a reducir el número de accidentes y víctimas en el tráfico.

CAPÍTULO 2 CHAPTER

STUDY 1:

Measuring vigilance while assessing the functioning of the three attentional networks: The ANTI-Vigilance task.

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Abstract

Vigilance could be a crucial aspect of attention that may modulate the functioning of the attentional system. Some behavioural tests, such as the Attention Network Test (ANT), have been developed to obtain an individual index of the three attentional networks (alertness, orientation, and executive control). However, alerting network measures are usually inferred using a phasic alertness task, and some indirect indexes of tonic alertness or vigilance have been proposed but not properly evaluated. The general aim for the present study is to provide the ANT with a direct measure of vigilance and then to analyse the relationship between this measure and other alternative indirect indexes. The obtained results suggest that the proposed new test (ANTI–Vigilance or ANTI–V) is useful to achieve a direct measure of vigilance and could be considered as a new tool available in cognitive, clinical or behavioural neurosciences for analysing vigilance in addition to the usual ANT scores. Other alternative indexes (such as global reaction time and global accuracy averaged across conditions) are only moderately correlated to a direct vigilance measure. As a consequence, although they may be to some extent related to the participants' vigilance level, they could not be used isolatedly as appropriate indexes of vigilance. Also, the role played by these global measures in the ANT task, which have been previously associated with some performance measures in applied areas (such as driving performance), is discussed.

Keywords: vigilance, tonic alertness, phasic alertness, attentional orienting, executive control, Attention Network Test (ANT), driving behaviour, Traffic and Transport Psychology.

1. INTRODUCTION

Considerable interest has arisen in recent years regarding the development of a quick and easy measure of the functioning of the three attentional networks (alertness, orienting, and executive control) in Posner and collaborators' neurocognitive model of human attention (Posner, 1994; Posner & Petersen, 1990). This increasing interest, initially originated in the Experimental Psychology and Cognitive Neuroscience literature, is now expanding to other applied areas such as Clinical and Developmental Psychology and even research on Traffic and Transportation Psychology, where the strength of a solidly founded model of attention could be of great benefit and provide well–defined and testable hypotheses (see, for example, López–Ramón, Castro, Roca, Ledesma & Lupiáñez, 2011; Weaver, Bédard, McAuliffe & Parkkari, 2009). However, an aspect of attention that seems critical for those applied fields, i.e., tonic alertness or vigilance, is missing so far in the tasks developed to assess the functioning of the attentional networks. Therefore, vigilance is usually inferred indirectly from the measure of phasic alertness or from other measures a priori not considered as an index of vigilance in the original task (Matchock & Mordkoff, 2009; Miró et al., 2011).

1.1. The three attentional networks

According to Posner and collaborators' model (Posner, 1994; Posner & Petersen, 1990), three different cognitive functions could be distinguished in human attention, which are subserved by three independent (although coordinated) neural systems. First, the alertness network involves some fronto–parietal regions, mainly in the right hemisphere, and also some brain stem areas such as the locus coeruleus (Posner, 2008). This neural circuit is aimed at achieving and maintaining a state of high sensitivity to incoming stimuli and is related to the performance in tasks that involve both phasic and tonic alertness (see, for example, Posner, 2008; Sturm & Willmes, 2001). Phasic alertness could be defined as the increased response readiness for a short period of time subsequent to a warning external stimulus, whereas tonic alertness or vigilance refers to a sustained activation over a period of time. Phasic alertness is usually measured by using a warning signal that precedes the target stimulus, and then analysing its influence on reaction time (RT) and accuracy (ACC). In contrast, the assessment of tonic alertness usually involves simple RT measurements in the absence of a warning signal. Also, a common approach to measure tonic alertness is to use a long and usually boring task to measure the vigilance to detect infrequent stimuli. The number of lapses, either computed as long RT responses or using the number of hits and false alarms to obtain the Signal Detection Theory (SDT) indexes of sensitivity and response bias, is usually taken as a measure of vigilance (see, for example, Lim & Dinges, 2008; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; and also, See, Howe, Warm, & Dember, 1995).

Second, the orienting network includes different areas of the parietal and frontal lobes, and it is involved in the selection of information from the sensory input (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The effect of attentional orienting is usually assessed by presenting spatial cues, indicating either the correct location of the upcoming target (i.e., valid trials), the opposite location (i.e., invalid trials), or a neutral location (i.e., centre–cue trials). The difference between some of these conditions (e.g., "centre–cue minus valid trials", when only valid trials have been presented, or "invalid minus valid trials", when both have been used) has being taken as an index of the efficiency of attentional orienting (see, for example, Fan et al., 2002; Callejas, Lupiáñez, Funes, & Tudela, 2005).

Third, the executive control network activates anterior areas of the frontal cortex, such as the anterior cingulate and the dorsolateral prefrontal cortex. This network is defined as involving the mechanisms for resolving cognitive conflict, and it could be efficiently assessed with the use of Stroop, Simon or flanker tasks (see, for example, Fan et al., 2002). The interference effect observed with these tasks (i.e., RT is slower when incongruent information is presented) is taken as an index of the efficiency of the executive control network.

Based on this neurocognitive model of human attention, Fan et al. (2002) developed a simple, although carefully designed task to obtain an individual index of the functioning of each attentional network. The task, known as the Attention Networks Test or ANT, was a combination a cuing task (Posner, 1980) and a flanker paradigm (Eriksen & Eriksen, 1974). In the original ANT task, a central target arrow is presented to the participants, flanked by four distracting arrows that may point to the same direction as the central one (congruent) or to the opposite direction (incongruent), or presenting a third neutral condition with lines as flankers. The task requires indicating the direction of the target central arrow by pressing the appropriate key, while ignoring the flanking distracters. The arrows could be preceded by a spatial cue indicating their forthcoming location (above or below a central fixation point), a central cue, a double cue (indicating both locations), or no cue. A different score for each attention network is obtained by subtracting the mean RT in specific experimental conditions: alerting effect (no–cue minus double–cue), orienting effect (centre cue minus spatial cue), and executive control effect (incongruent minus congruent). The evidence gathered by different authors support that these measures can be considered as usable indexes of the functioning of the attention networks (see, for example, Fan et al., 2002; Ishigami & Klein, 2009, 2010).

The original version of the ANT was suitable to obtain an appropriate index for each attentional network but some limitations were soon identified (Callejas, Lupiáñez, & Tudela, 2004). First, the alerting and orienting scores were both obtained from the cueing conditions, and thus their interactions could not be separately assessed. Also, the spatial cue was always 100% predictive of the imminent location of the target arrow, and therefore the exogenous and endogenous components of attention were confounded. As a consequence, an improved version of the task was presented by Callejas et al. (2004), which included an acoustic warning tone to independently assess the alertness network (measuring the difference in mean RT between the conditions without the warning tone and the conditions preceded by the warning tone) and the spatial cue was made unpredictable (50% valid, 50% invalid) of the location of the forthcoming target (and thus only exogenous attention should be involved). This improved version of the task is known as the Attention Networks Test for Interaction or ANTI. Recent studies have directly compared the functioning and the cognitive process involved in both tasks. For example, Ishigami & Klein (2009) administered both the original ANT and the ANTI task together with a self–report scale of absentmindedness (the Cognitive Failures Questionnaire or CFQ; Broadbent, Cooper, Fitzgerald, & Parkers, 1982) to large sample of participants (200) and found that the orienting effects in accuracy obtained from the two versions of the task varied with absentmindedness in opposite directions, suggesting that these two tests tap different aspects of orienting. Recently Fan et al. (2009) have proposed a revised Attention Network Test (or ANT–R) adding invalid cues to their original proposal. Importantly, Ishigami & Klein (2010) evaluated the stability, isolability, robustness, and reliability of ANT and ANTI by administering the two tests in 10 consecutive sessions to 10 young adults. Their conclusions pointed out that both ANTs are useful tools to measure the alerting, orienting, and executive control components of attention, although the scores measured with the ANTI were generally more reliable than with the ANT, especially regarding alertness. All indexes from the two tasks reached respectable reliability as data from more sessions were taken into account. Besides, Lawrence, Eskes, and Klein (2009) analysed the reliability of the ANT and the ANTI in nonclinical adults. They also found that the reliability for the ANTI test was higher in the alerting network than for the ANT.

1.2. Applications of the ANT and ANTI tasks

Both the ANT and the ANTI tasks have been successfully applied to assess the attentional functioning in a great variety of research contexts, such as studies with children (e.g. Rueda et al., 2004), different kinds of dementia patients (e.g. Fuentes, Fernández, Campoy, Antequera, García–Sevilla, & Antúnez, 2010), anxiety (e.g. Pacheco–Unguetti, Acosta, Callejas, & Lupiáñez. 2010), depression (e.g. Gruber, Rathgeber, Bräunig, & Gauggel, 2007), mindfulness (e.g. Van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2010), and many others. A further applied research area in which the study of human attention is of great relevance is the Traffic and Transportation Psychology. For example, driver distraction is a risk factor frequently involved in road traffic accidents. It has been estimated that the percentage of the distraction–related crashes could vary between 10% and 33% of all crashes, depending on the source of the data (Ranney, 2008). Driving is a complex behaviour in which different tasks are carried out simultaneously (Wickens, Gordon, & Liu, 1998). Therefore, it requires regulating information processing, by using the attentional functions. Also, vigilance or tonic alertness decays as a function of time, and the corresponding increase in fatigue and performance mistakes are then observed (see, for example, Campagne, Pebayle, & Muzet, 2004). As a consequence, the study of the functioning of the attentional networks while driving could be a useful tool to understand the driver behaviour and thus to prevent road traffic accidents.

Weaver et al. (2009) explored the possibility of using the ANT to predict driving performance outcomes. They administered the Fan and colleagues' ANT original version (Fan et al., 2002), as well as the Useful Field of Vision test (UFOV) and the Manitoba Road Test in both simulated and on–road driving. The UFOV is a widely used computer–based task to measure visual attention that consists of a central target identification task coupled with a peripheral target localization task, which together provided a measure of the size of the useful field of vision (see, for example, Ball, Owsley, Sloane, Roenker, & Bruni, 1993). The UFOV is considered to be the *gold standard* of cognitive tests for driving researchers (Weaver et al., 2009). The Manitoba Road Test is a demerit-based scoring system, aimed at assessing the general performance of the driver's behaviour (see, for example, Weaver et al., 2009). Demerit points are given for the commission of certain infractions (e.g. speeding or signal violations). In their study, Weaver and colleagues found that two measures obtained from the ANT, the global RT and the global ACC, were good predictors of both the UFOV and the performance in a driving simulator (although neither the ANT nor the UFOV were significantly related to the on-road test in this study). Interestingly, the concurrent validity of the ANT using the PC version of UFOV was found to be as good as the concurrent validity of the PC version of UFOV versus the original standard version. However, it should be noted that no clear evidence was found of an association between any of the three individual functions of attention (alerting, orienting, and executive control) and the driving performance. Only the conflict efficiency (executive control) showed a significant relationship with the UFOV (but not with the driving performance in the driver simulator or the on-road test). This was considered somehow surprising, as the three attentional networks were expected to play an important role while driving, and the authors recommended further exploring these possible relationships in different driving contexts, such as in vigilance-related driving situations. Also, it can be suggested that different driving performance measures should be explored, since the UFOV and, especially the Manitoba Road Test, may have not been appropriated to tap all the three different aspects of attention.

Also, López-Ramón et al. (2011) explored the relationship between the three attentional networks and the tendency in younger and older drivers to make attentional mistakes while driving. In this study the ANTI (Callejas et al., 2004) and the Attention-Related Driving Error Scale (ARDES), a self-report scale to evaluate the propensity to make attention-related errors while driving (e.g. "on approaching a corner, I don't realize that a pedestrian is crossing the street") (Ledesma, Montes, Poó, & López-Ramón, 2010) were employed. Their results showed a relationship between the proneness to make attentional errors while driving and both the overall RT and the alertness network score:

the group of participants with a higher score in the ARDES questionnaire (and thus more prone to make attentional errors while driving) obtained a higher overall RT and also a higher alerting score. According to these authors, the two measures might be taken as evidence of reduced vigilance. Increased overall RT may be interpreted as a slowdown in performance, while the increased alerting score suggests a decreased endogenous preparation for processing high priority warning signs, participants therefore taking a greater advantage from the external warning signal.

Both the study conducted by Weaver et al. (2009) and that by López–Ramón et al. (2011) showed an association of the global measures (RT) obtained from the ANT or the ANTI, respectively, with different kinds of driving outcomes (e.g. self–informed, pc–based or simulator–based performance measures). However, to our knowledge, it is still unclear which is the role that global measures could represent in the functioning of attention. Fan et al. (2002) found that overall mean RT was positively correlated to the conflict effect (executive control) in RT, but the magnitude of the correlation was modest (.44) and thus it seems inappropriate to consider that the overall RT is measuring the same thing that the executive control score. Also, both scores could not be considered as orthogonal measures (note that the conflict effect was obtained by subtracting mean RT of congruent conditions from mean RT of incongruent conditions, while overall mean RT is the summation of the same elements), and thus a positive correlation was expected as a consequence of this joint measurement. López–Ramón et al. (2011) suggested that the overall mean RT might be considered as a slowdown in performance related to reduced vigilance. Posner (2008) has claimed that overall RT and ACC performance measures can reflect different strategies of approaching the task (i.e., either a conservative or a liberal response bias). As a consequence, measures distinguishing between efficiency of performance and response bias are fundamental to interpret the network scores measured by the ANT or ANTI tasks and therefore should be carefully considered, especially when comparing groups with differences in overall RT and ACC.

1.3. Measuring vigilance with the ANT or the ANTI tasks

Although different versions of the original ANT task could be found in the scientific literature, all of them measure the functioning of the alerting network by means of phasic alertness task (i.e., comparing the performance when a warning signal has been presented to when no warning signal has been provided). Some authors have highlighted the interest of adding a measure of tonic alertness or vigilance to the ANT task. For example, although both phasic and tonic alertness have been associated with the functioning of the same alerting neural network, it has been argued (Posner, 2008) that some hemispheric differences could be found between these two aspects of alerting. Right hemisphere mechanisms usually involve slower effects (tonic alertness), whereas left hemisphere processes are more related to higher temporal frequencies (phasic alertness) (see, for example, Coull, Frith, Büchel, & Nobre, 2000; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Sturm & Willmes, 2001). According to Posner (2008), the exact reasons for these differences in laterality are still unknown and they are important in the interpretation of the ANT data. As a consequence, a single task useful to measure both phasic and tonic aspects of alerting could be of interest to analyse the different implications of both aspects of alerting, and their relationships to other attentional measures. Also, some models of attention emphasize the importance of vigilance over others aspects of cognition (Lim & Dinges, 2008), and claim, for example, that many cognitive deficits observed after sleep deprivation (including memory, executive function of other facets of attention) could be partially attributed to the reduced capacity to sustain attention.

In relation to the application of the ANT in Traffic and Transport Psychology, Weaver et al. (2009) and also López–Ramón et al. (2011) have highlighted the need of analysing specifically the role of the tonic alertness or vigilance to explain the drivers' attentional performance. Actually, it can be claimed that traditionally most attentional research in the driver behaviour domain has focused on studying tonic alertness or vigilance (see, for example, Campagne et al., 2004). Therefore, it is possible that, if the ANT or the ANTI task are provided with a direct measure of tonic alertness or vigilance, more clear relationships arise between the drivers' performance and the functioning the attentional networks (specially the alertness network).

Different experimental tasks have been proposed in the literature to measure tonic alertness or vigilance. For example, the Psychomotor Vigilance Test (PVT) has emerged as the dominant test of vigilant attention in paradigms of sleep deprivation (Lim & Dinges, 2008). The PVT is a test of simple RT to a target that occurs at random intervals. Participants are told to attend to a small, rectangular area on a dark screen, and to respond as rapidly as they can when a bright millisecond counter appears. The usual dependent variable in the PVT is the number of lapses, considered as responses greater than 500 ms. This measure has been found to be a reliable and valid index of vigilance (Lim & Dinges, 2008). Generally, under conditions of low vigilance (such as sleep deprivation), slower RT, higher RT variability, and more lapses are expected using the PVT. An alternative task to measure vigilance is the Sustained Attention to Response Task (SART) (Robertson et al., 1997). The SART uses a continuous performance paradigm involving key presses to frequently presented non–targets. Occasionally, a different target may appear and the participants have to withhold their response. When the infrequent targets occur, active controlled processing must be triggered to overcome the prepotent automatic response. As a consequence, attentional lapses manifest as errors in the SART, when the participants give a response expected for the frequent non–targets to an infrequent target. Actually, it has been found that attentional lapses in the SART are preceded by trials with faster RT, suggesting a lessening of active attention (Robertson et al., 1997).

Although no direct measure of tonic alertness or vigilance has been already included to our knowledge in any variation of the ANT or the ANTI tasks, some indirect indexes have been proposed. For example, Posner (2008) argued that in ANT no cue conditions the participants must rely on their own internal alertness, and therefore the no cue RT may reflect the tonic aspects of alertness. Also, it has been proposed that the RT obtained after subtracting overall RT collapsed across conditions in the first experimental block from RT in the last block could be used as a measure of tonic alertness (Sparkes, as cited in Ishigami & Klein, 2009). Furthermore, it is agreed that both simple RT and tonic alertness show a circadian variation, and thus the latter has been usually assessed by means of simple RT tasks (see, for example, Lim & Dinges, 2008, Sturm & Willmes, 2001). Therefore, it could be argued that global RT in the ANT or the ANTI task could be to some extent related to vigilance performance, as all the attentional effects would be cancelled out by averaging the opposed conditions (global RT). It is important to note that the latter hypothesis, if confirmed, could help to clarify the role played by overall RT in some of the previous studies on attention and driving behaviour (such as López–Ramón et al., 2011, and Weaver et al., 2009).

1.4. The present study

The general aim of the current study is to obtain a direct measure of tonic alertness or vigilance while assessing the functioning of the three attentional networks. In addition, it will be analysed whether any of the previously proposed indexes in the ANT or the ANTI task could be related to our direct measure of tonic alertness or vigilance. To achieve these objectives, a new version of the ANTI task has been developed, in which a secondary vigilance task has been embedded in the main task. Participants have to detect infrequent stimuli in some of the trials while doing the standard ANTI task in the remaining (most frequent) trials. The proposed new version (hereinafter referred as to ANTI–Vigilance or ANTI–V) is based on the variation proposed by Callejas et al. (2004) to measure the attentional functions and their interactions (ANTI). We decided to base the new task on the ANTI rather than on the ANT because, as discussed above, the ANTI is more suitable to measure the interactions between the attentional networks, and also it has been shown that the scores measured with the ANTI are generally more reliable than with the ANT, especially regarding alertness (Ishigami & Klein, 2010; Lawrence et al., 2009).

The proposed ANTI–V task is based on some previous experiments in our laboratory, aiming at analysing the functioning and the interactions of the attentional networks (alertness, orienting and executive control) under different task demands based on the variation of the target uncertainty (López–Ramón et al., 2010). In the work by Lopez–Ramón and collaborators' the participants were also required to detect some infrequent targets, although the ANTI–V presented here includes a different experimental manipulation more sensible for measuring vigilance.

The expected results of the present study may or may not corroborate that the global RT is an indirect index of tonic alertness or vigilance in the ANTI task, and thus, the role played by the overall RT in some applied areas, such as previous research on attention and drivers' behaviour (e.g. López–Ramón et al., 2011, and Weaver et al., 2009), will be discussed. We believe that this study can be considered the first attempt to compare the previously proposed indexes of vigilance or tonic alertness in the ANT or the ANTI task with a direct measure of vigilance.

2. MATERIALS AND METHODS

2.1. Participants

A sample of 55 students (41 females) at the University of Granada participated in this study for extra class credit. Average age was 21 (St.

Dev.=3). All participants had normal or corrected–to–normal vision. The experiments were conducted according to the ethical standards of the 1964 Declaration of Helsinki.

2.2. Apparatus and stimuli

An E–Prime v2.0 Professional (Psychology Software Tools, Inc.) script was developed to control the experimental task in a 15–in. PC. Responses were made by means of three possible input keys in a standard keyboard (“c”, “m” and spacebar). The following stimuli were used (see Figure 2.1A): a black fixation cross (~0.55º visual angle), a warning tone (2,000 Hz), a black asterisk (~0.85º), and a row of five black and blue cars (~1.71º each, ~10.21º the whole row) pointing either leftward or rightward.

Generally the distance between the cars was of ~0.44º visual angle but two important issues should be considered: first, the distance of the central target car was manipulated in this experiment, being either centred (~0.44º) or significantly displaced, appearing closer (~0.14º) to the immediate right or left flanker car (see Figure 2.1B). Second, the vertical and horizontal location of each car was slightly changed in every trial, adding a random variability from –0.07º to +0.07º (i.e., ±4 pixels) to make more difficult the discrimination between the centred and the displaced target car. The background was grey and shown in the centre of the screen was a white zenith view of a two–lane road with two parking lanes (see Figure 2.1C). The target central car and its four flankers appeared on one of the two parking lanes, above or below the fixation cross.

2.1. Procedure and design

The participants were tested on a new version of the ANT (Fan et al., 2002), based on the variation proposed by Callejas and colleagues to measure interactions (ANTI) (Callejas et al., 2004). The proposed new version (ANTI–Vigilance or ANTI–V), was specifically designed to obtain a direct measure of vigilance in addition to the usual attentional networks scores (i.e., phasic alertness, attentional orienting, and executive control). Also, stimuli and instructions were partially modified to describe the task to the participants as a game: they were asked to imagine that they were working in a Centre for Traffic Management, where the drivers' parking habits were being studied.

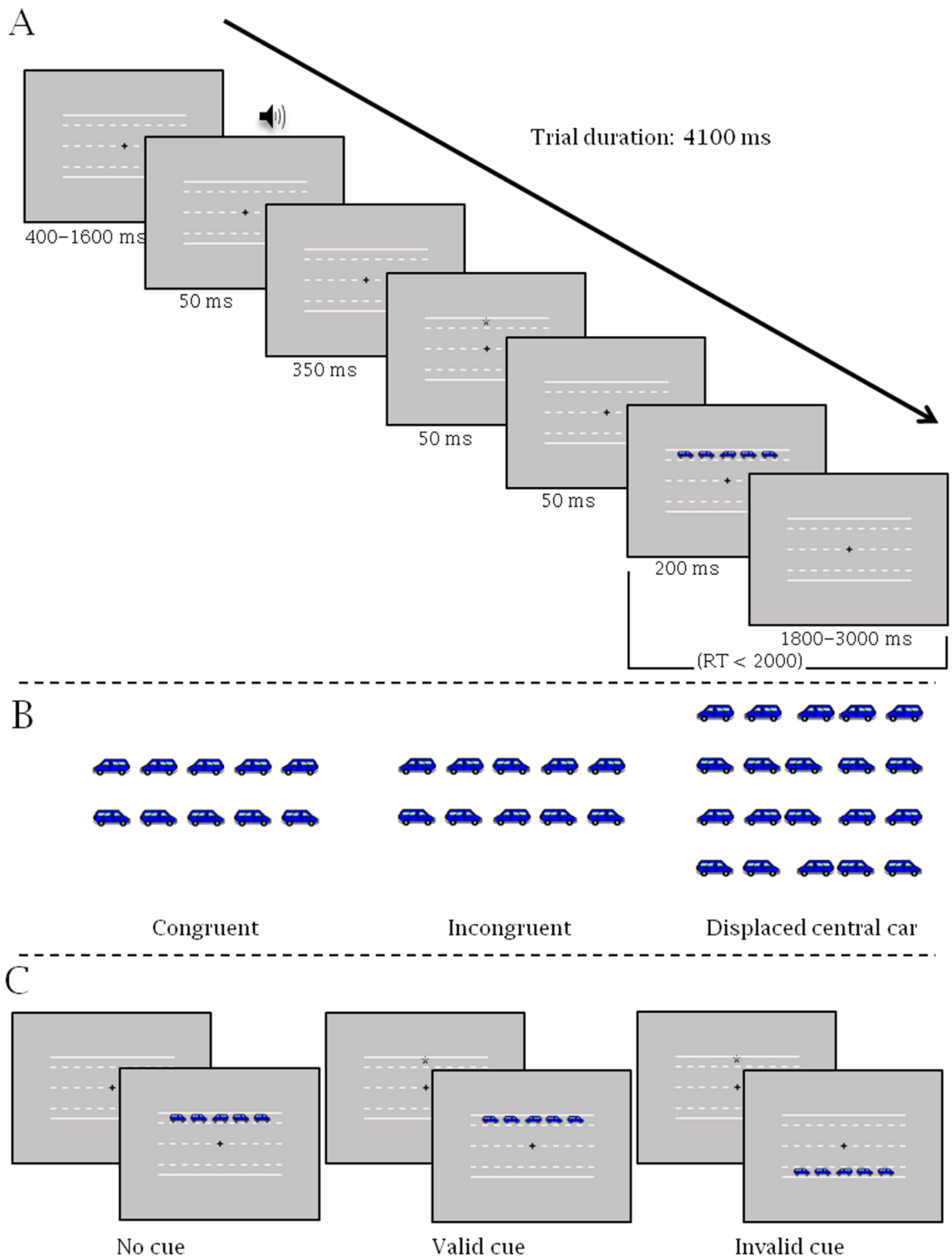

Figure 2.1: Experimental procedure and stimuli used in the attentional test (ANTI–V). (A) Schematic representation of the procedure. (B) The target stimuli. (C) The visual cue conditions.

The background road and the fixation point appeared at the beginning of the first trial and remained present throughout the experiment. On every trial, the duration of this initial empty scene was randomly determined between 400 ms and 1,600 ms, and the duration of an identical final empty scene was computed so that the total trial time was always of 4,100 ms. As a consequence, the participants were uncertain of the beginning of every new trial.

A row of five cars was presented to the participants above or below the fixation point, superimposed on one of the two parking lanes in the background road. Their task was to indicate the direction of the central car by using the keyboard ("c" for left and "m" for right). The row of cars was presented for only 200 ms, although the participants' responses were allowed up to 2000 ms. To analyze the functioning of the executive control network, half of the times the flanker cars were pointing in the same direction as the central target car (congruent condition) whereas they pointed in the opposite direction (incongruent condition) in the other half of trials. To assess the functioning of the orienting network, the row of cars was preceded 100 ms by a visual cue (an asterisk presented for 50 ms), either in the same location as the forthcoming target central car (valid cue condition) or in the opposite location (invalid cue condition), or was rather preceded by no asterisk (no cue condition). The visual cue was not informative regarding the target location, so that only exogenous orienting attention should be involved in the measurement. Also, to measure the functioning of the alertness network, a 50 ms warning auditory signal was either presented 500 ms before the target car appeared (warning tone condition) or not (no warning tone condition). Finally, to obtain a direct measure of vigilance, participants had to detect some infrequent stimuli embedded in the main task. In some trials the target central car was significantly displaced to the right or to the left. Participants were encouraged to identify these significantly displaced cars by pressing an alternative response key (spacebar). Therefore, when the participants detected an infrequent stimulus, they had to respond to the vigilance task and ignore the direction of the central car (and *vice versa*). The way that the ANTI–V measures vigilance is to some extent similar to the SART (Robertson et al., 1997), as both tests are composed by a main repetitive task and the infrequent presentation of a different stimulus that requires a change in the participant's response. However, in the ANTI–V both the main and the infrequent task require a key press (although different keys are required), whereas in the SART the participants have to withhold their response to the infrequent target.

The ANTI–V comprised 8 blocks (64 trials each)[2]. The first one was a practice block with visual feedback and followed by a pause. There were no more rest periods allowed until the end of the experiment. In the second block no feedback and no final pause were provided. To obtain a clearer measure of vigilance, this second block was considered as a warming up block and not considered for further analyses, given that the participants were still adjusting their performance to the task requirements. Thus, only the remaining 6 blocks were considered experimental trials (although for participants nothing changed between the end of the second block and the remaining blocks). The location of the central target (centred / displaced) was manipulated to measure vigilance. However, due to the infrequent presentation of the displaced central target used to measure vigilance (~25% of the trials), this variable was not crossed orthogonally with the three others, and only a random selection of the 12 possible combinations of warning signal, visual cue and congruency factors was used in the displaced central target trials. As a result, each block contained 48 trials for the ANTI usual measures and 16 vigilance trials with the displaced central target condition. A complete factorial design was used with the usual ANTI variables: 2 (Warning signal: No Tone / Tone) x 3 (Visual Cue: Invalid / No Cue / Valid) x 2 (Congruency: Congruent / Incongruent). Data from vigilance trials were only used to compute indexes of vigilance.

2.2. Data analyses

Mean correct reaction time (ms), accuracy (percentage of errors) and vigilance performance data (Signal Detection Theory–based indexes) were inspected for extreme values (higher or lower than 3 standard deviations, St. Dev.), and the data from two participants were excluded because the percentage of false alarms was unusually high (25%) or the sensitivity was zero. Besides, mean correct RT was filtered, discarding the trials with extreme values that were higher or lower than the mean ±2.5 St. Dev. per participant (3%). Then, the following analyses were performed.

First, to analyse the attentional effects usually assessed with ANTI task, mean correct RT and accuracy data were submitted to ANOVAs with warning

[2] Two variations of the ANTI–V task have been used (ANTI–V_a and ANTI–V_b), although their data have been integrated as a single experiment in the current paper. A comparison between both variations is presented in Appendix A.

signal (no tone and tone), visual cue (invalid, no cue, and valid) and congruency conditions (congruent and incongruent) as repeated–measures factors. The significance level in these and further analyses was .05. Planned paired comparisons with Bonferroni correction were performed when appropriate. Greenhouse–Geisser correction was applied when sphericity could not be assumed. Second, attention network scores were computed as a subtraction of specific conditions (phasic alertness score: no tone – tone, only in no–cue conditions; orientation score: invalid – valid; executive control score: incongruent – congruent). Following the procedure proposed by Ishigami & Klein (2009, 2010), one sample t–tests were used to assess whether theses subtraction scores were significantly different from zero and, thus, could be considered as an usable index of each network. Third, to evaluate performance in the vigilance task, the Signal Detection Theory (SDT) indexes of sensitivity (d') and response bias (beta, β) were computed from hits (proportion of correct spacebar responses to infrequent targets) and false alarms (proportion of incorrect spacebar responses to frequent targets). When the proportion of hits or false alarms was 0 or 1, those values were, respectively, substituted by .01 and .99, to obtain an appropriate approximation of the SDT indexes. Then, the SDT vigilance indexes were compared by means of correlation analyses to other potential vigilance or tonic alertness indexes that have been proposed elsewhere (e.g., no–cue RT, global RT or the difference between global RT in the last and first block). Finally, the SDT vigilance indexes were correlated with the attention network scores to analyse their possible relationships.

3. Results

3.1. ANTI effects

For RT data, the main effects of warning signal ($F(1,52)=69.03$, $p<.001$, $\eta^2=.57$), visual cue ($F(2,104)=96.86$, $p<.001$, $\eta^2=.65$), and congruency factors ($F(1,52)=416.64$, $p<.001$, $\eta^2=.89$) were statistically significant. As shown in Table 2.1, on average participants were faster when a warning tone was presented, when the visual cue was valid (i.e., it was presented in the same location that the forthcoming target central car), and when the row of cars was congruent (i.e., all the cars pointed to the same direction). Planned paired comparisons further analysed the differences in the visual cue factor and showed that participants were faster with a valid cue as compared to an invalid cue ($p<.001$) or to the no–cue condition ($p<.001$), and also that RT was slower in the invalid cue than in the no–cue condition ($p<.001$).

The interaction between the warning signal and visual cue factors was statistically significant ($F(2,104)=28.47$, $p<.001$, $\eta^2=.35$). Following Callejas et al. (2005), this interaction was further analysed by removing the no cue condition, where no visual orienting could be measured, and the interaction effect remained statistically significant ($F(1,52)=50.06$, $p<.001$, $\eta^2=.49$), suggesting that the cueing effect was greater for the tone (59 ms) than for the no tone (28 ms) conditions. The interaction between visual cue and congruency factors was also statistically significant ($F(2,104)=18.29$, $p<.001$, $\eta^2=.26$). Partial interactions were calculated and showed that the congruency effect was higher in the invalid (85 ms) than in the no cue conditions (59 ms) ($F(1,52)=21.09$, $p<.001$, $\eta^2=.29$), not being in this latter case larger than in the valid condition (53 ms) ($F(1,52)=1.05$, $p=.31$, $\eta^2=.02$). In contrast to some previous results with the ANTI task, the interaction between warning signal and congruency factors was not significant in this experiment with the ANTI–V task ($F(1,52)=0.02$, $p=.90$, $\eta^2<.001$). This interaction was further analysed by focusing only on the no–cue condition to rule out any influence of the cueing

	No tone			Tone		
	Invalid	**No cue**	**Valid**	**Invalid**	**No cue**	**Valid**
Reaction time						
Congruent	617 (88)	629 (89)	598 (89)	608 (83)	598 (95)	571 (88)
Incongruent	694 (96)	691 (98)	656 (108)	701 (92)	655 (92)	619 (95)
Accuracy						
Congruent	1.7% (3.2)	2.1% (3.1)	2.0% (3.7)	1.0% (2.1)	0.6% (1.5)	1.2% (1.3)
Incongruent	3.9% (5.3)	2.8% (4.0)	2.9% (5.7)	4.9% (7.6)	1.7% (3.4)	1.3% (2.6)

Table 2.1: Mean correct RT (ms) and accuracy (percentage of errors) for the factorial design: 2 (Warning Signal: No Tone / Tone) x 3 (Visual Cue: Invalid / No Cue / Valid) x 2 (Congruency: Congruent / Incongruent). Standard deviations are shown between parentheses.

effect (Callejas et al., 2005), and it remained still clearly non significant (F(1,52)=0.19, p=.66, η^2<.01). Finally, the three-way interaction between warning signal, visual cue, and congruency was not statistically significant in this experiment (F(2,104)=2.88, p=.06, η^2=.05).

Regarding the accuracy data, the main effects for warning signal (F(1,52)=5.43, p=.02, η^2=.09), visual cue (F(1.77,92.18)=5.01, p=.01, η^2=.09) and congruency (F(1,52)=15.80, p<.001, η^2=.23) factors were statistically significant. On average, participants were more accurate when a warning tone was presented, and when the row of cars was congruent. Planned paired comparisons in the visual cue factor showed that the participants made more errors with an invalid cue as compared to the no-cue condition (p=.04). Following the same analytical procedure as in RT data, the interactions between warning signal and visual cue factors (F(1,52)=4.13, p<.05, η^2=.07) and between visual cue X congruency factor (F(1,52)=10.49, p<.01, η^2=.17) were statistically significant. The cueing effect was larger in the tone (1.7%) than in the no tone (0.3%) condition. Partial interactions showed that the congruency effect was higher in the invalid (3.1%) than in the no cue conditions (0.9%) (F(1,52)=8.99, p<.01, η^2=.15), whereas this effect was similar to that observed in the valid condition (0.5%) (F(1,52)=0.37, p=.54, η^2<.01). The interaction between warning signal X congruency (F(1,52)=1.79, p=.22, η^2=.64) was not statistically significant. No second order interaction was found (F(2,104)=2.28, p=.11, η^2=.04).

3.2. Attention network scores

Three different attention network scores for each participant are usually obtained from the ANT task and its variants by subtracting the RT and accuracy data in specific conditions (see, for example, Callejas et al., 2004; Fan et al., 2002): the phasic alertness score was calculated by subtracting the tone from the no tone conditions, only considering the no cue conditions; the orientation score was calculated after subtracting the valid cue from the invalid cue conditions; and the congruency score was obtained after by subtracting the congruent from the incongruent conditions. Table 2.2 summarizes the results of the attention network scores in this experiment. For comparison, the indexes observed in the original ANTI task are also reported (Callejas et al., 2004). Following the procedure proposed by Ishigami & Klein (2009, 2010), one sample t-tests showed that all the attention network scores were statistically different from zero for RT data ($p<.001$) and for accuracy data ($p<.05$).

3.3. Vigilance indexes

The performance in the vigilance task was assessed by means of some SDT indexes. As shown in Table 2.2, the average percentage of hits and false alarms were 55% and 3.4%, respectively, and the average sensitivity (*d'*) and response bias index (β) were 2.1 and 7.6, respectively. These indexes were compared to other proposed measures of vigilance or tonic alertness in the ANT task. First, it has been argued that in no cue conditions the participants must rely on their own internal alertness, and therefore no cue RT collapsed across conditions may reflect the tonic aspects of alertness in the ANT (Posner,

		ANTI-V		ANTI*
		Mean	St. Dev.	Mean
(a) Attention network scores				
Reaction time (ms)	**Phasic alertness**	34	30	31
	Orientation	44	26	36
	Executive control	66	23	89
Accuracy (% errors)	**Phasic alertness**	1.3%	3.3	−2.7%
	Orientation	1.0%	3.0	1.7%
	Executive control	1.5%	2.8	3.8%
(b) Vigilance measures (SDT)				
	Hits	55%	20	--
	False alarms	3.4%	3.0	--
	Sensitivity (*d'*)	2.1	0.5	--
	Response bias (β)	7.6	4.7	--
(c) Global results				
	Global RT	636	88	589
	Global ACC	2.2%	2.0	3.3%

* Computed from Callejas et al. (2004)

Table 2.2: Summary of the results (mean and standard deviation, St. Dev.) for: (a) the attention network scores (phasic alertness, orientation and executive control) for reaction time (ms), and (b) for accuracy (percentage of errors) data; (c) the Signal Detection Theory (SDT)–based vigilance measures (hits, false alarms, sensitivity, and response bias); and (d) the global reaction time (RT, ms) and global accuracy results (ACC–percentage of errors). ANTI–V scores are presented accompanied by original ANTI scores obtained by Callejas et al. (2004).

2008). Note that Fan et al.'s ANT task used the visual cue factor to obtain both phasic alertness and orientation scores, and thus, in the ANTI–V task, only RT collapsed in both the no tone and the no cue conditions (NTNC RT) should be considered as an appropriate candidate for being a tonic alertness index.

Second, it has been suggested that the RT obtained after subtracting overall RT collapsed across conditions in the first experimental block from RT in the last block could be used as a measure of tonic alertness (Sparkes, as cited in Ishigami & Klein, 2009). Note also that this block difference (BD) could be applied to overall RT (BD RT) as well as the above–mentioned no tone and no cue RT (BD NTNC RT). Third, as both simple RT and tonic alertness show a circadian variation, the latter has been usually assessed by means of simple RT tasks (see, for example, Sturm & Willmes, 2001). Thus it could be argued that global RT in ANT task may be to some extent related to vigilance performance, as all the attentional effects may have been cancelled out by averaging the opposed conditions (global RT). Finally, all these analyses have been extended to accuracy data (ACC).

According to the correlation analyses performed (see Table 2.3), the percentage of hits was significantly correlated to global RT and NTNC RT, the former being slightly higher. The percentage of false alarms was significantly correlated to global RT and NTNC RT, again being the former the higher correlation. Sensitivity (*d'*) was significantly correlated to global RT, NTNC RT and Global ACC. This time the latter was the highest correlation. Response bias (β) was significantly correlated to global RT, NTNC RT, and global ACC, also being the latter the highest correlation.

Overall, we think that these results suggest that, among the indirect indexes, global RT and global ACC are the most related to vigilance performance (although this relationship is only moderate). Thus, as some of the alternative vigilance indexes were also correlated to the global measures (for example, global RT and NTNC RT were strongly correlated between them; r=.98, p<.001; even if we extract the NTNC conditions from global RT, the correlation with NTNC RT was still high; r=.95, p<.001), partial correlations were computed to separate the influence of both global RT and global ACC over the other proposed indexes. After partialling out the influence of the global measures, the only significant correlation was found between BD ACC and the percentage of false alarms (r=–.28; p<.05). Also, the following unconfirmed tendencies were observed: BD ACC and sensitivity-*d'* (*r*=.26; *p*=.07) and BD NTNC ACC and the percentage of false alarms (*r*=-.25; *p*=.07). No other correlation was found statistically significant (*p*>.10).

3.4. Relationship between attention network scores and vigilance indexes

The interdependence between the direct SDT-based vigilance indexes and the attention network scores was assessed by means of Pearson's correlation (see Table 2.4). For RT data, the executive control score was significantly correlated to the percentage of hits and there was an unconfirmed tendency in the correlation to the sensitivity index. According to these analyses, a higher congruency effect on RT was associated with better performance in detecting infrequent stimuli. Also, the orientation score was positively correlated with a conservative response bias, and there was also a

	Hits	False alarms	Sensitivity (d')	Response bias (β)
Reaction time (ms)				
Global RT	.64***	.46***	.39**	-.29*
NTNC RT	.62***	.43**	.39**	-.27*
BD RT	-.07	.16	-.21	-.19
BD NTNC	-.07	.19	-.18	-.08
Accuracy (% errors)				
Global ACC	-.25[1]	.17	-.45***	-.35*
NTNC ACC	.04	.16	-.08	-.13
BD ACC	.09	-.14	.11	-.02
BD NTNC ACC	.03	-.25[1]	.18	.15

[1] p<.10; * p<.05; ** p<.01; *** p<.001

Note: NTNC = No tone and no cue condition. BD = Last block minus first block difference. BD NTNC = Last block minus first block difference in no tone and no cue condition.

Note: After partialling out the influence of the global measures (global RT and ACC), the only significant correlation was found between BD ACC and the percentage of false alarms (*r*=-.28; *p*<.05). Also, the following unconfirmed tendencies were observed: BD ACC and sensitivity-*d'* (*r*=.26; *p*=.07) and BD NTNC ACC and the percentage of False Alarms (*r*=-.25; *p*=.07). No other correlation was found statistically significant (*p*>.10).

Table 2.3: Correlations between the Signal Detection Theory indexes (hits, false alarms, sensitivity, and response bias) and other vigilance or tonic alertness indexes proposed for the ANT, both for reaction time (RT, ms) and accuracy (ACC, percentage of errors) data.

negative tendency with the percentage of false alarms. For accuracy data, the executive control network score was also significantly correlated to the sensitivity, although this time showing that a higher congruency effect on accuracy was associated with a lower performance to detect infrequent stimuli. In addition, both the orienting and the executive control score were negatively correlated with a conservative response bias.

However, some of the attention network scores were also significantly correlated to the global RT or ACC measures (see Table 2.5). Thus it could be argued that the global measures could be mediating between the attention network scores and the SDT-based vigilance indexes. In fact, the attentional network scores and the global RT could not be considered as orthogonal measures, as they are computed from the same experimental conditions (e.g., the executive control network score is obtained by subtracting mean RT of congruent conditions from mean RT of incongruent conditions, while global RT is the summation of both conditions). Thus, global RT obtained from only a

	Hits	False alarms	Sensitivity (d')	Response bias (β)
Reaction time (ms)				
Phasic alertness	-.06	.00	-.05	.06
Orientation	.00	-.27[1]	.21	.32*
Executive control	.34*	.11	.26[1]	-.15
Accuracy (% errors)				
Phasic alertness	.10	.06	.06	.01
Orientation	-.09	.05	-.18	-.30*
Executive control	-.15	.12	-.32*	-.39*

[1] p<.10; * p<.05; ** p<.01; *** p<.001

Note: After partialling out the influence of the global measures (global RT and ACC), the only significant correlation was: RT-orientation and sensitivity (r=.34; p=.02). Also, there was an unconfirmed tendency between RT-orientation and response bias (r=.27; p=.06). No other correlation was found statistically significant (p>.10).

Table 2.4: Correlations between the Signal Detection Theory indexes (hits, false alarms, sensitivity, and response bias) and the attention networks scores (phasic alertness, orientation and executive control), both for reaction time (ms) and accuracy (percentage of errors) data.

half of the experimental trials (odd trials) was correlated with the executive network score in RT, computed using the remaining half of the experimental trials (even trials). In this analysis the correlation index was slightly reduced and close to the significance level (r=.25, p=.07), as compared to the original index (r=.30; p<.05). Using ACC data, the correlation was still significant (r=.41, p<.01), although it was also reduced as compared to the original index (r=.75, p<.001). This suggests that the observed relationship between the global measures and executive control scores may be partially reflecting the influence of the "joint measurement" of both scores, especially with ACC data. Additionally, partial correlations were computed to rule out the potential influence of the global RT and ACC measures over the relationship between the attention network scores and the direct SDT-based vigilance indexes. After this analysis the only significant correlation found was between RT-orienting and sensitivity (r=.34; p=.02). Participants showing a larger orienting effect were slightly more able to detect the infrequent stimuli in the vigilance task. Also, there was an unconfirmed tendency between RT-orienting and response bias (r=.27; p=.06). No other correlation was found statistically significant (all p>.10).

	Global RT	Global ACC
Reaction time (ms)		
Phasic alertness	-.02	-.14
Orientation	-.24[1]	-.20
Executive control	.30*	-.12
Accuracy (% errors)		
Phasic alertness	.28*	-.09
Orientation	-.06	.44***
Executive control	-.00	.75***

[1] p<.10; * p<.05; ** p<.01; *** p<.001

Table 2.5: Correlations between the attention networks scores (phasic alertness, orientation and executive control) and the global measures, both for reaction time (RT, ms) and accuracy (ACC, percentage of errors) data.

4. Discussion

The general aim for the present study was to provide the ANTI task with a direct measure of vigilance and then to analyse the relationship of this measure and other alternative indirect indexes that have been proposed for this task in neuropsychology and cognitive neuroscience research (e.g., global RT, no–cue RT or the difference between global RT in the last and in the first block). The most relevant finding is that the proposed ANTI–Vigilance task can be successfully applied to measure vigilance as well as other usual attentional functions (phasic alertness, attentional orienting, and executive control). Also, it is suggested that other alternative indirect indexes (such as global RT and global ACC) are only moderately correlated to a direct vigilance measure. As a consequence, although they may be to some extent related to the participants' vigilance level, they could not be used isolatedly as appropriate indexes of vigilance. As global RT has been previously related to some performance measures in applied areas (such as driving performance), the evidence presented here could be of interest to the discussion of the role played by each attentional network in some everyday human activities, such as driving a vehicle. To our knowledge, this is the first time that some alternative vigilance indexes in the ANT or the ANTI task have been compared to a SDT–based direct measure of vigilance.

The evidence gathered with the ANTI–V supports the findings of Fan et al. (2002) and Callejas et al. (2004) that it is possible to obtain a measure of the operation of each of the three attentional networks (alertness, orienting, and executive control) within a single task. The ANTI–V task has been successful in obtaining the main effects of the warning signal, the visual cue and the congruency factors for RT data, and also the interactions between the warning signal and visual cue factors, and between the visual cue and congruency factors. Besides, the three attention network scores of phasic alertness, orientation and executive control scores were statistically different from zero for RT data, and thus they could be used as a usable index of each network (Ishigami & Klein, 2009, 2010). It is interesting to highlight that the main effects and interactions obtained with the ANTI task have been found with the ANTI–V, taking in consideration that the latter uses a quite different set of stimuli and instructions (e.g. cars in a parking lane instead of arrows). Therefore, we think that the effects usually found with the ANT or the ANTI task are robust, even when major changes in the task configuration are made (see for example, Rueda et al., 2004, for other major variation of the ANT task, successfully applied in studies with children). However, as opposed to the usual findings with the ANTI task, the interaction between the warning signal and congruency factors was not significant in this experiment with the ANTI–V task. A possible explanation is that the way the three attentional networks interact may be dependent of the specific requirements of the task, adjusting attentional control to the current demands. In this regard, the vigilance task embedded in the ANTI–V may have increased the need for cognitive control to adequately distinguish the infrequent displaced target car from the frequent centred target car. Thus the higher congruency effect usually induced by the presentation of the warning signal vanishes, and participants show a similar congruency effect in both the tone and the no tone conditions. Further research with the ANTI–V task could be useful to analyse and discuss this finding.

A measure of vigilance has been successfully obtained from the ANTI–V. The way that the ANTI–V measures vigilance is to some extent similar to the SART (Robertson et al., 1997), as both tests are composed by a main repetitive task and the infrequent presentation of a different stimulus that requires a change in the participant's response (i.e., no–response in the PVT and an alternative key press in the ANTI–V). Thus, as in the SART, a direct vigilance measure has been obtained from accuracy performance (errors), although we have used in the present study hits and false alarms to compute the SDT indexes of sensitivity–*d'* and response bias–β. According to our results, the ANTI–V task has been successful in providing a direct measure of vigilance and could be considered as a new tool available for other researchers interested specifically in analysing vigilance in addition to the usual ANT scores. For example, although both phasic and tonic alertness have been associated with the functioning of the same alerting neural network, some hemispheric differences could be found between phasic and tonic aspects of alerting (see, for example, Coull et al., 2000; Fan, et al., 2005; Sturm & Willmes, 2001). According to Posner (2008), the exact reasons for these differences in laterality are still unknown and they are important in the interpretation of the ANT data. In that sense, the ANTI–V task could be useful to analyse both phasic and tonic aspects of alerting using a single task. Actually, the evidence gathered in this study may be consistent to the relative behavioural independence of these two different aspects of alerting, as the phasic alertness score was not correlated to any of the vigilance indexes. It has been claimed that a larger phasic alerting effect is usually found when the groups of participants have difficulty in maintaining tonic alertness, such as children, right–parietal stroke patients (Posner, 2008), or sleep problems in fibromyalgia (Miró et al., 2011). Our data with normal adult individuals may suggest, however, that phasic and tonic alertness could work independently in normal situations, as we observed in the ANTI–V task with healthy participants. In fact, the only relationship observed in this study between the attentional network scores and the vigilance performance, once the influence of the global measures had been removed, was the partial correlation between the orienting score in RT and sensitivity: participants who benefited more from valid cues (as compared to invalid cues) were slightly more able to detect the infrequent stimuli in the vigilance task. Note that detecting the displaced target requires attention, and therefore those participants orienting attention better might have some benefit in detecting the infrequent displaced targets.

The comparison of the different indirect vigilance indexes proposed for the ANT task against a direct measure of vigilance suggest that these indexes are only moderately correlated to a direct vigilance measure, and thus, they could not be used isolatedly to that purpose. Among them, the global RT and the global ACC measures could be the indirect indexes in the ANT to some extent more associated to the vigilance performance. Global RT averaged across all conditions is positively correlated with the percentage of hits, the percentage of false alarms, and the sensitivity (d'), whereas it is negatively correlated with a conservative response bias (β). Global ACC is negatively correlated with the sensitivity (d') and a conservative response bias (β), and there is as well an unconfirmed tendency in the correlation with the percentage of hits. Also, the performance index obtained only from no tone and no cue conditions (NTNC RT) can be moderately associated with a direct vigilance index. NTNC RT is correlated with the percentage of hits, the percentage of false alarms, the sensitivity (d') and the response bias (β) in a similar extent as the global RT index (although NTNC ACC was not significantly correlated to these indexes). As a consequence, our data support Posner's (2008) suggestion that, when no cue occurs in ANT task, people must rely on their own internal alertness, and thus this RT may reflect the more tonic aspects of alertness.

Regarding the remaining indexes based on the different performances between the first and the last block of ANTI–V task, there was an unconfirmed tendency in the correlation between BD NTNC ACC and the percentage of false alarms ($r=-.25$; $p=.07$). Also, after partialling out the influence of the global measures, there was a significant correlation between BD ACC and the percentage of false alarms ($r=-.28$; $p<.05$), and the following unconfirmed tendencies were observed: BD ACC and sensitivity–d' ($r=.26$; $p=.07$) and BD NTNC ACC and the percentage of false alarms ($r=-.25$; $p=.07$). Therefore, our data may be partially consistent with Sparkes's (as cited in Ishigami & Klein, 2009) suggestion that the RT obtained after subtracting overall RT collapsed across conditions in the first experimental block from RT in the last block could be used as a measure of tonic alertness, although this index might be only moderately correlated to a direct measure of vigilance. As a consequence, the lack of relationship found by Ishigami and Klein (2009) between tonic alertness and a measure of absentmindedness may be partially due to the use of an inefficient index of tonic alertness. However, we have to consider that in the present study the duration of the task was only about 30 minutes (and it is still possible that a clearer effect may appear with a longer interval between the first and the last blocks). As claimed by some authors (e.g., Klein, 2003), the use of attentional scores based on a subtraction of specific conditions could be a useful strategy, because the subtraction removes the undesirable factors that might influence attentional performance and, as a consequence, the specificity of the measure is increased (Klein, 2003). However, measuring vigilance has been generally accomplished in the academic literature by means of non–subtractive global measures, such as average RT or the number of lapses, defined either as long RT responses or using the number of hits and false alarms to obtain the SDT indexes of sensitivity and response bias (see, for example, Lim & Dinges, 2008; Robertson et al., 1997; and also, See et al., 1995). In fact, vigilance is generally considered as a "continuous" phenomenon while other attentional functions are better considered as "discrete". For example, phasic alertness is involved when a warning signal has been presented and it is absent when no warning signal is available. On the contrary, regarding tonic alertness or vigilance, there is always a lower or higher level to be measured. Thus, in the case of tonic alertness or vigilance, a subtraction score will partially eliminate the expected effect. Indeed, the evidence provided in the current study suggests that, in the case of the vigilance indexes, the proposed subtraction scores have not been completely successful in obtaining an efficient vigilance measure, as compared to other more powerful alternative indexes. Additionally, it should be noted that difference scores can have low levels of reliability (for example, MacLeod et al., 2010) and thus smaller correlations may be expected.

Overall, we think that, among the alternative indirect vigilance indexes analysed, the global RT and global ACC measures are to some extent related to the vigilance performance (although only moderately), because: (a) the number and size of the statistically significant correlations with the vigilance indexes tend to be higher for the global measures (maybe NTNC RT had comparable results, but clearly not NTNC ACC); (b) after partialling out the influence of the global RT and global ACC measures, no other alternative index still showed a significant correlation with the percentage of hits or the sensitivity (although BD ACC was still correlated to the percentage of false alarms). In accordance with these results, participants that carried out the ANTI–V more slowly were more able to correctly identify the displaced central cars and also tend to have a more liberal response bias. Besides, participants that made more errors were less able to correctly identify the displaced central cars and also tend to have a more liberal response bias. We explored whether other potential measures of vigilance proposed in the literature for the PVT, such as long RT responses (*lapses* as defined by Lim and Dinges, 2008) or RT variability, were also related to the vigilance indexes. They were indeed, but seemed to be not more appropriate measures for the ANTI task. The number of long RT responses, both in the main task (Lapses–ANTI) and in the vigilance trials (Lapses–V), as well as RT variability (St.Dev.–RT–ANTI and St.Dev.–RT–V) were computed from the ANTI–V and are shown in Table 2.6. The correlation between Global RT and the percentage of hits was the higher in comparison to the alternative measures, and the correlation with sensitivity was also one of the highest (the standard deviation of RT in the vigilance task, St.Dev.–RT–V, had a comparable, slightly higher correlation). Thus, we think that, among the alternative vigilance indexes, Global RT may be the most related to a direct vigilance measure in the ANTI task (note that St.Dev.–RT–V cannot be obtained from the previous ANT or ANTI tasks).

	Hits	False alarms	Sensitivity (*d'*)	Response bias (β)
Alternative vigilance indexes				
Global RT (ANTI)	.64***	.46**	.39**	−.29*
RT-V	.12	−.13	.27*	.29*
Lapses-ANTI	.55***	.46***	.28*	−.31*
Lapses-V	.13	−.06	.24[1]	.22
St.Dev.-RT-ANTI	.55***	.44**	.29*	−.28*
St.Dev.-RT-V	.38**	.02	.41**	.05

[1] p<.10; * p<.05; ** p<.01; *** p<.001

Note: Global RT = Average RT across all conditions in the main frequent task (ANTI). RT–V = Average RT in the vigilance task. Lapses–ANTI = Number of long RT responses (above 90th percentile) in the main frequent task (ANTI). Lapses–V = Number of long RT responses (above 90th percentile) in the vigilance task. St.Dev.–RT–ANTI = Standard deviation of RT in the main frequent task (ANTI). St.Dev.–RT–V = Standard deviation of RT in the vigilance task.

Table 2.6: Correlations between alternative vigilance indexes (as proposed for the PVT) and the Signal Detection Theory–based indexes used in the ANTI–V task (hits, false alarms, sensitivity, and response bias).

From our point of view, the role played by the global RT and the global ACC in the ANT or the ANTI tasks had not been yet completely defined. Posner (2008) claimed that overall RT and ACC performance measures are fundamental to interpret the network scores measured by the ANT or ANTI tasks, as they can reflect different strategies of approaching the task. Thus they should be carefully considered especially when comparing groups with differences in overall RT and ACC. Our results clearly support this claim, providing some evidence of a relationship of these global measures and some SDT–based vigilance indexes. Also, it could be argued that this "attitude toward the task" can be a partial explanation to the main correlations observed between the SDT–based vigilance indexes and the global measures. Some participants may perform more slowly the ANT–V task, trying to properly fulfil both subtasks (i.e., the ANTI and the vigilance task). As a consequence, global RT will increase, errors will decrease and the percentage of hits and the sensitivity will increase as well. For this reason, it is suggested that researchers using the ANTI–V in their studies should carefully consider this possible trade–off in their data. Global RT and ACC could not be used isolatedly to assess the vigilance level, as they are usually influenced by too many factors and their relationship with a direct vigilance measure was only moderate, but they can provide convergent evidence to support (or challenge) the direct measure of vigilance obtained from the ANTI–V. An example of this approach can be found in the work by Roca, Fuentes et al. (2011). The ANTI–V was used in a sleep–deprivation study. Data analyses showed that, after a 24–hour sleep deprivation, global RT and global percentage of errors increased; whereas in the vigilance subtask the percentage of hits and the sensitivity–*d'* decreased. In relation to the "attitude toward the task" hypothesis, it is interesting to note that the increase in the global RT was accompanied by neither a decrease in errors nor a better performance in the vigilance subtask. Indeed, the contrary pattern was found, as expected if vigilance was a better explanation to these results.

Previously, Fan et al. (2002) found the overall mean RT positively correlated to the conflict effect (executive control) in RT. We have also found this relationship, as well as a positive correlation between global ACC and the executive control effect in ACC. The participants who carried out the ANTI–V task more slowly obtained a greater advantage in their response speed when all the stimuli were congruent, as opposed to when the flanker cars were incongruent. In a similar way, the participants that made more errors in the main task obtained also a higher advantage in their accuracy when all the stimuli were congruent, as opposed to when the flanker cars were incongruent. It is important to note that both the executive control scores and the global measures were computed from the same experimental conditions, and thus they could not be considered as orthogonal measurements. However, according to the reported split–half correlation analyses, it is suggested that the observed relationship between the global measures and executive control scores may be partially reflecting the influence of the "joint measurement" of both scores, especially with ACC data.

The importance of the role played in the ANTI–V by the global measures of RT and ACC comes from some previously reported associations in applied areas, such as driving and road safety research. Weaver et al. (2009) explored the feasibility of using some ANT–based measures to predict driving performance outcomes. They found that the global RT and the global ACC were good predictors of both the UFOV and the performance in a driving simulator. Actually, the global RT appeared in this study as the most consistently useful measure obtained from the ANT. Besides, the conflict efficiency score (executive control) was the only association found between the three individual functions of attention (alerting, orienting, and conflict efficiency) and the UFOV, but not the driving performance, which was considered somehow surprising. According to the evidence gathered in the present study, it could be suggested that Weaver and his collaborators found indeed a potential relationship between the alerting network and both the UFOV and the simulated driving performance. The reported association between the global measures and the driving scores may be reflecting to some extent the influence of the vigilance level on the driving performance, which is controlled by the alerting network in Posner and others' model (Posner, 1994; Posner & Petersen, 1990). Also, as Fan et al.'s results (2002) and the evidence provided in the present study show a relationship between the global measures and the executive control score, the association found by Weaver et al. (2009) between the conflict efficiency score and the driving performance measures is also consistent. In addition to these results, the relationship observed by López-Ramón et al. (2011) between the proneness to make attentional errors while driving (as measured by the ARDES questionnaire) and both the global RT and the alertness network score (as measured by the ANTI), may be reflecting the influence of the tonic and the phasic components of the alerting network on the driving performance. Further evidence with a direct measure of vigilance may be useful to confirm these suggestions.

Finally, a discussion about the consideration of the components of attention as neuropsychological traits or states has been recently raised. MacLeod et al. (2010) claimed that the executive control should be considered more trait-like while phasic alertness and attentional orienting may be more state-like. They based this suggestion on differences observed between the network scores in reliability (being the executive control more stable across multiple-measurements), variance components (low within-subject variance and high between subjects variance for executive control, and a reverse pattern for phasic alertness and orientation), and also in some genetic studies (evidence have been reported for high heritability in executive network efficiency, but not for the alerting and orienting networks). In line with these arguments, Pacheco-Unguetti et al. (2010) found that executive control was related to anxiety-trait, whereas both alertness and orienting were rather related to anxiety-state. Regarding tonic alertness or vigilance, it should be noted that vigilance has been traditionally defined as a *state* or a temporary *level* (see, for example, Posner, 2008; and Sturm & Willmes, 2001). Besides, it is generally accepted that maintaining a vigilant and alert state is managed by the alerting network (e.g., Posner, 2008), which is also involved in the state–like phasic alertness function. However, it is also possible that the general ability to maintain vigilance over time may be better defined as a trait (i.e., a more stable cognitive control ability, probably related to the executive control network), whereas the momentary level of vigilance should better defined as a state. Further research will be useful to clarify the role of vigilance as a trait or a state.

4.1. Conclusions

As a general conclusion, the evidence gathered with the ANTI–V highlights the importance of taking into account a measure of tonic alertness or vigilance while measuring the functioning of the three attentional networks (alertness, orienting and executive control). This objective could be accomplished by means of a secondary vigilance task (such as the detection of an infrequent target, as in the ANTI–V) and, in addition, by carefully considering the global RT and global ACC (especially when comparing groups of participants, as it was previously pointed out by Posner, 2008). A direct measure of vigilance will be always necessary, as global RT and global ACC are only moderately associated with vigilance and they could be frequently influenced by several confounding factors in different tasks or situations. Also, the ANTI–V task could be of interest to those cognitive, clinical or behavioural neuroscience researchers interested in comparing both phasic and tonic aspects of alerting using a single experimental task.

Capítulo 3 Chapter

Study 2:

The effects of sleep deprivation on the attentional functions and vigilance.

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Abstract

The study of sleep deprivation is a fruitful area of research to increase our knowledge of cognitive functions and their neural basis. Also, it could be useful in several applied areas such as accident prevention. In the current work, a 24–hour sleep deprivation study was carried out, in which participants' performance on the Attentional Networks Test for Interactions and Vigilance (ANTI–V) was compared. This attentional task provides independent indices for tonic and phasic alertness, attentional orientation and executive control functions. Compared to some previous alternatives, the ANTI–V involves rather different components of attention, such as a vigilance measure, more reliable auditory alerting signals, non–predictive peripheral orienting cues, and also a neutral no–cue condition allowing the analysis of reorienting costs and orienting benefits. Thus, new evidence to evaluate the influence of sleep deprivation on attentional functioning is provided. Results revealed that sleep deprivation affected both tonic and phasic alertness. Vigilance performance was deteriorated, while a warning tone was helpful to increase participants' alertness, resulting in slightly faster RT and, in particular, fewer errors. The reorienting costs of having an invalid spatial cue were reduced after sleep loss. No sleep deprivation effect on the executive control measure was found in this study.

Keywords: Sleep deprivation; Attention Networks Test; Vigilance; Phasic alertness; Attentional orienting; Executive functions.

1. Introduction

The lack of proper sleep has a powerful detrimental effect on many everyday activities. Without a good night–time rest, people usually experience difficulties in, for example, performing effectively at work, carrying out habitual home duties or driving a vehicle safely. On the basis of these difficulties, it is frequent to find poorer cognitive functioning, including alterations in perception, attention, memory, executive functions, affective processing and others (see Killgore, 2010, for a review). As a consequence, the study of sleep deprivation (SD) is a fruitful area of research to increase our knowledge of cognitive functions and their neural basis. Also, a better understanding of SD would be useful in several applied areas, such as accident prevention, since lack of sleep is considered a major cause of road traffic accidents, especially at night or in professional drivers (Åkerstedt, Philip, Capelli, & Kecklund, 2011; Lal & Craig, 2001).

The influence of SD on attention has been studied frequently. Some researchers have even proposed that diminished attentional performance is the basis of many other cognitive alterations usually found after sleep loss (Lim & Dinges, 2008). However, the evidence gathered for the different attentional functions has shown inconsistent results and many questions remain open (Killgore, 2010). Most of the studies addressing the effect of SD on attentional components used different experimental procedures or lacked an attention theory, which makes comparisons between them difficult. In the present study we take Posner and colleagues' neurocognitive model as theoretical background on attention and use a new version of the Attention Networks Test (ANT) that allows measurement of the different attention components in a single experiment. According to the model (Posner, 1994; Posner, 2008; Posner & Petersen, 1990), three different neural networks can be distinguished: alerting, orienting, and executive control. First, the alerting network is necessary to achieve (phasic alertness) and maintain (tonic alertness or vigilance) a state of high sensitivity to incoming stimuli. It is generally accepted that SD is a powerful way of reducing tonic alertness or vigilance (Killgore, 2010; Lim & Dinges, 2008). However, the effect of sleep loss on phasic alertness has been less frequently studied and recent evidence (Martella, Casagrande & Lupiáñez, 2011; Trujillo, Kornguth & Schnyer, 2009) has failed to find differences using the Attention Networks Test (ANT) (Fan, McCandliss, Sommer, Raz & Posner, 2002) in a SD paradigm.

Second, the orienting network is aimed at selecting information from the sensory input by allocating the attentional focus to a potentially relevant area or object in the visual field. A few studies have analysed the influence of sleep loss on attentional orienting but have produced contrasting results (Bocca & Denise, 2006; Casagrande, Martella, DiPace, Pirri & Guadalupi, 2006; Martella et al., 2011; Trujillo et al., 2009; Versace, Cavallero, De Min Tona, Mozzato & Stegagno, 2006). For instance, Casagrande et al. (2006) found a general de–arousal effect (a significant increase in reaction time, RT) across 24 hours of SD, but not a selective effect on the orienting mechanisms. On the other hand, Versace et al. (2006), using a partial sleep reduction paradigm, observed a significant slowing down of response time in the invalid condition, suggesting an impairment of the reorienting mechanisms. Similar results were obtained by other authors using the gap and overlap paradigms of saccadic eye movements (Bocca & Denise, 2006). Specifically, a selective effect of sleep loss was found in the studies that used a peripheral predictive cue (Martella et al., 2011; Versace et al., 2006), but this was not observed by Casagrande et al. (2006) who used a central predictive cue. According to Martella et al. (2011), the main difference between these two types of task can be ascribed to some characteristics of the attentional processes involved: a central predictive cue produces a voluntary shifting of attention (Posner, 1980), while a peripheral predictive cue allows attentional orienting characterised by both automatic and voluntary processes (Jonides, 1981). Thus, one may assume that the low arousal due to SD affects the orienting mechanisms only when the task involves an automatic component of attention (Martella et al., 2011). However, some other studies have found apparently contrasting results. For example, Trujillo et al. (2009), in a SD neurophysiological study, compared two versions of the ANT, one using peripheral predictive cues and the other using central predictive cues, and concluded that a greater effect of SD is observed on endogenous (central) shifts of attention, as compared to exogenous (peripheral) orienting. Indeed, these results with spatial cues can be better explained in terms of peripheral (automatic) cueing compensating the deficits of SD due to reduced vigilance. For example, in Martella et al.'s (2011) study, a greater increase in RT was found in the centre–cue trials than in those with a spatial cue, which were less affected by SD. In Versace et al. (2006) similar RTs were found in the valid cue condition with and without SD, whereas the participants' responses were slower after sleep loss in the invalid and neutral conditions (although in the latter the difference was not statistically significant). Additionally, Trujillo et al. (2009), using neurophysiological data, showed that the response to the spatially cued targets in the exogenous task was preserved after SD, increasing the difference in amplitude of the N1 component with a spatial cue as compared to a neutral cue. On the other hand, this compensatory effect of the spatial cues might not take place when attention has to be oriented endogenously, probably because central resources are needed for endogenous orienting. Consequently, Casagrande et al. (2006), with central cues, observed a similar RT increment in each cue condition (valid, invalid, neutral) due to sleep loss. Also, Trujillo et al. (2009) found that the amplitude of the parietal N1 in response to both the neutrally cued and the spatially cued targets was similarly decreased by SD in the endogenous task.

Finally, the third network in Posner and colleagues' model of human attention, i.e. the executive control network, involves the mechanisms for resolving cognitive conflict. According to Killgore et al. (2010), inconsistent findings abound in the literature of the effects of SD on higher executive functions, and thus more studies are necessary to identify which components are more reliably altered. For instance, different studies failed to find a SD effect on interference using the Stroop task (Sagaspe et al., 2006; Cain, Silva, Chang, Ronda & Duffy, 2011), whereas others reported a diminished performance (e.g., Stenuit & Kerkhofs, 2008). Also, when SD studies evaluated the executive network by using a flanker task, the impairment in conflict control was observed by some authors (Martella et al., 2011; Tsai, Young, Hsieh & Lee, 2005) but not by others (Hsieh, Cheng & Tsai, 2007; Murphy, Richard, Masaki & Segalowitz, 2006). These inconsistent results could be ascribed to the high inter–subject variability of the effects of sleep loss (Banks & Dinges, 2007; Van Dongen, Baynard, Maislin & Dinges, 2004). In line with this hypothesis, it was found that, after 48 hours of SD, the deactivation of a neural network, including posterior cerebellum, right fusiform gyrus, precuneus, left lingual and inferior temporal gyri, was effective only in participants showing impairment in memory performance, but not in those able to maintain a higher performance (Bell–Mcginty et al., 2004). This variability in neural and behavioural responses to SD showing that greater activation of cortical areas during SD was associated with a better maintained performance, may account for many of these contrasting results.

1.1. The Attention Network Test for Interactions and Vigilance (ANTI-V)

In 2002, Fan and his collaborators developed the Attention Networks Test (ANT), a carefully designed computer task aimed at obtaining individual measures of alerting, orienting, and executive control attentional functioning (Fan et al., 2002). The ANT is a combination of the cued reaction time (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). According to the evidence gathered in different studies, the measures obtained from the ANT can be considered as usable indices of the three attentional networks, as found with behavioural data (Fan et al., 2002), in neuroimaging studies (Fan, McCandliss, Fossella, Flombaum & Posner, 2005) and with the assessment of different metric properties (Ishigami & Klein, 2010). However, some potential limitations of the task were soon identified (Callejas, Lupiáñez & Tudela, 2004). For example, the alerting and orienting effects were not assessed independently, as they were computed from the same factor manipulation. Also, exogenous and endogenous components of attentional orienting were confused, as the peripheral cue used was 100% predictable of the forthcoming appearance of the target stimulus. As a consequence, an improved variation of the task was proposed, known as the Attentional Network Test for Interactions or ANTI (Callejas et al., 2004). In the ANTI, an auditory warning signal was used, instead of a visual cue, to measure the alertness index independently, and non–predictive peripheral cues were presented to obtain the attentional orienting index.

Both the ANT and the ANTI have been successfully applied to assess attentional functioning in a great variety of research contexts, such as neurocognitive studies with children (Rueda et al., 2004), dementia patients (Fernandez et al., 2011; Fuentes, Fernández, Campoy, Antequera, García–Sevilla & Antúnez, 2010), anxiety (Pacheco–Unguetti, Acosta, Callejas & Lupiáñez, 2010), and even in the driver behaviour and traffic safety sphere (López–Ramón, Castro, Roca, Ledesma & Lupiáñez, 2011; Weaver, Bédard, McAuliffe & Parkkari, 2009). As a consequence, the tasks have been adapted to the different research contexts where they have been applied (for example, a lateralised version or LANT was developed to measure attention in both hemispheres; Greene et al, 2008). It is interesting to note that, in these tasks, alerting network functioning has generally been inferred from a phasic alertness measure, and the tonic alertness or vigilance level has been estimated indirectly (for example, by analysing the difference in RT between the first and the last block of the task, Ishighami & Klein, 2009; the overall RT across all correct trials, Martella et al., 2011, and Miró et al., 2011; or the overall RT only considering "no cue" trials, Posner, 2008). However, Roca, Castro, López–Ramón, & Lupiáñez (2011) have highlighted the importance of taking a direct measure of tonic alertness or vigilance while assessing the functioning of the three attentional networks. The indirect indices usually considered in the literature were only moderately associated with a direct measure of vigilance (i.e., the detection of an infrequent, unexpected and unpredictable stimulus embedded in an ANTI–based task). Thus, Roca, Castro et al. (2011) have proposed a new test, the Attention Network Test for Interactions and Vigilance or ANTI–V, as a new tool available for cognitive, clinical, or behavioural neuroscience research to obtain a measure of tonic alertness or vigilance, in addition to the usual phasic alertness, attentional orienting and executive control indices. As SD is usually associated with a reduction in arousal levels, the use of the ANTI–V in a SD study constitutes a unique opportunity to validate the vigilance index in the ANTI–V, in addition to the usual attention indices.

1.2. Objectives

The current study has two aims. First, as we mentioned above, we wanted to investigate whether the ANTI–V is actually measuring vigilance, and thus whether the vigilance indices calculated from this task are effectively influenced by sleep deprivation. This will provide further evidence of the validity of the ANTI–V, in addition to the original study by Roca, Castro et al. (2011). For example, it is expected that the percentage of hits and sensitivity will be reduced and the percentage of false alarms (or error commission) increased under SD. Regarding the response bias, previous evidence has generally found no change after sleep loss (Horne, Anderson & Wilkinson, 1983). Besides, as found previously with the ANT and other attentional tasks (Casagrande et al., 2006; Killgore, 2010; Lim & Dinges, 2008; Martella et al., 2011), the participants' overall responses under SD should be slower and less accurate, RT variability will increase and a convergent SD effect is expected on other complementary vigilance measures, such as subjective sleepiness.

Second, the current study will provide further information about the influence of SD on attentional functioning. Although some previous studies have used the ANT in a SD paradigm, this is the first time that the ANTI–V, which provides rather different measures of alertness, attentional orienting and executive control, is being used in this context. Thus, different results may be expected as a consequence of the dissimilarities between these tasks. For example, although previous studies using the ANT have failed to find a SD effect on phasic alertness (Martella et al., 2011; Trujillo et al., 2009), it is possible that this effect will be found using the ANTI–V. Phasic alertness is measured in the ANT using visual stimuli, while an auditory stimulus has been used in the ANTI–V. As claimed by Fan et al. (2002), auditory alerting cues often produce more automatic alerting than do visual cues and they might serve to aid the reliability of the alerting manipulation. Regarding the attentional orienting score, the ANTI–V uses non–predictive peripheral cues. As a consequence, it is mainly exogenous orienting that is measured and the effect of SD on this attentional component will be more finely evaluated, in comparison with the ANT or other tasks using predictive peripheral cues, in which both exogenous and endogenous components of attention may be involved. To our knowledge, no other study has previously analysed the effect of sleep loss on an attentional task with non–predictive peripheral cues. Also, unlike the ANT, the ANTI–V includes valid and invalid cue trials, and therefore a separate cost and benefit analysis can be performed by comparing these trials with a neutral, no cue condition. Finally, the ANTI–V is a more demanding task, since it requires a further vigilance component compared to the ANT or the ANTI, and it has been suggested that the need for cognitive control is increased to adequately distinguish the different types of stimuli (Roca, Castro et al., 2011). As a consequence, the increased cognitive control mechanism might partially compensate for the effects of SD on the executive control score.

2. MATERIAL AND METHODS

2.1. Participants

Thirty students from the University of Murcia participated in this study. Fourteen were males. Mean age was 21 (St. Dev. 2). The participants were selected as being right–handed and all of them reported normal or corrected to normal vision. Besides, they were all ignorant of the purpose of the experiment. At home, the participants were asked to complete a sleep questionnaire daily upon final awakening in the morning, for one week before the experimental session. Only those who reported normal sleep duration (7.5–8.5 hours *per* day) and schedule (going to sleep at 11.30 p.m. ± 60 min. and waking up at 7.30 a.m. ± 60 min.) and who reported no sleep, medical, or psychiatric disorders, were included in the study. Moreover, participants were all non–smokers and were all drug–free. During the experimental session, the participants did not drink or eat anything containing caffeine (e.g., coffee, tea, chocolate). The experiment was conducted according to the ethical standards of the 1964 Declaration of Helsinki and was approved by the local ethical committee.

2.2. Apparatus

The experimental task was controlled by E–Prime v2.0 (Psychology Software Tools, Inc.) on a standard computer. The stimuli were presented on a 19 inch monitor and the responses were collected using a standard keyboard.

2.3. Stimuli and task procedure

The ANTI–Vigilance (ANTI–V) was used in the current study (Figure 2.1). An extensive description of the task can be found in Roca, Castro et al. (2011). The following stimuli were presented: a black fixation cross, a warning tone, a black asterisk and a row of five cars pointing either left or right. The distance of the central target car was manipulated, being either centred or significantly displaced (i.e., appearing closer to one of the immediate flanker cars). Also, the vertical and horizontal location of each car was changed slightly in each trial, adding a random variability (±4 pixels) to make it more difficult to distinguish between the centred and the displaced target car. The background was grey and a two–lane road with two parking lanes was represented in the centre of the screen. The target central car and its flankers appeared on one of the two parking lanes, above or below the fixation cross.

The instructions presented the task to the participants as a game, in which they were working in a Centre for Traffic Management and studying the drivers' parking habits. The participants were presented for 200 ms with a row of five cars, above or below the fixation point. They had to indicate the direction of the central car, by pressing “c” (for left) or “m” (for right) on the keyboard. A period of 2,000 ms was allowed for responses. The background road and the fixation point remained present until the end of the experiment. In every trial, the duration of the initial empty scene was randomly determined (400–1,600 ms), and the duration of an identical final scene was adjusted so that the total trial time was 4,100 ms.

In half the trials the flanker cars were pointing in the same direction as the central target car (congruent condition) and in the other half, in the opposite direction (incongruent condition). Also, 100 ms before the row of cars appeared, an asterisk was briefly presented (50 ms), either in the same location as the forthcoming target central car (valid visual cue condition), in the opposite location (invalid visual cue condition), or preceded by no asterisk (no visual cue condition). These three visual cue conditions were equally probable. In addition, either a 50 ms auditory warning signal was presented 500 ms before the target car was shown (warning tone condition) or it was not presented (no warning tone condition). Finally, in 25% of the trials, the target central car was significantly displaced to the right or to the left. The participants were encouraged to identify these infrequent stimuli by pressing an alternative response key (spacebar) and ignoring the direction of the central car in these trials.

The task was composed of 8 blocks of 64 trials each (48 trials for the usual ANTI conditions and 16 vigilance trials with the displaced central target condition). In the first (practice) block, feedback on accuracy was provided. This first block was followed by a pause, and there were no more rest periods until the end of the task. In the second block, no feedback and no final pause were allowed, and thus nothing changed for the participants between the end of the second and the remaining blocks. Following Roca, Castro et al. (2011), the second block was not considered for further analyses, as the participants were still adjusting their performance to the requirements of the task. As a consequence, only the remaining 6 blocks were considered as experimental trials. The participants had to perform the task for more than 30 minutes, while completing the experiment required for around 40 minutes.

2.4. Complementary measures

We used a unidimensional Visual Analogue Scale (VAS) (Curcio, Casagrande, & Bertini, 2001) to evaluate subjective sleepiness. Participants were asked: "How do you feel right now with respect to the adjective *sleepy*?". They had to respond by making a stroke with a pen on a 100 mm long line. The stroke had to correspond with the point indicating the intensity of the self–evaluation. The VAS was anchored at one end with "not at all" (on the left) and at the other end with "very" (on the right). The distance of the mark from the left end of the line was considered as a dependent variable. In addition, the peripheral body temperature was measured, using a standard thermometer, to evaluate the participants' circadian rhythmicity.

2.5. Sleep deprivation procedure

The participants performed the experimental task on three consecutive days. First, an *initial experimental session* was scheduled on the afternoon previous to the sleep deprivation day, when the participants performed the ANTI–V task for the first time. The main objective of this initial experimental session was to reduce the impact of possible learning effects that may appear after a repeated presentation of the ANTI task (see Ishigami & Klein, 2010). Also, these data were used to evaluate whether the ANTI–V had been applied successfully and whether the main results by Roca, Castro et al. (2011) could be replicated. On the second day, after the participants had slept their usual time, they were received in the laboratory and kept awake for 28 hours. During this time, they were asked to perform the ANTI–V at 10 a.m. (*without SD session*) and at 10 a.m. on the following day, after 24–hour sleep deprivation (*with SD session*). The participants performed other cognitive tasks before and after completing the ANTI–V. In addition, subjective sleepiness (VAS) and corporal temperature were measured hourly from 9.00 a.m. on the second day to the end of the study. The participants had two breaks, one for lunch (about 2 p.m.) and one for dinner (about 10 p.m.). The experimenter continuously monitored the subjects, in order to avoid any naps.

2.6. Experimental design and data analysis

First, it should be noted that the initial experimental session, whose main aim was to reduce the impact of some potential learning effects and to replicate previous findings with the ANTI–V, was not directly comparable with the following two sessions (with and without SD), because the task was completed at different times of day and, thus, some circadian effects may also have arisen. As a consequence, data from the initial experimental session were analysed separately, by using a complete repeated–measures factorial design with the usual ANTI variables: 2 (Warning signal: No Tone / Tone) x 3 (Visual Cue: Invalid / No Cue / Valid) x 2 (Congruency: Congruent / Incongruent). Additionally, the location of the central target (Centred / Displaced) was manipulated to measure vigilance. Due to the infrequent presentation of the displaced central target and the fact that only a random selection of their combinations was used in the vigilance trials, this variable was not crossed orthogonally with the other three (warning signal, visual cue and congruency). Mean RT of correctly answered trials was inspected and values above or below two standard deviations were discarded (about 5% of trials). Twenty–six participants completed the task, although data from one of them was rejected from the analyses because the percentage of false alarms was unusually high (> 3 St. Dev.) and the sensitivity was zero. A repeated–measures ANOVA with warning signal (no tone / tone), visual cue (invalid / no cue / valid) and congruency conditions (congruent / incongruent) was performed. The overall significance level was set at .05 and planned paired comparisons with the Bonferroni correction were performed when appropriate. If sphericity could not be assumed, degrees of freedom were adjusted using the Greenhouse–Geisser correction.

Regarding the SD study, a complete repeated–measures factorial design was used with the following variables: 2 (Session: With / Without SD) x 2 (Warning signal: No Tone / Tone) x 3 (Visual Cue: Invalid / No Cue / Valid) x 2 (Congruency: Congruent / Incongruent). Vigilance was manipulated in the same way as described in the initial experimental session. Mean RT of correct response trials was inspected and values above or below two standard deviations were discarded (about 5% of trials). Twenty–nine participants took part in the sleep–deprivation session, although the data from three of them were discarded because their percentage of errors was unusually high (> 3 St. Dev.)[3]. Mean correct RT and mean percentage of errors were then submitted to ANOVAs with session (with / without SD), warning signal (no tone / tone), visual cue (invalid / no cue / valid) and congruency conditions (congruent / incongruent) as repeated–measures factors.

Different attentional network scores were computed as a subtraction from specific average conditions: a) Phasic alertness score: no tone – tone conditions, considering only no–cue trials; b) Orientation score: invalid – valid conditions; c) Executive control score: incongruent – congruent conditions. Also, complementary cost and benefit indices were obtained from the visual cue conditions, in which the costs of presenting an invalid spatial cue were calculated as the difference between the average invalid trials minus no cue trials, and the benefits of having a valid spatial cue were computed as the

[3] Four participants failed to complete the initial experimental session. Data analyses were computed with and without these participants, and results were approximate. Thus, the complete sample size has been used in the present paper.

difference between the no cue and valid trials. Regarding the vigilance task, the number of hits (proportion of correct spacebar responses to infrequent displaced targets) and false alarms (proportion of incorrect spacebar responses to frequent targets) were used to compute the sensitivity (*d'*) and response bias (β), following the Signal Detection Theory (SDT) procedures. If hits of false alarms were 0 or 1, these values were substituted by .01 or .99, respectively, to obtain a suitable approximation to the SDT indices. Attentional networks scores and vigilance performance indices were submitted to ANOVAs with session (with / without SD) as a repeated–measures factor. Additionally, some global measures, such as overall RT, overall percentage of errors and overall St. Dev. of RT, were calculated separately for ANTI and vigilance subtasks and also submitted to similar ANOVAs.

3. RESULTS

3.1. Initial experimental session

3.1.1. Reaction time

The analysis of RT data (Table 3.1) from the initial experimental session showed that the following main effects were statistically significant: warning signal ($F(1,24)=13.51$; $p=.001$; $\eta^2=.36$), visual cue ($F(2,48)=43.67$; $p<.001$; $\eta^2=.65$) and congruency ($F(1,24)=118.97$; $p<.001$; $\eta^2=.83$). Average RTs were faster when a warning tone had been presented (630 ms) than when it was absent (647 ms), and when the stimuli were congruent (612 ms) versus incongruent (664 ms). Planned comparisons of the visual cue factor revealed that average RTs were faster in valid trials (617 ms) than in invalid (656 ms) or no cue trials (641 ms), and also faster in no cue than invalid trials.

The Warning signal X Visual cue interaction was statistically significant ($F(2,48)=4.30$; $p<.05$; $\eta^2=.15$). However, no differences were found in the orientation score (i.e., invalid minus valid conditions) between the no tone (34 ms) and tone trials (45 ms) ($F(1,24)=2.01$, $p=.17$, $\eta^2=.08$). The Visual cue X Congruency interaction was significant ($F(2,48)=6.57$; $p<.01$; $\eta^2=.21$). Partial interactions showed that the congruency effect was higher in the invalid (64 ms) than in the no cue conditions (47 ms) ($F(1,24)=6.57$, $p<.05$, $\eta^2=.22$), while in the latter, the congruency effect was similar to the valid condition (44 ms) ($F(1,24)=.38$, $p=.54$, $\eta^2=.02$). The Warning signal X Congruency interaction was analysed by focusing only on the no cue condition to discard any influence of the cueing effect, and, as expected, it was non–significant ($F(1,24)=.37$; $p=.55$;

η^2=.02). Finally, the second order interaction was not significant ($F(2,48)=.72$; $p=.49$; η^2=.03).

3.1.2. Accuracy

According to the analysis of the percentage of errors, the main effect of warning signal was statistically significant ($F(1,24)=5.27$; $p<.05$; η^2=.18), and the participants made more errors when the warning tone had not been presented (3.6%) than when it was presented (2.7%). The main effect of visual cue was statistically significant ($F(2,48)=3.61$; $p<.05$; η^2=.13). Planned comparisons with the Bonferroni correction failed to confirm any difference between the invalid (3.7%), no cue (3.3%) and valid conditions (2.5%), although values were in the direction expected. The main effect of congruency was also significant ($F(1,24)=6.22$; $p<.05$; η^2=.21), showing that participants made more errors in the incongruent (3.9%) than in the congruent condition (2.4%). The Warning signal X Visual cue interaction approached significance level ($F(2,48)=2.83$; $p=.07$; η^2=.11). The Visual cue X Congruency interaction was

		Initial Session		Without SD		With SD	
		No Tone	Tone	No Tone	Tone	No Tone	Tone
Reaction time (ms)							
Invalid	**Congruent**	629 (79)	620 (83)	604 (66)	596 (70)	660 (111)	659 (103)
	Incongruent	689 (89)	687 (88)	659 (71)	671 (81)	710 (77)	722 (103)
No Cue	**Congruent**	630 (72)	604 (75)	619 (64)	580 (63)	676 (91)	645 (104)
	Incongruent	681 (87)	648 (77)	659 (75)	628 (65)	717 (89)	713 (116)
Valid	**Congruent**	605 (74)	586 (87)	578 (65)	554 (69)	632 (89)	629 (96)
	Incongruent	646 (85)	632 (99)	627 (78)	609 (82)	677 (88)	678 (116)
Percentage of errors (%)							
Invalid	**Congruent**	3.2 (4.4)	1.5 (3.4)	1.1 (2.5)	0.8 (2)	15.3 (12.6)	8.0 (9.1)
	Incongruent	5.9 (5.6)	4.0 (4.9)	4.4 (6.2)	3.3 (4.2)	22.6 (19.2)	13.1 (12.6)
No Cue	**Congruent**	2.9 (4.5)	2.0 (3.9)	1.0 (1.8)	0.6 (1.5)	14.8 (12.2)	10.7 (11.9)
	Incongruent	5.0 (6.3)	3.5 (4.6)	3.0 (3.6)	1.8 (4)	18.3 (15)	12.2 (10.3)
Valid	**Congruent**	2.5 (4.2)	2.6 (3.7)	1.9 (2.7)	0.7 (2)	15.2 (13.3)	8.5 (8.7)
	Incongruent	2.4 (3.7)	2.6 (4.2)	2.3 (3.4)	2.1 (4.1)	15.5 (11.3)	10.5 (10.7)

Table 3.1: Mean correct reaction time, percentage of errors, and standard deviations (between parentheses) for the three experimental sessions: Initial Session, Without Sleep Deprivation, and With Sleep Deprivation. Warning signal (No tone / Tone), Visual cue (Invalid / No Cue / Valid), and Congruency (Congruent / Incongruent) conditions have been differentiated.

significant (F(2,48)=3.73; p<.05; η^2=.13). As shown by partial interactions, the congruency effect was similar in the invalid (2.6%) and the no cue conditions (1.8%) (F(1,24)=.58, p=.45, η^2=.02), whereas in the latter, the congruency effect tended to be higher than in the valid condition (~0%) (F(1,24)=3.49, p=.07, η^2=.12). The Warning signal X Congruency interaction was not statistically significant (F(1,24)=.26; p=.61; η^2=.01). The second order interaction was not significant (F(2,48)=.11; p=.90; η^2<.01).

	Initial Session	Without SD		With SD
a) Attentional scores: RT (ms)				
Phasic Alertness	30 (31)	35 (32)	*	17 (42)
Orientation	39 (20)	40 (20)		34 (24)
Executive Control	51 (24)	54 (25)		53 (27)
b) Attentional scores: % errors				
Phasic Alertness	1.2 (3.4)	0.7 (2.3)	*	5.2 (6.6)
Orientation	1.1 (2.5)	0.7 (2.3)		2.3 (5.5)
Executive Control	1.5 (2.9)	1.8 (2.1)		3.3 (5.6)
c) Vigilance measures (SDT)				
Hits (%)	55 (19)	57 (17)	*	45 (16)
False Alarms (%)	2.8 (2.9)	1.7 (1.1)		2.4 (1.8)
Sensitivity (*d'*)	2.1 (0.6)	2.3 (0.5)	*	1.9 (0.5)
Response Bias (β)	8.4 (4.1)	9.8 (3.8)		8.4 (4)
d) Global results				
ANTI RT (ms)	638 (78)	615 (66)	*	677 (92)
ANTI % errors	3.2 (3.1)	1.9 (2.0)	*	13.7 (10.4)
ANTI St. Dev.	160 (44)	148 (51)	*	217 (71)
Vigilance RT (ms)	804 (100)	775 (78)	*	864 (119)
Vigilance St. Dev.	143 (48)	157 (54)	*	195 (63)

*p< .05 (Without SD vs. With SD)

Table 3.2: Summary of main attentional measures in the three experimental sessions: Initial Session, Without Sleep Deprivation, and With Sleep Deprivation. Mean (and standard deviation) are shown for: a) Attentional scores in reaction time (phasic alertness, orientation, and executive control); b) Attentional scores in percentage of errors; c) Vigilance measures (Signal Detection Theory indices); and d) Global results (reaction time, percentage of errors, and standard deviation of reaction time).

3.1.3. Attentional scores

Finally, Table 3.2 shows the attentional scores obtained in the initial experimental session, including the SDT–based measures for vigilance. Additionally, to evaluate whether the main results by Roca, Castro et al. (2011) could be found, correlations between the SDT vigilance measures and some other vigilance indices proposed for the ANTI (such as global RT or no tone and no cue RT) are reported in Table 3.3.

3.2. Sleep deprivation study

3.2.1. Reaction time

The analysis of RT data (Table 3.1) from the two sessions in the SD study (with and without SD) showed that all main effects were statistically significant: Session (F(1,25)=27.14; p<.001; η^2=.52),warning signal (F(1,25)=5.96; p<.05; η^2=.41), visual cue (F(2,50)=52.02; p<.001; η^2=.68), and congruency (F(1,25)=175.83; p<.001; η^2=.88). Average RTs were faster after a normal sleep night (615 ms) than under SD (677 ms), when a warning tone had been sounded (640 ms) compared to when it was absent (652 ms), and when all the stimuli were congruent (619 ms) versus when they were incongruent (673 ms). Planned comparisons of the visual cue factor revealed that average reaction time was faster in valid trials (623 ms), than in invalid (660 ms) or no cue trials (655 ms).

	Hits	False alarms	Sensitivity (d')	Response bias (β)
ANTI RT	.53**	–.03	.44*	–.13
ANTI% errors	–.29	–.09	–.19	.14
NTNC RT	.48*	.03	.36¹	–.16
NTNC % errors	–.31	–.10	–.20	.22

Note: ANTI RT = Average RT across all ANTI conditions (i.e. excluding vigilance trials); ANTI % errors = Average percentage of errors across all ANTI conditions; NTNC RT = Average RT of no tone and no cue ANTI conditions; NTNC % errors = Average percentage of errors of no tone and no cue ANTI conditions.

¹ p<.10; * p<.05; ** p<.01; *** p<.001

Table 3.3: Correlations between the direct vigilance measures and other vigilance indices proposed for the ANTI.

The following interactions were statistically significant: Warning signal X Visual cue (F(2,50)=11.77; p<.001; η^2=.32) and Warning signal X Congruency (F(1,25)=6.50; p<.05; η^2=.21). First, following Callejas, Lupiáñez, Funes & Tudela (2005), the Warning signal X Visual cue interaction was further analysed after removing no cue conditions, where no visual orienting could be measured. The interaction was significant (F(1,25)=7.94, p<.01, η^2=.24), suggesting that the cueing effect was greater for the tone (45 ms) than for the no–tone (30 ms) conditions. Second, the Warning signal X Congruency interaction was analysed by focusing only on the no–cue condition, to discard any influence of the cueing effect, and this was also significant (F(1,25)=4.99, p<.05, η^2=.17). Further analyses revealed that the congruency effect was higher when a warning tone had been presented (58 ms) than when the tone was absent (41 ms). As this interaction was unexpected (it is usually non–significant with the ANTI–V task), separate analyses were carried out for the without SD session (F(125)=1.40, p=.25, η^2=.05) and the SD session (F(1,25)=3.36, p=.08, η^2=.12), suggesting that the interaction effect may be unreliable (it was not significant in the separate analyses) and, possibly was only present in the SD session (where an unconfirmed tendency was observed). Regarding the Visual cue X Congruency interaction, this was close to reaching statistical significance (F(2,50)=2.60; p=.08; η^2=.09). In relation to the SD effects, the interaction between Session and Warning signal was statistically significant (F(1,25)=6.13, p<.05, η^2=.20). Further analyses revealed that the phasic alertness effect was smaller in the SD session (17 ms) than in the without SD session (35 ms). No other interaction was found to be statistically significant (neither approached, all p>.10).

Finally, an additional cost and benefit analysis was performed on the visual cue variable, showing that the costs were lower under SD (~0 ms) than without the influence of SD (11 ms) (F(1,25)=6.02; p=.02; η^2=.19), whereas the benefits were not statistically significant after sleep loss (34 ms vs. 30 ms, respectively) (F(1,25)=.60; p=.45; η^2=.02).

3.2.2. Accuracy

The average percentage of errors was analysed and all main effects were also statistically significant: Session (F(1,25)=37.40; p<.001; η^2=.60), warning signal (F(1,25)=40.82; p<.001; η^2=.62), visual cue (F(2,50)=4.33; p<.05; η^2=.15), and congruency (F(1,25)=13.46; p=.001; η^2=.35). On average the participants made more errors when they were under SD (13.7%) than after a normal sleep night (1.9%), when the warning tone was absent (9.6%) than when it had been presented (6.0%), and when distracters were incongruent (9.1%) versus when they were congruent (6.5%). Planned comparison of the visual cue factor showed that the percentage of errors was smaller in the valid trials (7.1%) than in invalid trials (8.6%). No cue trials (7.8%) were not found to differ significantly from valid or invalid trials.

The interaction between Visual Cue and Congruency factors was statistically significant ($F(2,50)=7.42$; $p<.01$; $\eta^2=.23$). As shown by partial interactions, the congruency effect was higher in the invalid condition (4.5%) than in the no cue condition (2.1%) ($F(1,25)=7.78$; $p<.01$; $\eta^2=.24$), whereas the latter was similar to the valid condition (1.0%) ($F(1,25)=1.56$; $p=.22$; $\eta^2=.06$). In addition, the interaction between Session and Warning signal factors was statistically significant ($F(1,25)=12.07$; $p<.01$; $\eta^2=.33$). Further analyses revealed that the phasic alertness effect was higher in the SD session (5.2%) than in the without SD session (0.72%). No other interaction was found to be significant.

Finally, the cost and benefit analyses on the visual cue variable did not reveal any statistically significant difference in the percentage of errors. The costs were similar with and without SD (<1%) ($F(1,25)<.01$; $p=.96$; $\eta^2<.01$), and the benefits were slightly higher after sleep loss (2% vs. ~0%), although this difference was not statistically significant ($F(1,25)=2.82$; $p=.11$; $\eta^2=.10$).

3.2.3. Attentional scores

Table 3.2 summarises the attentional scores with and without SD. Results and significance tests are identical to the Session interaction effects presented above, and are therefore omitted here. In relation to the vigilance performance indices, the percentage of hits was lower under SD (45%) than after a normal sleep night (57%) ($F(1,25)=23.71$; $p<.001$; $\eta^2=.49$), and the sensitivity–d' was also lower with SD (1.9) than without SD (2.3) ($F(1.25)=24.11$; $p<.001$; $\eta^2=.49$). The differences in the percentage of false alarms ($F(1,25)=2.78$; $p=.11$; $\eta^2=.10$) and the response bias ($F(1,25)=1.74$; $p=.20$; $\eta^2=.07$) were not statistically significant in this study.

Additionally, the global differences in Vigilance RT ($F(1,25)=23.48$; $p<.001$; $\eta^2=.48$) and Vigilance St. Dev. of RT ($F(1,25)=7.42$; $p<.05$; $\eta^2=.23$) were statistically significant. Under SD, participants were slower (864 ms vs. 775 ms) and their variability was higher (195 vs. 157 ms) compared to the without SD session. Also, the differences in global St. Dev. (of RT) for the ANTI subtask was also found to be statistically significant (F(1,25)=32.09; p<.001; η^2=.56), suggesting that the variability was higher after SD (217 ms) than without SD (148 ms). Results and significance tests for global ANTI RT and for global ANTI % errors are identical to the Session main effects presented above, and are therefore also omitted here.

3.2.4. Complementary measures

Subjective sleepiness (VAS) and corporal temperature measures are shown in Figure 3.1. VAS hourly scores were submitted to a repeated-measures ANOVA and significant overall differences were found (F(27,675)= 25.14; p<.001; η^2=.50). A planned trend analysis revealed a strong lineal component (F(1,25)=149.94; p<.001; η^2=.86), suggesting a clear increase in subjective sleepiness over time. The average VAS score in the morning (9 to 12) after SD was significantly higher than the morning after a normal sleep night (F(1,25)=55.37; p<.001; η^2=.69).

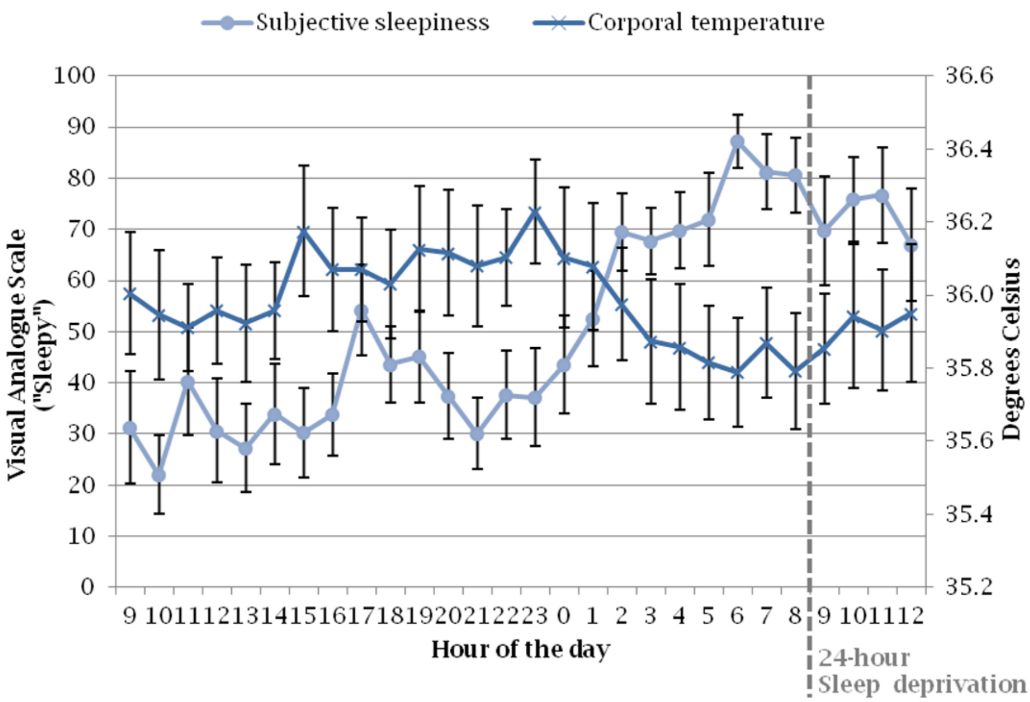

Figure 3.1: Subjective sleepiness (Visual Analogue Scale for "Sleepy") and corporal temperature (degrees Celsius) average measures in the sleep deprivation study. A total of 28 measures were taken hourly from the participants, from 9.00 a.m. after a normal sleep night (second day) until the end of the sleep deprivation study. The vertical dotted line indicates 24–hour sleep deprivation.

Regarding the participants' corporal temperature, an expected circadian rhythmicity was found with minimum values around 6 a.m. The repeated–measures ANOVA revealed significant differences in the hourly measures (F(27,675)=3.51; p<.001; η^2=.12), and a planned trend analysis showed both a lineal (F(1,25)=10.09; p<.01; η^2=.29) and a quadratic component (F(1,25)=7.20; p<.05; η^2=.22). However, the average morning temperature (9 to 12) after SD was not significantly different from the morning temperature after a normal sleep night (F(1,25)=.62; p=.44; η^2=.02).

4. Discussion

In the current work, a 24–hour sleep deprivation study was carried out, in which the participants' performance on the Attentional Networks Test for Interactions and Vigilance (ANTI–V) was compared. Although previous research has analysed the effects of sleep loss on different attentional tasks, including the original Fan and collaborators' ANT, this is the first time to our knowledge that the ANTI–V, which involves rather different components of attentional functioning, has been used in a SD study. The results obtained with the ANTI–V revealed that, under SD, both the tonic and the phasic alertness indices were affected, and that the reorienting costs of having an invalid spatial cue were reduced. In addition, the present study provides further evidence of the usefulness of the ANTI–V as an attentional task providing a measurement of vigilance along with the indices for phasic alertness, attentional orientation and executive control functioning.

Firstly, the comparison of the vigilance indices between the two sleep conditions (with and without SD) provides strong evidence of the validity of the ANTI–V as a vigilance or tonic alertness measure. Sleep loss is considered an effective way to reduce the vigilance level (see, for example, Killgore, 2010; Lim & Dinges, 2008). As expected, the percentage of hits and the sensitivity (d') obtained from the ANTI–V were significantly lower under SD. The percentage of false alarms was slightly higher after a night of sleep loss, although this difference failed to be statistically significant in this study. Consistently with previous evidence, the response bias was similar in both sleep conditions. According to Horne et al. (1983), the β index in a SD study can be considered as a "willingness" to respond positively to the vigilance task, and is interpreted as a motivational factor. Thus, we may claim that the motivation to perform the vigilance task was similar in both sleep conditions. Moreover, these results were accompanied by a slower RT and an increased percentage of errors, which suggests that the change in the vigilance indices was not better explained by a different “attitude towards the task” (i.e., a worse performance in the vigilance task may be expected if the participants do the main task more quickly, for example, if they feel more confident after a repeated presentation of the ANTI–V task). As previously highlighted by Roca, Castro et al. (2011), the global measures of RT and accuracy could not be used in isolation to assess the vigilance level, as they are usually influenced by too many factors (for example, they can reflect different strategies for approaching the task), but they can provide convergent evidence to support the direct measure of vigilance obtained from the ANTI–V. Additionally, various results from this study, such as slower overall RT, higher overall percentage of errors, increased RT variability, and higher subjective vigilance (VAS), confirm that the SD procedure was successful in reducing the vigilance level. Also, corporal temperature measures followed the expected circadian rhythmicity.

Secondly, the results obtained in the initial experimental session show that the ANTI–V has been applied successfully in the current study, and the principal results found by Roca, Castro et al. (2011) have been replicated. Main effects of warning signal, visual cue and congruency factors, as well as main expected interactions were obtained. Additionally, the SDT–based vigilance measures (hits, false alarms, sensitivity, and response bias) were obtained and the expected pattern of moderate correlations with other proposed indexes for the ANT or the ANTI tasks (such as global RT and “no tone and no cue” RT) was observed. Therefore, as found in Roca, Castro et al. (2011), the ANTI–V has been successful in obtaining a direct measure of tonic alertness or vigilance, as well as the usual phasic alertness, attentional orientation, and executive control indices.

A significant effect on the phasic alertness indices was found after SD, suggesting that the two components (phasic and tonic) of the alerting network may influence each other. In both sleep conditions, a warning signal induced a faster reaction time and fewer errors. However, under SD, the phasic alertness effect was smaller in RT (17 ms vs. 35 ms), whereas the effect in percentage of errors was higher (5.2% vs. 0.72%). Previous research with the ANT (Martella et al., 2011; Trujillo et al., 2009) failed to find a SD effect on the phasic alertness indices. However, the ANTI–V uses an auditory signal instead of a visual warning and it has been suggested that auditory alerting cues produce more automatic alerting than do visual cues and thus they might serve to aid the reliability of the alerting manipulation (Fan et al., 2002). Actually, the phasic alertness score was found to be more reliable in the ANTI (with auditory alerting cues) than in the ANT (with visual alerting cues) (Ishigami & Klein, 2010; Lawrence, Eskes, & Klein, 2009). Therefore, the results with auditory alerting cues in the current study indicate that, under reduced vigilance, a warning tone might be helpful to increase participants' alertness, which results in a slightly faster RT and, particularly, in fewer errors. It has been claimed (Posner, 2008) that larger alerting effects generally arise when one group of participants has difficulty in maintaining alertness. Consequently, a greater advantage in performance with a warning tone signal has usually been associated with groups of participants with reduced vigilance (see, for example, Miró et al., 2011). The results with the ANTI–V task may be consistent with this idea, although only with accuracy data. Additionally, it should be noted that a warning signal generally tends to produce a faster reaction time and a higher error rate (Posner & Petersen, 1990), and this pattern has been also found with the ANT and the ANTI tasks (see, for example, Ishigami & Klein, 2009). According to Posner and Petersen (1990), in states of high alertness, the selection of a response occurs more quickly, based upon a lower quality of information, thus resulting in an increase in errors. In contrast, with the ANTI–V task, the warning tone usually produces a faster RT and a lower error rate (see, also, Roca, Castro et al., 2011). It is possible that, as the ANTI–V is a more demanding task than the ANT or the ANTI and overall RT is usually slower, the participants have more time to correctly classify the target stimuli (even when a warning tone has been presented). Thus, an increase in alertness may be able to improve performance, both in RT and accuracy. Also, as shown in the current study, under SD (i.e., a state of low alertness where participants are, again, slower) this particular effect of the warning tone was increased in accuracy.

Regarding the attentional orienting function, the present study failed to find a significant effect of SD on the orienting score (invalid minus valid conditions) using a non–predictive peripheral cue. However, a more detailed analysis of the costs and benefits of attentional cueing revealed that the reorienting costs of having an invalid spatial cue (invalid minus no cue conditions) were reduced RT under SD, whereas the benefits of presenting a valid spatial cue (valid minus no cue conditions) tended to be slightly higher (although this difference was not statistically significant). It is interesting to note that a different influence of SD on cost and benefits may result in a clear alteration in the functioning of the attentional orienting network, without observing an effect on the *complete* orienting index (as may happen, for example, if the costs are reduced and the benefits increased after sleep loss). Some relevant dissociations in the orienting costs and benefits have been found previously. For example, Lasaponara, Chica, Lecce, Lupiáñez and Doricchi (2011) manipulated the predictiveness of the orienting cue in a covert attention paradigm and found that by making central cues non–predictive, the costs of reorienting from invalidly cued locations can be selectively reduced while maintaining the benefits provided by valid cuing. Also, these authors pointed out that the costs and benefits are mediated by functionally independent brain mechanisms, as the benefit–related brain activity was reflected by the N1 component and the cost–related activity by the P1 component. With respect to the SD effects on attentional orienting, Trujillo et al. (2009) used two different cueing tasks (a central and a peripheral predictive task) and found that the N1 component was differently affected by sleep loss and cue manipulation: as compared to regular sleep, the N1 amplitude of validly and neutrally cued targets was similarly reduced under SD with central cueing (thus, similar benefits were observed after normal sleep and after SD). However, with peripheral cues, the N1 response to the validly cued targets was preserved after SD, whereas the amplitude with neutrally cued targets was reduced, leading to greater benefits under SD. No difference in the P1 component was found in this study, although it should be noted that no invalid cues were used and therefore it was not possible to analyse the reorienting costs. Also, Martella et al. (2011) used a peripheral predictive cueing task and found higher benefits in RT under SD, suggesting that peripheral spatial cues were more helpful after sleep loss. Again, no invalid cues were used in this study, and thus the influence of SD on reorienting costs was not analysed. However, Versace et al. (2006) used a peripheral predictive task with valid, invalid, and neutral cues in a partial SD study. These authors found that RT was higher after SD with invalid cues, which was somehow expected as lack of sleep usually increases RT. More interesting was the null effect of SD observed with valid cues (no increase in RT was observed after SD in this case), which is consistent with the idea of valid peripheral cues being more useful after sleep loss. Finally, Casagrande et al. (2006) failed to find differences after SD with a central predictive task with valid, invalid, and neutral cues. RT was similarly increased by sleep loss in each cue condition, and thus the endogenous components of attentional orienting may be similarly affected by sleep loss. Overall, it is proposed that the alerting and the orienting networks can influence each other, in the sense that a reduced tonic alertness after SD may be more detrimental to the endogenous (voluntary) components of attentional orienting while the exogenous (automatic) components will be more resistant. As a consequence, different results will be expected in SD studies using central vs. peripheric cueing tasks and also by analysing the reorienting costs and the orienting benefits separately. Central cueing tasks involve mainly endogenous attention, and thus the different orienting components may be similarly affected by SD, and an overall increase in RT will be found. Also, the reorienting costs are endogenously influenced (as shown by Lasaponara et al., 2011), and thus will be reduced after SD. On the other hand, peripherial cueing is more automatic, and thus peripheral valid cues will be more helpful after sleep loss, compensating for the general increase in RT. Further research, using both behavioural and neurphysiological data, will be necessary to clarify the influence of SD on the different components of attentional orienting.

Moreover, previous evidence has also found an interaction between the alerting and orienting networks, using a phasic alertness manipulation. For example, Callejas et al. (2004) and Fuentes & Campoy (2008) found that a warning tone enhanced the orienting score. The same result has also been found in the SD study, where the cueing effect was greater for the tone than the no tone conditions. As a consequence, it is suggested that increasing the alertness level (for example, by presenting a warning cue) interacts with the functioning of the orienting network, making the orienting effect greater.

With respect to the executive control score, no SD effect was found in the present study. The literature on the influence of SD on this network has shown inconsistent results (see, for example, Killgore, 2010). In the current study, the results may suggest that SD has no influence on the congruency effect, as measured by the ANTI–V. This is inconsistent with previous studies using the ANT (Martella et al., 2011), where a higher congruency effect (more interference) was found after sleep loss. However, it should be noted that the ANTI–V task requires a further vigilance component compared to the ANT task, and the need for cognitive control is increased to adequately distinguish the different types of stimuli (Roca, Castro et al., 2011). Therefore, the increased cognitive control mechanism may have partially compensated the effect of SD on the executive control score, and no larger interference was observed. Also, these inconsistent results could be ascribed to the high inter-subject variability of the effects of sleep loss (Banks & Dinges, 2007; Bell-Mcginty et al., 2004; Van Dongen et al., 2004).

Finally, the warning signal and congruency interaction was statistically significant in the SD study, as opposed to previous results with the ANTI-V task. The congruency effect was higher when a warning tone had been presented than when the tone was absent. This warning signal X congruency interaction is consistent with the data obtained with the ANTI (Callejas et al., 2004), but it was unexpected using the ANTI-V, as both the results by Roca, Castro et al. (2011) and the data in the initial experimental session of the current study suggested an absence of interaction. However, separate analyses for the without SD and the SD session failed to confirm this interaction, suggesting that the interaction effect may be unreliable and, possibly, was only present in the SD session (where an unconfirmed tendency was observed). It should be noted that the without SD and SD sessions were the second and third time that the participants completed the ANTI-V task (the first time was the initial experimental session performed on the afternoon previous to the SD day, aimed at reducing the impact of possible learning effects that may appear after a repeated presentation of the ANTI task; see Ishigami & Klein, 2010). Therefore, future research would be useful to explore the potential effect of a repeated presentation of the ANTI-V on the warning signal X congruency interaction. Also, it is possible that the SD manipulation affected the way in which the phasic alertness modulates the executive control network in the ANTI-V. Generally, the ANTI-V is considered to be a more demanding task (compared to the ANT of the ANTI) and, as argued above, the need for cognitive control is increased to adequately distinguish the infrequent displaced target from the frequent centred target (Roca, Castro et al., 2011). Thus, the warning signal and congruency interaction is absent because the congruency effect is quite low, even in the presence of a warning signal. However, under SD, it is more difficult to maintain cognitive control and thus the interaction between a warning signal and the congruency effect can again be observed. Nevertheless, this suggestion should be considered carefully, as we failed to find a significant SD effect on the congruency index in the present study.

4.1. Conclusions

The present study provides new evidence to evaluate the influence of sleep deprivation on attentional functioning. First, both tonic and phasic alertness were affected by sleep loss. A poorer performance in vigilance tasks is usually found under SD (Killgore, 2010), and thus these results show that the ANTI–V is useful to obtain an appropriate vigilance measure. Interestingly, previous evidence failed to find a SD effect on a phasic alertness measure, using the ANT with visual warning signals (Martella et al., 2011; Trujillo et al., 2009). Since it has been shown that the use of auditory warning signals, as in the ANTI–V, is associated with an increased reliability of the measurement (Fan et al, 2002; Ishigami & Klein, 2010; Lawrence et al., 2009), we propose that under SD, a warning tone might be helpful to increase participants' alertness, which results in a slightly faster RT and, especially, in fewer errors. Secondly, the attentional orienting function was also affected by sleep loss, showing that the reorienting costs of having an invalid spatial cue were reduced. Based on these results and the evidence from previous studies (see Discussion in section 4), it is suggested that SD may be more detrimental to the endogenous (voluntary) components of attentional orienting while the exogenous (automatic) components will be more resistant. Finally, in relation to the executive control network, no SD effect was found in the present study. It has been claimed that the need for cognitive control is increased in the ANTI–V to adequately distinguish the different types of stimuli (Roca, Castro et al., 2011), and this may have partially compensated for the effect of SD on the interference measure. Also, the inconsistent results that were found with regard to executive control functioning (Killgore, 2010; Martella et al., 2011) could be ascribed to the high inter–subject variability of the effects of sleep loss (Banks & Dinges, 2007; Bell–McGinty et al., 2004; Van Dongen et al., 2004).

CAPÍTULO 4 CHAPTER

STUDY 3:

Are drivers' attentional lapses (DBQ) associated with the functioning of the attentional networks (ANTI-V) and cognitive failure (CFQ)?

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ABSTRACT

Driver distraction and inattention is considered to be a major contributing factor in road traffic accidents. One of the most widely used tools to study drivers' attentional lapses and other types of aberrant behaviour is the Driving Behaviour Questionnaire (DBQ). In the present work, further evidence of the feasibility of the DBQ to study driver distraction and inattention is provided. The relationships between the DBQ and both a computer–based neurocognitive test on attentional performance (the Attention Networks Test for Interactions and Vigilance, ANTI–V) and a self–reported measure of cognitive failure (the Cognitive Failures Questionnaire, CFQ) are analysed. Results show that attentional lapses are negatively associated with vigilance and positively associated with cognitive failure. In this study, other types of aberrant behaviour in driving (driving errors, traffic violations and aggressive behaviours) were not found to be related to any attentional performance index (executive control, attentional orienting, phasic or tonic alertness), whereas their relationship with cognitive failure was significant but more moderate (except for DBQ–Errors, which was also highly correlated). Overall, these results are consistent with the idea of DBQ–Lapses being related to driving distraction and inattention, and suggest that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour. Further evidence with improved versions of the DBQ or alternative questionnaires would be helpful to clarify whether proneness to attentional lapses while driving may be associated with crashes. Additionally, a higher tendency to make cognitive errors in everyday life has been associated with a higher attentional orienting effect (more reorienting costs) and a worse vigilance performance (lower hits), which is consistent with the suggestion that high–CFQ participants fail to ignore automated actions.

Keywords: Driver Behaviour Questionnaire; Attentional Lapses; Attention Networks Test; Vigilance; Tonic alertness; Cognitive Failures Questionnaire

1. Introduction

Driver distraction and inattention is considered to be one of the major contributing factors in road traffic accidents (e.g. Kircher, 2007; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Ranney, 2008) and its negative influence on road safety is expected to further increase in the coming years, due to the proliferation of in–vehicle technologies (Regan, Hallett, & Gordon, 2011; Stutts, Reinfurt, Staplin, & Rodgman, 2001). To reduce attention–related accidents, road traffic researchers and practitioners would benefit from the synergy of complementary methodologies to analyse the driver distraction and inattention phenomenon and to evaluate potential countermeasures, such as experimental studies using driving simulators (e.g., Lee, McGehee, Brown, & Reyes, 2002; Weaver, Bédard, McAuliffe, & Parkkari, 2009), self–informed questionnaires (e.g., Reason, Manstead, Stradling, Baxter, & Campbell, 1990; Ledesma, Montes, Poó, & López–Ramón, 2010) and field studies with naturalistic data (e.g., Klauer et al., 2006; Olson, Hanowski, Hickman, & Bocanegra, 2009). One of the most widely used tools to study self–reported aberrant behaviour in drivers is the Driving Behaviour Questionnaire (DBQ; Reason et al., 1990), which usually includes an attentional lapses subscale. The current study will provide further evidence in order to discuss the feasibility of this questionnaire for studying driver distraction and inattention, by analysing its relationships with both a computer–based neurocognitive test on attentional performance and self–reported measures of cognitive failure.

According to a recent meta–analytic review (Winter & Dodou, 2010), the DBQ has been used in at least 174 studies to date, including cross–cultural comparisons and group difference analyses (professional drivers, motorbike riders, traffic offenders, older drivers, etc). Originally, the DBQ aimed to distinguish between driving errors and deliberate violations of the traffic rules, supporting the idea that different psychological processes influence these factors. Reason et al. (1990) performed a factor analysis and found support for the difference between errors and violations, plus a third factor that included mainly attentional failures (“silly errors”, “slips and lapses” or “lapses”). However, the relevance of this latter factor was questioned in later studies and the corresponding items have not always been included in the questionnaire, probably for at least two principal reasons: (1) the lapses factor was initially considered as trivial and failed to be consistently associated with reported accidents, and (2) the three–factor model has not been found consistently in different analyses on DBQ factorial structure.

Initially, Reason et al. (1990) characterised the DBQ–Lapses factor as "relatively trivial slips and lapses, more likely to bring embarrassment [...] than cause danger to others" (p. 1330), because the driving behaviours included were considered of minimal risk by independent judges. Consistently, Parker, Reason, Manstead and Stradling (1995), using regression analysis, found that it was mainly the DBQ–Violations factor that was predictive of participants' overall number of reported accidents, whereas DBQ–Errors was only predictive of active accidents and DBQ–Lapses was not predictive of any type of accident. Later, the role played by the DBQ subscales in predicting reported accidents became quite controversial in the literature (for a review, see Winter & Dodou, 2010). Despite the conflicting literature, a meta–analysis has recently confirmed the predictive value of DBQ–Violations and DBQ–Errors in reported accidents (overall correlation was of .13 and .10, respectively; Winter & Dodou, 2010), but in this study DBQ–Lapses was not differentiated from the latter factor, and thus the specific relevance of DBQ–Lapses is still under discussion. For example, among older drivers, a relatively high DBQ–Lapses score has been reported to predict involvement in both active and passive accidents (Parker, McDonald, Rabbitt, & Sutcliffe, 2000). Conversely, other authors have failed to find a significant correlation using a sample composed of younger and older drivers (e.g., Parker et al., 1995), and a negative non–significant tendency in the correlation (–.16) has even been reported in young drivers (Stephens & Groeger, 2009). Recently, Ledesma et al. (2010) applied an alternative questionnaire to measure failures of attention in driving (the Attention–Related Driving Errors Scale or ARDES) and found that it was predictive of self–informed traffic collisions with only material damage (adjusted odds ratio = 7.14), using participants in a wide age range.

Secondly, regarding the DBQ factor structure, initial studies (Reason et al., 1990; Parker et al., 1995) found a three–factor model (errors, violations and lapses). Some modifications aimed at measuring aggressive behaviours were then proposed (Lawton, Parker, Manstead, & Stradling, 1997), and using this expanded version, the violations factor was usually divided into ordinary and aggressive violations. According to Özkan, Lajunen and Summala's review (2006), although different solutions have been reported (two to six factors), the original three– or four–factor structure (errors, ordinary violations, aggressive violations and lapses) has been broadly replicated. However, these authors found that the four–factor solution was not stable for a period longer than three years, whereas the two–factor structure (errors including lapses, and violations including both types) was the most interpretable one (Ozkan et al., 2006). Additionally, Lajunen, Parker and Summala (2004) studied the cross–cultural viability of the DBQ and found satisfactory agreement between the British, Finnish and Dutch versions. In their study, the usual four–factor structure (errors, lapses, ordinary violations and aggressive violations) was found after first–order rotation in an exploratory factor analysis but, interestingly, second–order rotation was also computed and a two–factor model arose (errors and violations). This result suggests that the four factors reflect the original distinction between deliberate violations and unintentional errors (Lajunen et al., 2004), and implies that considering a hierarchical taxonomy of aberrant driving behaviour might clarify the discussion.

Overall, it can be claimed that there is enough evidence for using either a two–factor solution (errors and violations) or a four–factor one (errors, lapses, ordinary violations and aggressive violations). With respect to this, it has been suggested that, for every–day use, the four subscales might be more informative for road safety practitioners (Lajunen et al., 2004), and this is also true for researchers particularly interested in studying, for example, attentional lapses or aggressive behaviour. Additional evidence supporting the validity of each subscale (for example, by analysing their relationship with other theoretically–related measures) would therefore be helpful to expand the results previously found with factor analysis. The DBQ–Errors and DBQ–Violations factors have been previously associated with many other questionnaires and scales (see, for example, Winter & Dodou, 2010). In our investigation we aimed to investigate the part played by attention in the DBQ–Lapses factor. Thus, the current study will analyse the relationship between the DBQ subscales (errors, lapses, ordinary violations and aggressive violations), the functioning of the attentional networks (as measured with a computer–based attentional performance test, the Attentional Networks Test for Interactions and Vigilance) and cognitive failures (as measured with the self–informed questionnaire on cognitive failures, the Cognitive Failures Questionnaire).

1.1. Attentional networks performance

The neurocognitive study of human attention has recently produced a quick and easy computer–based task, carefully designed to measure the participants' performance in three basic components of attention (executive control, attentional orienting and alerting). This test, known as the Attention Networks Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), is based on a widely accepted neurocognitive model of human attention that distinguishes three relatively independent neural networks controlling the different attentional functions (Callejas, Lupiáñez, & Tudela, 2004, Fan et al., 2002; Posner, 1994; Posner, 2008; Posner & Petersen, 1990). The first network (executive control) involves the mechanisms for ignoring distracters and resolving cognitive conflict. It activates anterior areas of the frontal cortex, such as the anterior cingulate and the dorso–lateral prefrontal cortex, and is usually assessed by using Stroop, Simon or flanker tasks. The second network (attentional orienting) is aimed at selecting information from the sensory input by allocating the attentional focus to a potentially relevant area or object in the visual field. It includes different areas of the parietal and frontal lobes, and is usually assessed by presenting valid, invalid and neutral spatial cues in a reaction time task. The third network (alerting) is necessary to achieve and maintain a state of high sensitivity to incoming stimuli. It involves some fronto–parietal regions of the brain, mainly in the right hemisphere, and also some brain stem areas (such as the locus coeruleus). It is related to performance in tasks that involve phasic alertness (i.e, the increased readiness to respond after a warning signal) and tonic alertness or vigilance (i.e., the ability to maintain attention over a prolonged period of time).

Convergent evidence from different disciplines, such as Neuroscience, Neuropsychology and Experimental Psychology, provides support for the soundness of the ANT (e.g., Fan et al., 2002; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Ishigami & Klein, 2010; Posner, 2008), and so this attentional test and its variations are currently being used in a wide range of basic and applied studies, including driver behaviour and road traffic safety research (e.g., López–Ramón, Castro, Roca, Ledesma, & Lupiáñez, 2011; Weaver et al., 2009). The test has been adapted to different research contexts and some alternative versions are available (for example, the ANTI to analyse network interactions, Callejas et al., 2004; and the child–ANT to measure attention in children, Rueda et al., 2004). Among these versions, the

Attentional Networks Test for Interactions and Vigilance (ANTI–V; Roca, Castro, López–Ramón, & Lupiáñez, 2011) is a recent version that includes a measure of tonic alertness or vigilance, in addition to the usual executive control, attentional orienting and phasic alertness indices (see section 2.2.1 for a description). The vigilance measure is obtained from the performance to detect infrequent, uncertain and unpredictable stimuli, and has recently been validated in a sleep deprivation study (Roca, Fuentes et al., 2011). The ANTI–V could be especially useful in driver behaviour studies, since low vigilance is considered one of the major causes of road accidents (Åkerstedt, Philip, Capelli, & Kecklund, 2011; Lal & Craig, 2001). Also, by using this task, the individual influence of each attentional component on driving behaviour can be explored.

To our knowledge, no previous study has yet associated DBQ scores and the ANT or a similar test. López–Ramón et al. (2011) used the ANTI (Callejas et al., 2004) to evaluate attentional networks functioning and the ARDES (Ledesma et al., 2010) to measure failures of attention in driving, in a study with 55 drivers in Argentina. The ARDES is a 19–item self–informed questionnaire specifically aimed at evaluating individual differences in proneness to attentional errors while driving, and thus this scale is measuring a construct similar to the DBQ–Lapses factor. The authors found that participants more prone to attentional lapses while driving (i.e., with the higher ARDES scores), as well as older drivers, obtained slower reaction times and a higher phasic alertness score. Taken together, these results were interpreted as evidence to suggest a general slowdown in performance and less endogenous preparation for high–priority warning signs, probably due to their reduced internal vigilance. As a consequence, López–Ramón and her collaborators proposed that future research should include specific measures of tonic alert or vigilance, which can be accomplished by the use of the ANTI–V, as in the current study.

1.2. Cognitive failures

A cognitive failure can be defined as a mistake in the performance of an action that the person is normally capable of completing (e.g., Wallace, Kass, & Stanny, 2002). A higher frequency of cognitive failures has been associated with self–reported deficits in memory, absent–mindedness and slips of action (Broadbent, Cooper, Fitzgerald, & Parkes, 1982). Also, cognitive failure measures have been positively related to automobile accidents (Larson &

Meritt, 1991; Wallace & Vodanovich, 2003), and negatively to vigilance performance (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). To evaluate this psychological construct, Broadbent et al. (1982) proposed the Cognitive Failure Questionnaire (CFQ), which is a 25–item questionnaire aimed at measuring self–reported mistakes in everyday life, including mistakes in perception, memory and motor function. The initial validation of the scale showed a general factor of cognitive failure or CFQ–Total score (Broadbent et al., 1982). Later research identified four factors (memory, distractibility, blunders and names) (Wallace et al., 2002). However, these subscales are so closely associated that both the one–factor and the four–factor scores are frequently used (Wallace & Vodanovich, 2003).

A close association between the CFQ–Total score and DBQ–Lapses has previously been reported (r = .66), suggesting that a higher tendency to cognitive failure is related to more attentional lapses while driving (Van de Sande, 2008). No further information was provided in this study about the other DBQ or CFQ factors. Also, from a different theoretical perspective (a dual–process framework), Wickens, Toplak and Wiesenthal (2008) found positive correlations among the three DBQ factors and different components of attentional failure (extremely focused attention, inattention, and impulsivity). In this study, both DBQ–Errors and DBQ–Lapses factors were significantly correlated with the Differential Attention Processes Inventory – Extremely Focused Attention (DAPI–EFA), the inattention scale from the Adult Self–Report Scale (ASRS–I) and an impulsivity scale. Also, driving violations were positively correlated with impulsivity, DAPI–EFA, and DAPI–Dual Attention Cognitive–Cognitive (DAPI–DACC). Regarding the relationship between CFQ and the ANT, Ishigami & Klein (2009) found some links between the CFQ and the alerting and attentional orienting networks. Using the original ANT (Fan et al., 2002), a higher CFQ–Total score was associated with a smaller orienting effect on the error rate. On theother hand, using the ANTI (Callejas et al., 2004), a higher CFQ–Total score was associated with a higher orienting effect on the error rate and a larger alerting effect on reaction time. The divergent results were seen as a consequence of the differences between the tasks. The ANT uses peripheral predictive cues, and therefore it might index a mixture of endogenous and exogenous components of attentional orienting, whereas the ANTI uses non–predictive peripheral cues, thus indexing a rather purer measure of exogenous orienting. Regarding alertness, the ANTI uses auditory warning signals (which may be more alerting than the visual cues used in the ANT), which might explain its more reliable measure of alertness (Ishigami & Klein, 2010).

1.3. Objectives

The main objective of the current study is to provide further evidence of the construct validity of the attentional lapses subscale of the DBQ, which is one of the most widely used research tools available to traffic researchers to obtain information about drivers' aberrant behaviour, including attentional lapses. To achieve this objective, first, the DBQ scores will be compared to the measures obtained from the ANTI–V, a recent version of the Attentional Network Test, which adds a measure of vigilance to the usual executive control, orienting and phasic alertness performance scores. If the DBQ–Lapses factor is actually measuring driving inattention, it would be expected that a higher score in this subscale will be associated with a worse attentional performance in the ANTI–V, and following López–Ramón et al. (2011), an association with the alerting network may be expected (Hypothesis 1). In addition, as the other DBQ subscales (errors, ordinary violations and aggressive violations) are not specifically related to attentional behaviour, no clear association would be expected between these subscales and the ANTI–V (Hypothesis 2). These objectives will provide further specific information to characterise the constructs measured by the different DBQ subscales.

Additionally, the DBQ scores will be compared to the measures obtained from the Cognitive Failures Questionnaire (CFQ), a self–informed test to evaluate the tendency to make minor mistakes in everyday life. As previous evidence has suggested (Van de Sande, 2008), a positive correlation between CFQ and DBQ–Lapses would be expected (Hypothesis 3), but the current research will also evaluate whether this association between the CFQ and DBQ is specific to attentional behaviour (lapses) or is also present in other DBQ factors (errors, ordinary violations and aggressive violations). With regard to this, a positive relationship would be expected between the DBQ–Errors subscale and the CFQ total score (Hypothesis 4), as both measure non–deliberate performance errors. Again, this information will be helpful to better understand and distinguish the constructs measured by DBQ–Lapses and the other DBQ subscales.

Finally, the current study will attempt to replicate the previously reported association between some attentional components and the CFQ–Total score. Ishigami & Klein (2009), using the ANTI, found that the CFQ–Total was positively correlated with the orienting effect in error rate and with the alerting effect in reaction time. As the ANTI–V is based on the ANTI, these correlations are also expected in the current study (Hypothesis 5). Whether vigilance is associated with CFQ scores will also be explored. This association has not been analysed using the ANT or the ANTI, since both tests lack a proper measure for vigilance (see Roca, Castro et al., 2011; Roca, Fuentes et al., 2011,). However, a negative association between the CFQ and vigilance has been previously reported using alternative vigilance tests (Manly et al., 1999; Robertson et al., 1997), and this is also expected in the current study (Hypothesis 6).

2. Material and Methods

2.1. Participants

A group of 104 students from the University of Granada (Spain) participated in this study. Mean age was 21 (St. Dev. = 4). Ninety–seven were females. Sixty–five had a valid driving licence. All of them reported normal or corrected–to–normal vision and were unaware of the purpose of the study. The experiment was conducted according to the ethical standards of the 1964 Declaration of Helsinki.

2.2. Procedure and measures

Participants were received in a laboratory at the School of Psychology, and were offered an informed consent form to consider and sign. They then completed the ANTI–V, the CFQ, and, in the case of drivers, the DBQ, in a separate experimental room. The presentation order of the three tasks was counterbalanced across participants. Standardised instructions were provided via the computer monitor or were included in the questionnaires. A member of the research team remained in the laboratory to assist the participants when necessary. A complete experimental session usually required less than 60 minutes.

2.2.1. Attention Networks Test for Interactions and Vigilance (ANTI-V)

The participants' attentional performance was assessed by using the Attention Networks Test for Interactions and Vigilance or ANTI–V (see Roca, Castro et al., 2011, for a detailed description). This computer–based task provides independent measures for executive control, attentional orienting and phasic alertness, obtained by subtracting average reaction time and percentage of errors of specific conditions (see Fan et al., 2002; Callejas et al., 2004; Ishigami & Klein, 2010). Also, a measure for tonic alertness or vigilance is obtained, by analysing the participants' ability to detect infrequent, unpredictable, uncertain targets (Roca, Castro et al., 2011; Roca, Fuentes et al., 2011). The task consists of 8 blocks of 64 trials and the participants have to perform the task continuously for more than 30 minutes. In each trial, a row of five cars pointing either left or right is briefly presented (200 ms). The background scene represents a two–lane road and the line of cars appears on one of two parking lanes, above or below a central fixation point (see Figure 2.1). The participants have to indicate the direction of the central car (target) by pressing "c" for left or "m" for right, and ignore the direction of the flanking cars (distracters). The flanking cars are pointing either in the same direction as the central car (congruent condition) or in the opposite direction (incongruent condition), with equal probability. Incongruent trials require the participants to use cognitive control to ignore the distracters, and thus the difference in performance between incongruent and congruent conditions can be used as an individual measure of the functioning of the executive control attentional network (a higher score means worse cognitive control). A spatial cue (a black asterisk) is briefly presented (50 ms) 100 ms before the line of cars, above or below the central fixation point. The spatial cue is shown, with equal probability, in the same location as the target central car (valid cue condition), in the opposite location (invalid cue condition), or is absent (no cue condition). Valid spatial cues help the participants to focus their attention on the forthcoming target, and thus the difference in performance between valid and no cue conditions is considered a measure of the *benefits* of orienting attention. Conversely, invalid spatial cues focus the participants' attention on a wrong location, and thus the difference between invalid and no cue conditions is used as a measure of the *costs* of reorienting attention. In consequence, the difference between invalid and valid conditions is generally used to assess the participants' orienting network functioning, including both costs and benefits (a higher score means a greater advantage when using valid spatial cues). At 500 ms before the target car appears, either a warning tone is presented for 50 ms (warning condition) or it is absent (no warning condition), with equal probability. As warning signals momentarily increase participants' alertness, the difference in performance between no warning and warning conditions is considered as a measure of phasic alertness (a higher score means a better performance when using a warning signal). Finally, to measure tonic alertness or vigilance, the central target car is displaced considerably, to the right or to the left, in 25% of the trials (appearing closer to one of the flanking cars), in which case participants have to press an alternative response key (spacebar) ignoring the direction of the central car. The participants' ability to detect this infrequent, unpredictable, uncertain target can be used to evaluate their vigilance performance, by analysing the percentage of hits and false alarms and then computing the Signal Detection Theory–based (SDT) sensitivity and response bias indices.

2.2.2. Cognitive Failures Questionnaire (CFQ)

All the participants completed a Spanish version of the Cognitive Failures Questionnaire or CFQ (Botella, 2008; García–Martínez & Sánchez–Cánovas, 1994). This questionnaire provides a measure of self–reported mistakes in everyday life, including different perception, memory and motor function daily tasks. The participants have to read a list of 25 minor everyday mistakes (e.g., "*you forget why you went from one part of the house to the other*") and indicate how often these things have happened to them in the past 6 months. A 5–point verbal scale is presented, ranging from "*never*" (0) to "*very often*" (4)[4]. A higher score means more mistakes in everyday life. Evidence supporting a one–factor total score was found in the Spanish version, although three separate subscales (memory, attention and cognitive failures) are also frequently considered (Botella, 2008; García–Martínez & Sánchez–Cánovas, 1994).

2.2.3. Driver Behaviour Questionnaire (DBQ)

Participants holding a valid driving licence completed a Spanish adaptation of the Driver Behaviour Questionnaire or DBQ (López de Cózar et al., 2004; López de Cózar, Molina, & Sanmartín, 2005). This version of the DBQ consists of 34 items measuring aberrant behaviour in three categories: attentional lapses, driving errors, traffic violations and aggressive behaviours. Individual scores for each of these four categories are obtained by averaging the corresponding items. The participants have to indicate how often they

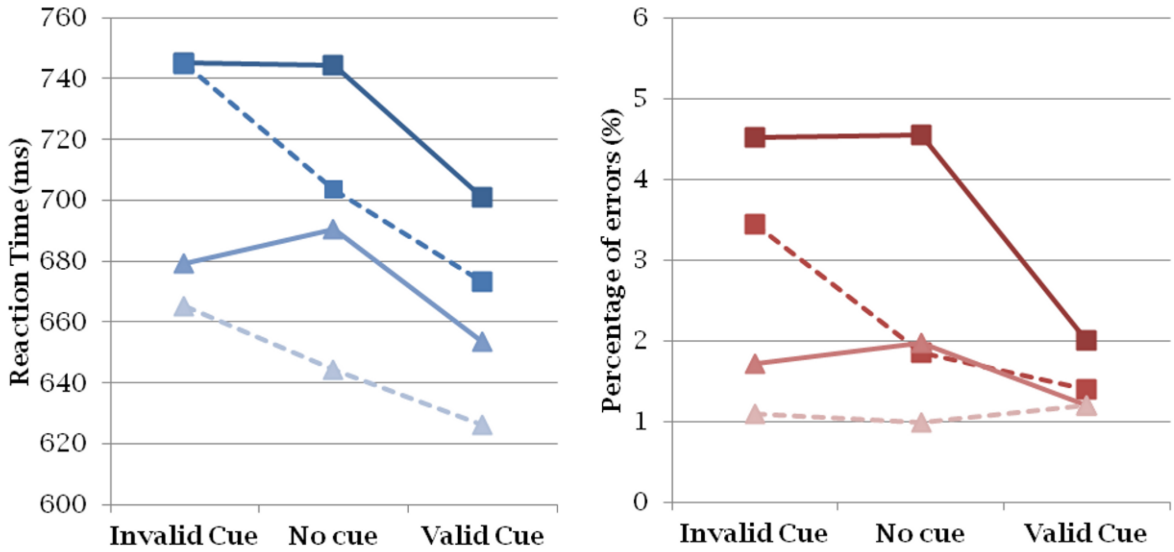
[4] The Spanish version of the CFQ has an inverse scoring scale ranging from "*very often*" (1) to "*never*" (5). However, we have adjusted later the scores according to the same scale as in the original English version, from "*never*" (0) to "*very often*" (4), to make it easier to compare the results with other studies.

behave in the way described by each item (e.g., "*misread the signs and exit from the roundabout on the wrong road*"), using a 10–point scale, and thus a higher score means a higher aberrant behaviour frequency in each category. Additionally, the questionnaire dossier included some final questions aimed at obtaining socio–demographic information, including age, gender, driving experience (years) and driving frequency.

2.3. Design and data analyses

Data from the ANTI–V were inspected for extreme values. Mean correct–trial reaction time (RT) above or below 2.5 standard deviations (St. Dev.) was filtered out (< 3% of trials). Also, five participants were discarded because they failed to successfully complete the task or their overall percentage of errors was unusually high (> 3 St. Dev.). Reaction time (ms) and accuracy data (percentage of errors) were then submitted to a 2 (Flanker congruency: incongruent / congruent) x 3 (Cue validity: invalid cue / no cue / valid cue) x 2 (Warning tone: no one / tone) repeated–measures ANOVA. The significance level was set at .05 and the Bonferroni correction was applied in planned pair comparisons. When sphericity could not be assumed, degrees of freedom were adjusted using the Greenhouse–Geisser method. In addition, different attentional performance indices were obtained for each participant by subtracting average RT and percentage of errors of specific conditions (Fan et al., 2002; Callejas et al., 2004; Ishigami & Klein, 2010): Executive Control score (EC = incongruent – congruent flankers), Attentional Orienting score (AO = invalid – valid cues) and Phasic Alertness score (PhA = no warning – warning tone, using only no cue trials). Also, vigilance was assessed by analysing the percentage of hits (H) and false alarms (FA) when detecting the infrequent target, and then computing the Signal Detection Theory–based (SDT) sensitivity (*d'*) and response bias (β) indices.

DBQ and CFQ scores were obtained for each participant. Pearson's correlation indices were then computed to assess the degree of association between the attentional measures and the questionnaire scores. Seventeen participants were novice drivers, with less than a year of driving experience, and their DBQ data were not considered in the corresponding analyses.



	Flanker congruency	Warning tone	Cue validity: Invalid Cue	Cue validity: No Cue	Cue validity: Valid Cue
Reaction time (St. Dev.)					
	Incongruent	**No Tone**	745 (106)	744 (114)	701 (107)
	Incongruent	**Tone**	745 (106)	704 (107)	673 (110)
	Congruent	**No Tone**	679 (103)	691 (109)	653 (101)
	Congruent	**Tone**	665 (101)	644 (103)	626 (110)
Percentage of errors (St. Dev.)					
	Incongruent	**No Tone**	4.5 (5.2)	4.6 (5.2)	2.0 (3.2)
	Incongruent	**Tone**	3.4 (4.6)	1.8 (3.0)	1.4 (3.0)
	Congruent	**No Tone**	1.7 (3.0)	2.0 (3.5)	1.2 (2.8)
	Congruent	**Tone**	[illegible]	1.0 (2.4)	1.2 (2.6)

Figure 4.1: Results from the attentional test (ANTI–V). Average reaction time (upper left) and percentage of errors (upper right) is shown for the 2 (Flanker congruency: incongruent / congruent) x 3 (Cue validity: invalid cue / no cue / valid cue) x 2 (Warning tone: no tone / tone) repeated–measures ANOVA. The table below includes the figure legend and shows average values (ms and % errors) and their standard deviation between parentheses (St. Dev.).

3. Results

3.1. Attention Networks Test for Interactions and Vigilance (ANTI-V)

The usual main effects and interactions with the ANTI–V were found in the current study (see Figure 4.1). RT results show that the participants were faster: (a) when the flanker cars were congruent (F(1,98)=403.09; p<.001; η^2=.80); (b) when a valid cue had been presented (F(2,196)=169.30; p<.001; η^2=.63; all planned pair comparisons p<.001); (c) when a warning tone had been sounded (F(1,98)=123.71; p<.001; η^2=.56). Besides, the *Warning tone* X *Cue validity* (F(1,98)=23.14; p<.001; η^2=.19) and *Cue validity* X *Flanker congruency* (F(1,98)=38.21; p<.001; η^2=.28) interactions[5] were statistically significant, whereas the *Warning tone* X *Flanker congruency* (F(1,98)=.69; p=.41; η^2<.01) and the three–way (F(2,196)=1.41; p=.25; η^2=.01) interactions were non–significant.

Regarding the accuracy results, the participants made fewer errors: (a) when the flanker cars were congruent (F(1,98)=51.44; p<.001; η^2=.34); (b) when a valid cue had been presented (F(1.79,176.05)=18.36; p<.001; η^2=.16; all planned pair comparisons p<.001, but for *invalid – no cue*, p=.42); (c) when a warning tone had been sounded (F(1,98)=24.95; p<.001; η^2=.20).

In addition, with the accuracy results, the *Warning tone* X *Flanker congruency* (F(1,98)=13.53; p<.001; η^2<.12) and *Cue validity* X *Flanker congruency* (F(1,98)=17.40; p<.001; η^2=.15) interactions[5] were statistically significant, while the *Warning tone* X *Cue validity* (F(1,98)=2.06; p=.154; η^2=.02) and the three–way (F(2,196)=1.31; p=.27; η^2=.01) interactions were non–significant. As the previous results suggested that the ANTI–V had been applied successfully, the different attentional scores (executive control, attentional orienting, phasic alertness and vigilance indices) were computed for each participant and average values are shown in Table 4.1.

[5] Following Callejas et al. (2005), the *Warning tone* X *Cue validity* and *Cue validity* X *Flanker congruency* interactions were calculated after extracting no–cue trials, because this condition is not relevant for measuring the orienting score. Also, the *Warning tone* main effect and the *Warning tone* X *Flanker congruency* interaction were computed focusing only on no–cue trials to ensure that the alerting effect was not confounded by a potential alerting effect from the visual cue. The results were approximate when using all the conditions in the analysis.

	Mean (St. Dev.)
Attentional scores: RT (ms)	
Executive control	59 (29)
Attentional orienting	45 (27)
Phasic alertness	44 (39)
Attentional scores: % errors	
Executive control	1.6 (2.2)
Attentional orienting	1.2 (2.2)
Phasic alertness	1.8 (3.7)
Vigilance measures	
Hits (%)	59 (18)
False Alarms (%)	3.7 (3.9)
Sensitivity (*d'*)	2.2 (0.5)
Response Bias (β)	7.6 (4.6)
Global Measures	
Overall ANTI RT (ms)	689 (101)
Overall ANTI % errors	2.2 (1.9)

Note: N = 99

Table 4.1: The attentional performance measures obtained from the ANTI–V. Mean and standard deviation (St. Dev.) are shown for: (a) the attention network scores (executive control, attentional orienting and phasic alertness) with reaction time (RT, ms), and (b) with accuracy data (percentage of errors); (c) the Signal Detection Theory–based (SDT) vigilance measures (hits, false alarms, sensitivity and response bias); and (d) the overall reaction time (ms) and global accuracy results (percentage of errors).

3.2. Correlation between attentional scores and questionnaire measures

Data from the DBQ and the CFQ were analysed and average values are shown in Table 4.2. Individual scores in the ANTI–V and in the questionnaire measures were correlated and the results are shown in Table 4.3. A negative correlation was found between the DBQ–Lapses subscale and both the percentage of hits (r = –.32; p = .03) and the sensitivity (r = –.41; p = .004) in the vigilance subtask from the ANTI–V. Additionally, the DBQ–Violations subscale was only marginally correlated with the EC score in accuracy data (r = .29; p = .05). No other correlation with the DBQ was significant nor approached significance level (all $p > .10$).

Regarding the CFQ, a positive correlation was found between the CFQ–Total and the Attentional Orienting (AO) score in RT data (r = .23; p = .02). To further explore this result, the correlation between the CFQ–Total and the two subcomponents of the AO index (the reorienting costs, i.e. invalid minus no cue trials, and the orienting benefits, i.e. no cue minus valid trials) were performed separately. Results showed that the CFQ–Total was positively correlated with the reorienting costs (r = .20; p = .04), with a magnitude similar to the full AO score, but was not correlated with the orienting benefits (r = .05; p = .65). Similar results were found with the three CFQ subscales of the CFQ.

It should be noted that the CFQ–Total was significantly correlated with overall RT in the ANTI–V (r = .22; p = .03). Previous evidence has shown the existence of a moderate correlation between overall RT and accuracy measures and the vigilance indices in the ANTI–V, probably reflecting different strategies to perform the task (see Roca, Castro et al., 2011; Roca, Fuentes et al., 2011). In accordance with this, the different strategies for performing the ANTI–V could be masking a potential association between the CFQ–Total and the vigilance

	Mean (St. Dev.)
Driver Behaviour Questionnaire (DBQ)	
Attentional lapses	2.8 (1.5)
Driving errors	1.7 (1.2)
Traffic violations	2.2 (1.6)
Aggressive behaviours	1.4 (1.2)
Cognitive Failures Questionnaire (CFQ)	
Total score	35 (12)
Memory	14 (5)
Attention	9 (4)
Cognitive failures	12 (4)

Note: N_{CFQ} = 104, N_{DBQ} = 48

Table 4.2: The average measures from the Driver Behaviour Questionnaire (DBQ) and the Cognitive Failures Questionnaire (CFQ). Mean and standard deviation (St. Dev.) are shown for: (a) the DBQ four factor scores for Attentional lapses, Driving errors, Traffic violations and Aggressive behaviours subscales; and (b) the CFQ Total score and the three factor scores for Memory, Attention and Cognitive failures subscales.

	Attentional scores (RT)			Attentional scores (% errors)			Vigilance measures (SDT)				Overall measures	
	EC	AO	PhA	EC	AO	PhA	H	FA	*d'*	*ß*	RT	% errors
Driver Behaviour Questionnaire (DBQ)												
Attentional lapses	–.17	.03	.22	.08	–.10	.04	**-.32***	.02	**-.41*****	–.03	.07	.14
Driving errors	–.08	.02	.22	.08	–.13	.02	–.17	.00	–.23	.02	.15	–.02
Traffic violations	–.13	–.10	–.04	**.29[1]**	.03	.13	–.18	.00	–.16	.15	.00	.12
Aggressive behaviours	–.22	–.21	.06	.20	.11	.16	–.05	.17	–.15	–.04	.21	.23
Cognitive Failures Questionnaire (CFQ)												
Total score	.01	**.23***	.03	–.08	–.14	–.09	–.10[a]	–.10[a]	.00	.11[a]	**.22***	.02
Memory	.05	**.21***	–.10	–.01	–.09	–.05	–.11[a]	–.09[a]	–.01	.14[a]	**.19[1]**	.07
Attention	–.03	**.20[1]**	.10	–.14	**-.18[1]**	–.13	.00[a]	–.06[a]	.04	–.02[a]	**.27***	–.07
Cognitive failures	–.01	**.22***	.12	–.10	–.14	–.08	–.14[a]	–.11[a]	–.02	.15[a]	.16	.04

[1] p<.10; * p<.05; ** p<.01; *** p<.001

Note: AO = Attentional Orienting score; ***ß*** = SDT index for response bias in the vigilance subtask; *d'* = SDT index for sensitivity in the vigilance subtask; EC = Executive Control score; FA = Percentage of false alarms in the vigilance subtask; H = Percentage of hits in the vigilance subtask; PhA = Phasic Alertness score; RT = Reaction Time (ms); SDT = Signal Detection Theory; % errors = Percentage of errors. N_{CFQ} = 99, N_{DBQ} = 48

[a] Partial correlations were computed to control for the influence of overall RT and accuracy (which may be reflecting different strategies to perform the task). According to this analysis, the CFQ–Total score is correlated with the percentage of hits (r = –.23; p = .03), false alarms (r = –.21; p = .04), and response bias (r = .21; p = .04). Similar results were found with the other CFQ factors. See text (section 3.3) for further information.

Table 4.3: Correlation between the attentional performance measures from the ANTI–V (the executive control, attentional orienting and phasic alertness scores in reaction time and percentage of errors, plus the vigilance indices) and the measures from the Driver Behaviour Questionnaire (DBQ) and the Cognitive Failures Questionnaire (CFQ).

performance indices. Actually, in the current study, overall RT was also correlated with the percentage of hits (r = .40; p < .001), false alarms (r = .39; p < .001) and response bias (r = –.36; p < .001); whilst overall ACC was negatively correlated with the percentage of false alarms (r = –.20; p = .04) and sensitivity (r = .34; p = .001). Thus, partial correlations were computed to control for the influence of overall RT and accuracy. In this analysis, the CFQ–Total now appeared to be correlated with the percentage of hits (r = –.23; p = .03), false alarms (r = –.21; p = .04) and response bias (r = .21; p = .04), while the previously reported association with the orienting network was preserved (r = .27; p = .007). Similar results were found with the three CFQ subscales.

Finally, the correlations between the CFQ and DBQ scores were obtained and are shown in Table 4.4. According to these results, all the correlation indices were positive and statistically significant, with only two exceptions that were quite close to being significant (DBQ–Traffic violations and CFQ–Attention, r = .25; p = .09, and DBQ–Aggressive behaviours and CFQ–Cognitive failures, r = .23; p = .11). In addition, it should be noted that both the DBQ–Attentional lapses and DBQ–Driving errors were highly correlated with all the CFQ scores (all r > .60, and all p < .001).

4. Discussion

The Driver Behaviour Questionnaire (Reason et al., 1990) is one of the most widely used research tools available to traffic researchers to obtain information about drivers' aberrant behaviour. The original version of the questionnaire includes an attentional lapses subscale, which could be useful to road traffic researchers and practitioners to analyse the driver behaviour and

	Cognitive Failures Questionnaire (CFQ)			
	Total score	Memory	Attention	Cognitive failures
Driver Behaviour Questionnaire (DBQ)				
Attentional lapses	.71***	.63***	.65***	.66***
Driving errors	.69***	.61***	.63***	.65***
Traffic violations	.40***	.48***	.25¹	.31**
Aggressive behaviours	.35**	.39**	.31**	.23

¹ p<.10; * p<.05; ** p<.01; *** p<.001

Note: N = 48

Table 4.4: Correlation between the Cognitive Failures Questionnaire (CFQ) and the Driver Behaviour Questionnaire (DBQ) scores.

inattention phenomenon and its potential countermeasures. The current study provides pioneering evidence of the construct validity of the DBQ–Lapses subscale. In particular, the DBQ–Lapses subscale has been found to be associated with an independent computer–based measure of vigilance (the Attention Networks Test for Interactions and Vigilance; Roca, Castro et al., 2011) and with a self–informed measure of cognitive failure (the Cognitive Failures Questionnaire; Broadbent et al., 1982). The other DBQ subscales were not related to vigilance in this study, and their relationship with cognitive failure was significant but more moderate (with the exception of the DBQ–Errors factor, which was also highly correlated).

Consistently with our first hypothesis, a higher score in the DBQ–Lapses factor is negatively correlated with hits and sensitivity in the vigilance subtask from the ANTI–V. This suggests that a higher self–informed tendency to suffer attentional lapses while driving is associated with a worse attentional performance and, specifically, with a reduced tonic alertness or vigilance. No other attentional component (executive control, attentional orienting or phasic alertness) was significantly associated with the DBQ–Lapses in the current study. The results are consistent with López–Ramón et al. (2011), who used an alternative questionnaire to measure failures of attention when driving (ARDES) and suggested that this measure was associated with the alerting network. In their study, the participants with higher ARDES scores showed a general slowdown in performance and less endogenous preparation for high–priority warning signs, which was attributed to their reduced internal vigilance. The results reported in the current study with the DBQ support this suggestion (although it should be noted that the correlation with the phasic alertness score failed to be significant). Also, the reported results support the idea that the DBQ–Lapses factor may be related to driving inattention which, if confirmed in further studies, suggest that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour. For example, Parker et al. (2000) found that, unlike previous studies with younger drivers, a relatively high DBQ–Lapses score was predictive of both active and passive accidents in older drivers. Thus, if DBQ–Lapses are associated with vigilance even in a young sample such as that used in the current study, this suggests that the relationship between this attentional function and road traffic accidents would be stronger still in older drivers (a diminished vigilance performance is usually found with ageing; e.g., Parasuraman, Nestor, &

Greenwood, 1989). If we had used a sample with older participants, a much stronger relationship might have emerged; future research should explore this possibility.Furthermore, consistently with our findings using a computer-based attentional performance test, previous research found an association between DBQ and different self-informed questionnaires on attention. For example, Wickens et al. (2008) reported that the DBQ-Lapses factor was positively correlated with the Differential Attention Processes Inventory – Extremely Focused Attention (DAPI-EFA; e.g., “Can you lose yourself in thought so that you are hardly aware of the passage of time?”) and an inattention scale from the Adult Self-Report Scale (ASRS-I; e.g., “When you have a task that requires a lot of thought, how often do you avoid or delay getting started?”). However, these scales were not specifically measuring vigilance, and thus it could be argued that some other attentional components may also be involved (for example, DAPI-EFA is assessing the ability to engage in the main task and ignore distracters, which could be related to the executive control function). As the ANTI-V is based on a solid neurocognitive model of human attention (Posner, 1990; Posner & Petersen, 1994), we propose that the relationship between the DBQ and the attentional components can be better assessed with this test, and thus vigilance is the attentional component most clearly associated with attentional lapses while driving. Future research will be helpful to confirm whether or not the DBQ-Lapses factor is associated with other attentional components in addition to vigilance. Also, further analysis should be carried out to discover which cognitive components are tackled by the above-mentioned self-reported attentional measures (DAPI-EFA and ASRS), since they may also be reflecting the influence of some other non-attentional skills.

Regarding the other DBQ factors (driving errors, traffic violations and aggressive behaviours), no clear association was found with any attentional score in this study (Hypothesis 2). However, Wickens et al. (2008) observed that DBQ-Errors was positively correlated with the above-mentioned DAPI-EFA and ASRS-I, and DBQ-Violations was positively correlated with the DAPI-EFA and DAPI-Dual Attention Cognitive-Cognitive (DAPI-DACC; e.g., “Can you read or study easily while at the same time listen easily to a conversation?”). The fact that these self-reported attentional scales are clearly correlated with other non-attentional DBQ factors is consistent with the idea of DAPI and ASRS questionnaires being influenced by non-attentional skills. However, it is also possible that other DBQ factors were associated with the attentional functioning. Actually, some dangerous slips and lapses were included in the unintentional error factor proposed by Reason et al. (1990), and therefore some significant correlations might be found in other studies with larger sample sizes or that analyse specific groups of drivers. Moreover, the DBQ–Violations factor was close to being significantly correlated with the EC score in percentage of errors, in the current study (more violations, more flanker interference, and thus less cognitive control), which may be inconsistent with Wickens et al.'s (2008) results (more violations, higher focused and dual attention). Again, although we think that the ANTI–V is more appropriate for evaluating attentional performance, further research would be useful to clarify whether or not the DBQ factors are influenced by the different attentional functions.

With reference to the CFQ, a positive correlation was found between the CFQ–Total score and DBQ–Lapses (Hypothesis 3). Thus, the participants with a higher tendency to make minor mistakes in everyday life were also those who reported more attentional lapses while driving. This is consistent with previous evidence found by Van de Sande (2008). However, the results from the current study show that this association between the CFQ and DBQ is not specific to the attentional lapses factor, since it is indeed present in the other three DBQ factors (driving errors, traffic violations and aggressive behaviours).Nevertheless, according to the magnitude of the correlations, the tendency to make minor mistakes in everyday life seems to be more closely associated with lapses and errors (r index was .71 and .69, respectively) than with violations and aggressive behaviours (r index was .40 and .35, respectively), which is partially consistent with our fourth hypothesis. Therefore, although cognitive failure can be a relevant factor in explaining drivers' aberrant behaviour overall, it seems particularly associated with the second–order factor of non–deliberate errors (including both driving errors and attentional lapses, as defined by Lajunen et al., 2004, and in accordance with the initial objectives of Reason et al., 1990). In addition, similar results were found in each of the four subscales of the CFQ, and thus these data are more consistent with the idea of a general factor of cognitive failure (Broadbent et al., 1982).

The analysis of the relationship between the ANTI–V and the CFQ shows that the CFQ–Total score was positively correlated with the orienting effect in reaction time, which provides partial evidence for our fifth hypothesis. Ishigami & Klein (2009), using the ANTI, found that the CFQ–Total was associated with orienting network functioning (which is consistent with the current study, although it was observed in the orienting error rate score) and also with alerting network functioning (the phasic alertness score in RT). The ANTI–V manipulates phasic alertness in a similar way to the ANTI, and thus a similar pattern of correlation of this score was expected. However, it is also possible that the phasic alertness manipulation in the ANTI and the ANTI–V tackles slightly different aspects of attentional alerting (actually, in the former, the usual trade–off between speed and accuracy is generally observed, i.e. the warning tone produces a faster RT but more errors, whereas in the latter, a faster RT and fewer errors are usually found).Nevertheless, it should be noted that a significant relationship between the CFQ–Total score and tonic alertness (vigilance) measures was found (Hypothesis 6), although to observe this result, the potential influence of global reaction time and accuracy had to be partialed out (as they may be reflecting different strategies to perform the attentional task, see for example Posner, 2008, and Roca, Castro et al., 2011; Roca, Fuentes et al., 2011). Thus, our results are still consistent with the idea of an association between the CFQ and the alerting network. In Ishigami and Klein (2009) higher CFQ scores were associated with greater alerting effects, which are usually found in participants with lower endogenous alertness or vigilance (for example, Miró et al., 2011; Roca, Fuentes et al., 2011). In the current study, higher CFQ scores were associated with a lower percentage of hits, and thus lower vigilance, which is consistent with previous evidence (Manly et al., 1999; Robertson et al., 1997). However, this result should be considered with care, since the correlation with sensitivity (d') failed to be significant.

Finally, the reported association between the CFQ–Total score and orienting network functioning was further explored by analysing separately the two subcomponents of the Attentional Orienting index (i.e., the reorienting costs and the orienting benefits). According to these results, a higher tendency to make minor mistakes in everyday life is associated with an increased reorienting costs index, whereas the orienting benefits seem to be preserved. When the participants are presented with a valid peripheral cue, their performance improves similarly. However, when they are presented with an invalid peripheral cue, those with a higher CFQ score find it more difficult to disengage from the erroneous spatial location and move their attentional focus towards the target location. This is consistent with Ishigami and Klein's (2009) proposal that high–CFQ participants fail to ignore automated actions to a greater extent than low–CFQ participants.

4.1. Conclusions

The current study provides further evidence of the construct validity of the DBQ–Lapses factor. This subscale was found to be significantly associated with an independent computer–based measure of vigilance (from the ANTI–V) and with a self–informed measure of cognitive failure (the DBQ). The participants who claim to have more attentional lapses while driving tend to be those with the worst vigilance performance and with a higher frequency of self–reported cognitive failures in everyday life. The other DBQ factors were not related to vigilance or any other attentional index in this study, and their relationship with cognitive failure was significant but more moderate (with the exception of the DBQ–Errors factor, which was also highly correlated). Overall, these results are consistent with the idea that DBQ–Lapses are related to driver distraction and inattention which, if confirmed in further studies, may suggest that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour. However, the DBQ–Lapses factor has failed to be consistently associated with self–reported accidents. Further evidence would be helpful to clarify whether proneness to attentional lapses while driving could be associated with crashes, using, for example, improved versions of the DBQ–Lapses factor (with new items asking about more dangerous inattention behaviour) or alternative questionnaires (such as the ARDES, which has recently been associated with traffic collisions; see Ledesma et al., 2010, for further information). Additionally, the present study has analysed the relationship between the ANTI–V and the CFQ. A higher tendency to make cognitive errors in everyday life has been associated with a higher orienting effect (particularly, more costs of reorienting attention) and with a worse vigilance performance (lower percentage of hits). This is consistent with the suggestion that high–CFQ participants fail to ignore automated actions to a greater extent than low–CFQ participants.

CAPÍTULO 5 CHAPTER

STUDY 4:

The influence on drivers' performance of individual differences in the functioning of the attentional networks.

Pre-print version of the manuscript: *Roca, J., Crundall, D., Moreno-Ríos, S., Castro, C., & Lupiáñez, J. (2011). The influence on drivers' performance of individual differences in the functioning of the attentional networks. Manuscript submitted for publication.*

ABSTRACT

Considerable research efforts are currently being devoted to analysing the role that the attentional system plays in determining driving behaviour, with the ultimate objective of reducing the number of attention–related accidents. The present study aims to assess the influence of individual differences in the functioning of the three attentional networks (executive control, attentional orienting and alerting) when drivers have to deal with some common hazardous situations, for example, when an oncoming car or a pedestrian unexpectedly crosses their trajectory. Multiple measures of participants' attentional functioning were obtained from a computer–based neurocognitive test: the Attention Networks Test for Interactions and Vigilance or ANTI–V). These measures were compared to performance in a driving simulator where different types of hazardous situations were presented. Correlation and linear regression analyses revealed significant associations between individual attentional measures and driving performance in specific traffic situations. In particular, a higher attentional orienting score on the ANTI–V was associated with safer driving in situations where a single precursor anticipated the hazard source, whereas in complex situations with multiple potential hazard precursors, higher orienting scores were associated with delayed braking. Additionally, partial evidence of a relationship between crash occurrence and the functioning of both the executive control and the alerting networks was found. Overall, the current research may provide some insights into the theoretical grounding of the measures of the three attentional networks and may also improve our understanding of the driving task, which would be of interest to both theorists on attention and applied psychologists in the field of driving.

Keywords: Attention Networks Test, driver behaviour, distraction, inattention, hazardous situations, driving simulator

1. INTRODUCTION

Driving a vehicle is a complex multi–tasking activity, in which all cognitive resources should be applied in a coordinated way to safely complete a journey. Of the different cognitive resources, research efforts have increasingly been devoted to analysing the role played by the attentional system in driving behaviour, with the aim of reducing the number of road traffic accidents. In fact, driver distraction and inattention are considered among the major contributing causes of road traffic casualties and their negative impact on road safety is expected to further increase in the immediate future, mainly due to the proliferation of some potentially distracting in–vehicle technologies (e.g. Kircher, 2007; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Ranney, 2008; Regan, Hallett, & Gordon, 2011; Stutts, Reinfurt, Staplin, & Rodgman, 2001). On this basis, the study of attention during driving is vitally important, though theoretical models of attention could also benefit from seeing how their hypotheses transfer to such complex, real–world tasks.

The present study will provide additional evidence to explain the influence of the attentional functions (such as executive control, attentional orienting, phasic alertness and tonic alertness or vigilance) when drivers have to deal with common hazardous situations, such as when an oncoming car or a pedestrian unexpectedly crosses their trajectory. To achieve this objective, multiple measures of attentional function were obtained individually from the participants using a single computer–based neurocognitive test termed the Attention Networks Test for Interactions and Vigilance (ANTI–V; Roca, Castro, López–Ramón, & Lupiáñez, 2011), and these measures were compared with performance in a driving simulator where a number of hazardous situations had to be safely negotiated. Although some previous attempts have been made with other neurocognitive tests to link attentional network functions to driving behaviour (e.g., Weaver, Bédard, McAuliffe, & Parkkari, 2009), the relationship between the attentional components assessed by the ANTI–V and performance data from a driving simulator presenting hazardous situations is still unclear.

1.1. The three attentional networks model

As the result of a decade of neurocognitive research on human attention, a quick and easy computer–based task has been designed with the aim of measuring participants' performance in some basic components of attention. The original task is known as the Attention Networks Test or ANT

(Fan, McCandliss, Fossella, Flombaum, & Posner, 2002) and is a combination of the cued reaction time (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). Participants are required to determine as fast as possible the direction of a central arrow (left or right), and the efficiency of the three attentional networks is assessed by measuring the influence of alerting signals, spatial cues, and flankers on performance. The ANT is based on a widely accepted neurocognitive model of human attention, i.e. the three attentional networks model (Posner, 1994; Posner, 2008; Posner & Petersen, 1990). According to this model, three relatively independent neural networks are responsible for controlling the different attentional functions: the executive control, attentional orienting and alerting networks. First, the executive control network involves mechanisms for ignoring distracters and resolving cognitive conflict, and is usually assessed by using Stroop, Simon or flanker tasks (e.g., Callejas, Lupiáñez, & Tudela, 2004; Fan et al., 2002). It activates anterior areas of the frontal cortex, such as the anterior cingulate and the dorso–lateral prefrontal cortex, and dopamine is the main neurotransmitter modulating its functioning. Second, the attentional orienting network is aimed at selecting information from the sensory input by allocating the attentional focus to a potentially relevant area or object in the visual field, and is usually assessed by presenting valid, invalid and neutral spatial cues in reaction time tasks (e.g., Callejas et al., 2004; Fan et al., 2002). It includes different areas of the parietal and frontal lobes, with acetylcholine implicated as the main neurochemical modulator. Finally, the alerting network is necessary to achieve and maintain a state of high sensitivity to incoming stimuli (Posner, 2008). It involves fronto–parietal regions of the brain, mainly in the right hemisphere, and also brain stem areas such as the locus coeruleus, in which noradrenaline is the main neurotransmitter. The alerting network is related to performance in tasks that involve both phasic alertness (i.e, the increased readiness to respond after a warning signal) and tonic alertness or vigilance (i.e., the ability to maintain attention over a prolonged period of time) (see, for example, Posner, 2008; Sturm & Willmess, 2001).

The validity of the ANT measures is solidly supported by evidence from different disciplines, such as neuroscience, neuropsychology and experimental psychology (e.g., Fan et al., 2002; Fan, McCandliss, Sommer, Raz, & Posner, 2005; Ishigami & Klein, 2010; Posner, 2008). As a consequence, this attentional test and its variations are currently being used in a wide range of basic and applied studies, and also in the driver behaviour and road traffic safety areas (see for example, López-Ramón, Castro, Roca, Ledesma, & Lupiáñez, 2011; Roca, Lupiáñez et al., 2011; Weaver et al., 2009). Some alternative versions of the test are currently available, such as the ANTI to analyse the interaction between the networks (Callejas et al., 2004), the child-ANT to measure attentional functioning in children (Rueda et al., 2004) and the ANTI-V, which includes an extra measure of tonic alertness or vigilance in addition to the executive control, attentional orienting and phasic alertness indices (Roca, Castro et al., 2011). To assess vigilance, the ANTI-V analyses the participants' ability to detect infrequent, uncertain and unpredictable stimuli. As in other versions of the ANT, the most frequent trials require that participants report the direction of a central target (i.e., a car icon), but in the ANTI-V, the central target is occasionally displaced (appearing significantly closer to one of the immediate flankers), and participants are encouraged to identify these infrequent trials by pressing an alternative key. The vigilance measure in the ANTI-V has been recently validated in a sleep deprivation study (Roca, Fuentes et al., 2011), and thus the test may be especially useful in driver behaviour studies, since low vigilance is considered to be one of the major causes of road accidents (Åkerstedt, Philip, Capelli, & Kecklund, 2011; Campagne, Pebayle, & Muzet, 2004; Lal & Craig, 2001; Larue, Rakotonirainy, & Pettitt, 2011). Indeed the ANTI-V has already been applied successfully to studying drivers' attentional behaviour, with Roca, Lupiáñez et al. (2011) reporting recently that poor vigilance performance in this test was significantly associated with a higher tendency to have attentional failures while driving (as measured using the lapses subscale in the Driving Behaviour Questionnaire; Reason, Manstead, Stradling, Baxter, & Campbell, 1990). In addition, by employing this task, the influence of each specific attentional component (executive control, attentional orienting, phasic and tonic alertness) on driving behaviour can be analysed separately.

1.2. Functioning of attention networks and driving behaviour

Previous research has tried to associate the functioning of the attentional networks with driving performance. First, Weaver et al. (2009) used the original ANT version (Fan et al., 2002), the Useful Field of Vision test (UFOV) and the Manitoba Road Test in both a simulated driving evaluation and an on-road test. The UFOV (Ball, Owsley, Sloane, Roenker, & Bruni, 1993) is a computer-based task that aims to measure visual attention. It consists of a central target identification task coupled with a peripheral target localisation task, providing a measure of the size of the useful field of vision. The Manitoba Road Test (Weaver et al., 2009) is a demerit–based scoring system, aimed at assessing driving performance. Demerit points are given for the commission of certain infractions, such as speed, turning or signal violations. In this study, two overall measures from the ANT (global reaction time and global accuracy) were good predictors of the UFOV and overall performance in the driving simulator. However, no association was found between the three separate functions of attention (executive control, attentional orienting and phasic alerting) and driving performance. Only the executive control score (conflict efficiency) showed a significant relationship with the UFOV, but not with the measures taken from the driver simulator or an on–road test. The authors found these results surprising, since the attentional functions are considered to play an important role while driving. Thus, looking for potential associations in different driving situations and using alternative driving performance measures was recommended, since the UFOV and especially the Manitoba Road Test may not have been appropriate to tap all the different aspects of attention. The current study may be considered as an attempt to follow these recommendations and find evidence for significant associations, for example, by using performance measures that are more specific regarding both the components of attention assessed and the aspects of driving simulated (e.g., presenting some common hazardous driving situations instead of assessing infractions while engaged in everyday driving).

A second attempt to link the attentional networks with driving behaviour was undertaken by López–Ramón et al. (2011). They applied the Attention Networks Test for Interactions (ANTI) and the Attention–Related Driving Errors Scale (ARDES) to a sample of 55 drivers in Argentina. The ANTI (Callejas et al., 2004) is a variation of the original ANT, in which the functioning of the three attentional networks is estimated more independently and thus interactions can be analysed more efficiently (see, for example, Callejas et al., 2004; Ishighami & Klein, 2010). The ARDES (Ledesma, Montes, Poó, & López–Ramón, 2010) is a 19–item self–informed questionnaire aimed at evaluating proneness to making attentional errors while driving (e.g., "*On approaching a corner, I don't realize that a pedestrian is crossing the street*"). The authors found that the group of participants with a higher ARDES score (and thus more prone to attentional lapses while driving) obtained slower overall reaction times and had a higher phasic alertness score in the ANTI (i.e., they showed a greater benefit in RT from the presentation of a warning signal that indicates an upcoming target). The results were interpreted as these participants showing a general slowdown in performance and less endogenous preparation for high–priority warning signs, probably due to reduced vigilance. However, the ANTI lacks a direct vigilance measure, and therefore it was suggested that future research investigating the role played by the three attentional networks should also include specific measures of tonic alertness or vigilance (for example, by using the ANTI–V).

The third and most recent attempt to link attentional network measures to driving was reported by Roca, Lupiáñez et al. (2011). In that study the relationships between the Driver Behaviour Questionnaire (DBQ) and both the Attention Networks Test for Interactions and Vigilance (ANTI–V) and the Cognitive Failures Questionnaire (CFQ) were analysed. The DBQ (Reason et al., 1990) is one of the most widely used scales to study self–reported aberrant behaviour in drivers and includes an attentional lapses subscale (which measures a construct similar to the above–mentioned ARDES). The CFQ (Broadbent, Cooper, Fitzgerald, & Parkes, 1982) is a 25–item questionnaire aimed at measuring self–reported mistakes in everyday life (e.g., "*you forget why you went from one part of the house to the other*"). Results showed that the attentional lapses subscale in the DBQ was negatively correlated with vigilance and positively correlated with cognitive failure. Therefore, it was claimed that a worse vigilance performance in the ANTI–V was significantly associated with a higher tendency to suffer attentional failures while driving.

Finally, other studies using a variety of attentional tests have found relevant associations between separate measures of the attentional functions (executive control, attentional orienting, phasic and tonic alertness) and driving performance. For example, previous evidence has shown that low performance in executive functions was associated with poor driving performance, using either a sample of young drivers in a simulated driving task (Mäntylä, Karlsson, & Marklund, 2009), a group of older drivers in an on–road study (Adrian, Postal, Moessinger, Rascle, & Charles, 2011) or analysing self–reported crash involvement in older drivers (Daigneault, Joly, & Frigon, 2002). It should be noted that different components of executive function were distinguished in these studies (response inhibition, working memory updating and mental shifting), and the evidence in relation to response inhibition (which is the executive component measured by the ANT) has been conflicting. While Daigneault et al. (2002) showed that a lower ability to inhibit incongruent responses was associated with a higher accident involvement, neither Mäntyla et al. (2009) nor Adrian et al. (2011) found a significant association between inhibition and driving performance. The current study will provide further evidence on which to base discussion about the role of this executive component, by using the ANTI–V and alternative (hazardous) driving situations.

Regarding the attentional orienting network, Bédard, Leonard, McAuliffe, Weaver, Gibbons and Dubois (2006) observed that a higher inhibition of return effect (IOR, a reflexive visual attention mechanism that prevents attention being re–allocated to a recently scanned location or object), was associated with a measure of drivers' ability to scan the traffic environment (fewer scanning errors). Also, in a recent review of eye tracking studies, Underwood, Crundall and Chapman (2011) reported convergent evidence to support certain types of hazard being associated with a general reduction in the spread of visual search while driving and the idea that certain individuals (e.g. novice drivers) might be more prone to such attentional capture by hazards. This suggests, therefore, that individual differences in the functioning of the attentional orienting network might be related to driving performance when resolving hazardous situations.

Finally, in relation to the alerting network, it should be noted that vigilance (or tonic alertness) is considered as an attentional component with a considerable influence on driving performance (e.g., Åkerstedt et al., 2011; Campagne et al., 2004; Lal & Craig, 2001; Larue et al., 2011). Also, different studies have shown the feasibility of driver warning devices (which may increase phasic alertness) to prevent road traffic accidents, such as lane departure or collision avoidance warning systems (for a review see May & Baldwin, 2009).

1.3. Objectives

Previous research (Weaver et al., 2009) found that overall attentional measures were related to overall driving performance, but failed to find associations of specific attentional functions with specific driving situations. This may have occurred for a number of reasons, such as the gap between real driving and the measures included in the previous studies. The tasks that drivers were asked to complete may not have represented those situations where the correct functioning of the attentional networks is most in demand (i.e., hazardous situations are likely to place the greatest demand on attentional functions). Unfortunately, pragmatic and ethical issues prevent the study of truly hazardous real–world situations (unless one can undertake a large scale naturalistic study; see Dingus et al., 2006). As a consequence, the main objective of the current study is to analyse specific relationships between individual differences in the functioning of the three attentional networks (executive control, attentional orienting and alerting) and the participants' performance in a driving simulator presenting particular hazardous situations. The simulated environment provides a compromise between the realism of the task and the ability to place participants in controlled yet hazardous situations.

To achieve this objective, three aspects of the current study should be highlighted. First, the driving simulator required the participants to drive through several common hazardous situations in which demands are made on attention to avoid crashing (see material and methods section). Therefore, the driving performance measures obtained from the simulator should be considered more appropriate for evaluating the role played by the attentional system than previous studies using, for example, indices based on traffic infractions (e.g. Weaver et al., 2009).

Secondly, general driving performance measures will be obtained together with separate measures in different types of traffic situation (three categories of hazard have been differentiated: Behavioural Prediction, Environmental Prediction, and Dividing and Focusing Attention situations, as described in material and methods section; see Crundall et al., 2010, in press). Since driving is considered to be a complex multi–tasking activity, in which different cognitive resources will be differentially required in a great variety of traffic situations, it can be hypothesized that the relationship of each attentional network to driving performance might not be unidirectional in any given traffic situation. On the contrary, a specific attentional function could be helpful in some specific situations, whereas in some other cases it might be associated with a worse performance. For example, focusing our attention on a preceding vehicle (and thus partially ignoring the traffic environment) will be helpful when this vehicle unexpectedly brakes, but this attentional behaviour can be dangerous when a pedestrian suddenly steps out in front of one's car. As a consequence, some qualitative differences might be found in the relationship of a specific attentional network score with performance in different traffic situations. From a theoretical viewpoint this is very interesting as it can ground performance indicators in abstract cognitive tests in terms of actual behaviour (i.e., what does a high score on a measure of responsiveness to an orienting cue mean in various real life situations?).

The third aspect of the study to take particular note of is that the experimental task used in the current study to assess attentional functioning (i.e., the ANTI–V, as described in material and methods section) provides an additional measure of vigilance, as well as the usual executive control, attentional orienting and phasic alertness indices. Vigilance is an attentional component with a great influence on driving performance (see, for example, Åkerstedt et al., 2011; Campagne et al., 2004; Lal & Craig, 2001; Larue et al., 2011). However, the current study was not specifically interested in vigilance during driving, and did not, therefore, contain any task demands to manipulate vigilance (e.g., using a prolonged task or sleep deprivation). Despite this, it is possible that short term concentration may be related to vigilance, and thus the role of vigilance as measured by the ANTI–V may still be relevant.

Finally, as the evidence reviewed so far has shown that the ANT–based tasks can be considered as valid measures of attentional functioning (see, for example, Callejas et al., 2004; Fan et al., 2002, 2005; Ishigami & Klein, 2010), the current work may aid researchers in the field of driving simulation, if the current simulator can be shown to relate to attentional functioning in predictable ways. The potential associations between the attentional indices from the ANTI–V and performance in the driving simulator will suggest that the latter is able to tackle important cognitive components of real driving (i.e. the attentional functions of executive control, attentional orienting, phasic or tonic alertness). Thus, the current research may not only provide insights into the grounding of the measures of attentional networks (benefitting the theorists on attention) and improve our understanding of the driving task (benefitting applied psychologists in the field of driving), but may also benefit the developers and users of simulator technology, providing a possible alternative route to simulator validation.

2. Material and methods

2.1. Participants

A sample of 42 students from the University of Nottingham volunteered for this study. Twenty were females (48%) and their mean age was 22 (St. Dev. = 4). Each of them had a valid UK driving licence and a minimum experience of 12 months since passing the driving test. Also, normal or corrected–to–normal vision was required. None of them had previous experience with the driver simulator.

2.2. Stimuli and apparatus

2.2.1. ANTI-Vigilance

The *Attention Network Test for Interactions and Vigilance* (ANTI–Vigilance or ANTI–V) was used to measure the participants' attentional functioning (for a more detailed description see Roca, Castro et al., 2011; Roca, Fuentes et al., 2011). An E–Prime v2.0 (Psychology Software Tools, Inc.) script controlled the stimulus presentation on a 21" monitor and responses were collected from a standard keyboard. The task was presented to the participants as a game where they were working in a Centre for Traffic Management and the drivers' parking habits were under study. As shown in Figure 2.1, the background scene represented a two–lane street with two parking lanes in the centre of the screen. For each trial, a row of five cars pointing either left or right was briefly presented (200 ms) on one of the two parking lanes. Each car subtended ~1.71 degrees of horizontal visual angle with a gap of ~0.43 degrees between them in a standard (non–vigilance) trial. The participants had to indicate the direction of the central car (target) by pressing "c" (left) or "m" (right) keys, and they had to ignore the direction of the flanker cars (distracters). Responses up to 2,000 ms were allowed. In every trial, the duration of the initial and final empty scenes were adjusted so that the total trial time was 4,100 ms.

In half the trials, the flanking cars were pointing in the same direction as the central target car (congruent condition) and in the other half in the opposite direction (incongruent condition). This manipulation was designed to test *executive control* functioning, with participants needing to identify the direction of the central car while inhibiting any response to the flanking vehicles.

At a lapse of 100 ms before the row of cars appeared, a black asterisk was presented for 50 ms. The asterisk was shown, with equal probability, in the same location as the forthcoming target central car (valid cue condition), in the opposite location (invalid cue condition), or it was absent (no cue condition). This manipulation was designed to test the *attentional orienting* function, by analysing the influence on participants' performance of non–predictive peripheral (thus automatic) cueing.

A 50 ms warning tone was also presented 500 ms before the target car (warning tone condition) or it was absent (no warning tone condition). As warning signals momentarily increase participants' alertness, the difference in performance between no warning and warning conditions is considered to test *phasic alertness*.

Finally, the target central car was visibly displaced to the right or to the left (thus appearing closer to one of the flanking cars) in 25% of the trials. The gap between the central car and one flanker was reduced to ~0.14 degrees of visual angle (with a concomitant increase to ~0.71 degrees for the gap to the flanking vehicle on the other side of the target). Participants were asked to identify these infrequent, unpredictable, uncertain stimuli by pressing an alternative response key (spacebar) and ignoring the direction of the central car. The task comprised 8 blocks of 64 trials each (48 trials for ANTI conditions and 16 vigilance trials). Accuracy feedback was only provided in the first (practice) block. The participants had to perform the task continuously for more than 30 minutes.

2.2.2. The driving simulator

Driving performance measures were taken from a Faros GB3 medium fidelity fixed–base simulator located in the Accident Research Unit at the University of Nottingham (see, for example, Crundall, Andrews, van Loon, & Chapman, 2010; and Crundall et al., in press, for a more detailed description). The simulator was based on a Vauxhall Corsa cabin, with a realistic car seat, pedal set, steering wheel, manual gearbox, speedometer and the other usual controls and indicators. The driving environment was displayed on three 19" LCD monitors covering an approximate visual angle of 90º (width) x 21º (height), depending of the seat adjustment required by each participant. Side and rear–view mirror images were also shown in the scene video (see Figure 5.1). A virtual city that included streets, buildings, junctions, other traffic, pedestrians, signs, traffic lights and other normal urban elements was available for participants to drive through. The participants were guided by a navigation voice along a route where nine hazardous situations were to be found. Also, a direction arrow appeared above the dashboard after each instruction to help the participants take the correct route.

The driving simulator presented the participants with a route where nine hazardous situations were triggered when they approached (for example, a child pedestrian suddenly stepping out in front of the car). According to Crundall et al. (2010, in press), three categories of hazards could be differentiated: Behavioural Prediction (BP), Environmental Prediction (EP), and Dividing and Focusing Attention (DF) hazardous situations. First, BP hazards could be avoided if the drivers anticipated the behaviour of a visible traffic factor (i.e. a pedestrian or another vehicle) before it became hazardous. This category included the following situations: a child pedestrian who is standing visibly between two parked cars and suddenly steps out in front of the participant's car, a vehicle waiting in a side road that moves forward unexpectedly, and an oncoming motorcycle that invades the participant's trajectory. Second, in EP situations the source of the hazard is not visible before the hazard is triggered. This category includes a child stepping out from behind an ice-cream van, a man carrying a box who steps out from behind a truck, and a broken-down vehicle around a blind bend. It should be noted that the precursors to EP hazards are part of the environment and they conceal the hazard source (such as the ice-cream van hiding the child), while the precursors to BP hazards are the same stimuli as the hazard sources (for example, the motorcycle is both a precursor and a hazard source). Third, DF situations require

Figure 5.1: A picture taken from inside the Faros GB3 cabin. Some of the different car controls and indictors are shown. Also, an example of the simulated traffic environment, including the side and rear-view mirror images, can be observed (adapted from Crundall et al., in press).

the drivers to monitor multiple sources of potential risk before selecting one as the actual hazard. This is a more complex category containing potential hazards from both BP and EP categories, but specifically in this category, more than one hazard was visible at the point at which the hazard triggered. The following DF situations were used in the driving simulation: a) a bus is parked on the left side of the road (a potential hazard, since a pedestrian may emerge from behind the bus) and a pedestrian is positioned on the right (which becomes the actual hazard, when he finally crosses the road to reach the bus); b) when driving over a crossroads junction, there is traffic from the right that fails to give way (while a hazard from the left was equally plausible); and c) two pedestrians are waving to each other from either side of the road, when one of them steps into the road and invades the trajectory of the car (both pedestrians were potential hazards, but only one crosses the road).

2.3. Procedure

Upon arrival at the Accident Research Unit, participants were asked to sign an informed consent form. The tasks were then completed in a counterbalanced order to avoid serial effects. The driving task was performed in the Faros GB3 simulator room. A researcher invited the participant to enter the car and make any necessary adjustment to the seat. Once the driver was comfortably installed, a brief tutorial video described the general characteristics of the simulator and modelled the usual control operations (for example, the use of the gearbox). Then, the participant completed a hazard–free practice ride to familiarise her/himself with the driving simulation. The researcher remained next to the participant until the end of the practice and provided specific assistance when necessary. The experimental route with the nine hazards was then performed. On average, the route required about 11 minutes to be completed. All the participants encountered the situations in the same order, although this order was pseudorandomly assigned to avoid all hazards in the same category appearing consecutively. The simulation session generally took less than 20 minutes. The ANTI–V task was performed in a different experimental room. Standardised instructions were provided via the computer. Completing this task required around 40 minutes. Finally, the participants filled in some questionnaires and performed other brief tasks, although these were not related to the objectives of this paper.

2.4. Design

Mean correct–trial reaction time (RT, ms) and accuracy data (percentage of errors) from the ANTI–V task were submitted to a 2 (Congruency: congruent / incongruent flankers) x 3 (Validity: valid / no cue / invalid cue) x 2 (Warning: Tone / No tone) repeated–measures ANOVA. Trials with an average RT above or below 3 standard deviations (St. Dev.) were filtered out (1% of trials). Significance level was set at .05 and Bonferroni adjustment was applied in pairwise comparisons. Degrees of freedom were adjusted using the Greenhouse–Geisser method when sphericity could not be assumed. Different performance indices for the functioning of the three attentional networks were obtained for each participant by subtracting average RT and percentage of errors of specific conditions (see, for example, Fan et al., 2002; Callejas et al., 2004; Ishigami & Klein, 2010). An "Executive Control" score (EC) was obtained by subtracting "congruent" conditions from "incongruent" conditions. A higher EC score means that flankers have a greater impact on a participant's performance (suggesting that the participant has worse executive control functioning). An "Attentional Orienting" score (AO) was measured as the difference between "invalid" and "valid" conditions. A higher AO score is obtained when the participant is more intensely influenced by non–predictive peripheral (thus automatic) spatial cues, which confers a greater advantage when the cue is valid but a greater disadvantage when the cue is invalid. A "Phasic Alertness" score (PhA) was obtained from "no cue" conditions, as the difference between "no tone" and "tone" conditions. A higher PhA score is associated with a better performance at using the warning signal to prepare to respond. Additionally, the ANTI–V task provides a measure for vigilance by analysing the participant's performance on the detection of infrequent stimuli. Following Roca, Castro et al. (2011), the percentages of hits and false alarms were obtained and Signal Detection Theory (SDT) indices for sensitivity (*d'*) and response bias (*ß*) were computed. Three participants were discarded because they failed to successfully complete the task or their overall percentage of errors was unusually high (> 3 St. Dev.).

The driving simulator provides detailed performance data for each participant. For example, in each of the nine hazardous situations, speed (km/h) and brake pedal depression (%) were recorded every 10–metre interval from 100 m to 10 m before the hazard (hereafter the *hazard window*). The different performance indicators were then obtained from these data. First, *approach speed change* (km/h) was calculated as the difference between the maximum speed at the beginning of each hazard window (100 m to 40 m) and the minimum speed before reaching the hazard (30 m to 10 m). Second, brake pedal depression was inspected to identify the *braking distance* in each hazardous situation. Typically the brake pedal is unpressed when the participants enter a hazard window (thus brake pedal depression is zero), until some point where they start braking before the hazard. The farthest distance at which the participant started pressing the brake pedal was considered the *braking distance* (m) in each hazardous situation. Also, crash occurrence was recorded when the drivers collided with the hazard source or with any other element in the traffic environment along the whole route. Crundall et al. (2010), using the same simulator and driving situations, found that a safety trained group reduced their speed to a greater extent on approach to hazards, applied pressure to the brakes sooner and had fewer crashes than untrained drivers. Therefore a greater approach speed change, greater (sooner) braking distance and lower crash frequency can be considered indicators of safer driving in hazardous situations, and in the current study, individual scores in these measures were submitted to analysis. Two participants failed to complete the driving session due to simulator sickness and their data were discarded.

Finally, with the aim of analysing the relationship between attentional functioning and driving performance, Pearson's correlation indices between the attentional scores obtained from the ANTI–V (executive control, attentional orienting, phasic alertness and tonic alertness measures) and the driving indicators from the simulator (approach speed change, braking distance and the number of crashes) were examined. Significance tests were computed for the null hypothesis $r = 0$ and, also, when the difference between two correlations was of specific interest, for the null hypothesis $r_1 - r_2 = 0$. When the correlation analysis revealed a significant association, a linear regression analysis was computed to examine whether the driving simulator measures could be predicted by using the attentional scores. The linear regression models were constructed in two steps: First, overall RT and percentage of errors were considered using stepwise selection (since individual differences in these overall measures might mask the influence of the attentional components and reveal different strategies when performing the ANTI–V; see Roca, Castro et al., 2011, and Roca, Fuentes et al., 2011). Second, the attentional scores were considered for inclusion using stepwise selection. Condition indices were inspected to evaluate collinearity, and no value was equal or greater than 15 in these models.

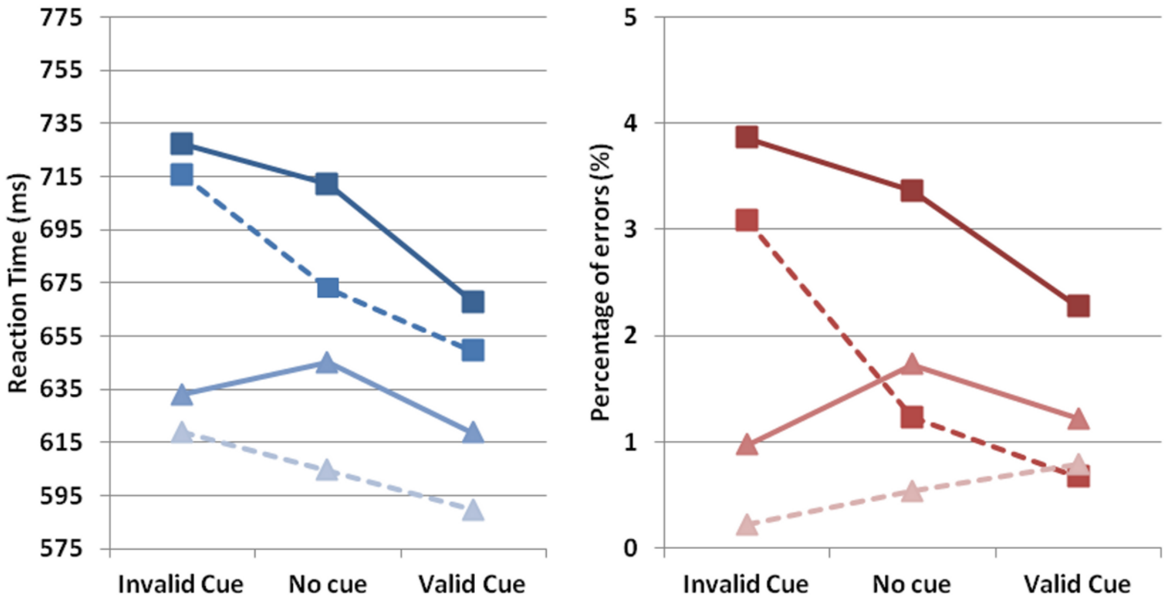
3. RESULTS

3.1. Attentional networks functioning

The usual main effects and interactions expected with the ANTI–V task were obtained in the 2 (Congruency) x 3 (Validity) x 2 (Warning) repeated–measures ANOVA (see Figure 5.2). RT results revealed that the participants were faster when the central and the flanker cars were congruent as compared to when they were incongruent (618 ms and 691 ms, respectively; $F(1,38)=122.89$; $p<.001$; $\eta^2=.76$). Similarly, participants were faster when a valid cue was presented in comparison to the no cue and invalid conditions (631, 659, and 674, respectively; $F(2,76)=41.17$; $p<.001$; $\eta^2=.52$). Pairwise comparisons with Bonferroni correction confirmed the differences between these three conditions (all $p<.009$). With regard to the phasic alertness manipulation, faster RTs were obtained with the warning tone than when it was absent (639 and 679, respectively; $F(1,38)=42.04$; $p<.001$; $\eta^2=.53$).

The overall pattern of correlations found by Roca, Castro et al. (2011) with the ANTI–V was also observed in the current study. The interaction between cue validity and the congruency of the flankers was statistically significant ($F(2,76)=14.02$; $p<.001$; $\eta^2=.27$). Further analysis revealed that the congruency effect was higher in invalid conditions (96 ms) than in no cue (68 ms) ($p=.005$), whereas the difference between the latter (no cue) and valid conditions (54 ms) was smaller and failed to reach the significance level ($p=.06$). The interaction between the presence of a warning tone and cue validity was statistically significant ($F(2,76)=5.09$; $p=.008$; $\eta^2=.12$). Further analysis showed that the difference between invalid and valid cues was slightly higher after a warning tone (48 ms) than without the tone (37 ms), although this interaction was not statistically significant when "no cue" trials were excluded ($F(1,38)=1.66$; $p=.21$; $\eta^2=.04$). The ANTI–V typically does not produce a significant interaction between the presence of the warning tone and flanker congruency (Roca, Castro et al., 2011), and the current study repeated this result ($F(1,38)=.66$; $p=.42$; $\eta^2=.01$). No second–order interaction was found. Similar results were observed with accuracy data.

As these results suggested that the ANTI–V had been applied successfully, attentional scores were computed as a subtraction of specific conditions (see material and methods section) and average data are shown in Table 5.1. These scores provide an index of the functioning of the three attentional networks for each participant.



	Flanker congruency	Warning tone	Cue validity: Invalid Cue	No Cue	Valid Cue
Reaction time (St. Dev.)					
	Incongruent	**No Tone**	727 (106)	712 (95)	668 (90)
	Incongruent	**Tone**	716 (104)	673 (90)	649 (90)
	Congruent	**No Tone**	633 (87)	645 (89)	619 (94)
	Congruent	**Tone**	619 (84)	605 (78)	590 (80)
Percentage of errors (St. Dev.)					
	Incongruent	**No Tone**	3.9 (5.6)	3.4 (4.6)	2.3 (4.0)
	Incongruent	**Tone**	3.1 (5.9)	1.2 (3.2)	0.7 (1.9)
	Congruent	**No Tone**	1.0 (2.0)	1.7 (2.5)	1.2 (2.8)
	Congruent	**Tone**	0.2 (1.0)	0.5 (1.4)	0.8 (2.5)

Figure 5.2: Results from the attentional test (ANTI–V). Average reaction time (upper left) and percentage of errors (upper right) is shown for the 2 (Congruency: congruent / incongruent flankers) x 3 (Validity: invalid / no cue / valid cue) x 2 (Warning: Tone / No tone) repeated–measures ANOVA. The table below includes the figure legend and shows average values (ms and % errors) and their standard deviation between parentheses (St. Dev.).

3.2. Driving performance measures

Data from the driving simulator were processed as described in material and methods section and average measures of approach speed change, braking distance and crash frequency across the hazardous situations are shown in Table 5.2. Individual scores in each hazardous situation were averaged overall for the nine situations and also separately for each hazard category (Behavioural Prediction, BP, Environmental Prediction, EP, and Dividing and Focusing Attention, DF). In addition, the number of crashes for the whole route (including crashes that occurred outside the hazard windows) is reported. The differences between the three categories of hazard (BP, EP and DF) on each driving measure (approach speed change, braking distance and crashes) were analysed using separate repeated-measures ANOVAs. Results revealed overall

	Mean	St. Dev.
a) Attentional scores: RT (ms)		
Executive Control	73	41
Attentional Orienting	43	34
Phasic Alertness	39	39
b) Attentional scores: % errors		
Executive Control	1.6	2.3
Attentional Orienting	0.8	2.9
Phasic Alertness	1.7	3.1
c) Vigilance measures (SDT)		
Hits (%)	56	16
False Alarms (%)	2.7	2.7
Sensitivity (d')	2.2	0.4
Response Bias (β)	9.0	4.7
d) Global results		
ANTI RT (ms)	656	82
ANTI % errors	1.7	3.1

Table 5.1: Summary of results for the attentional measures taken from the ANTI-V (mean and standard deviation, St. Dev.): Attention network scores (executive control, attentional orienting and phasic alertness), for both (a) reaction time and (b) the percentage of errors; (c) Vigilance measures (hits, false alarms, sensitivity, and response bias); and (d) Global reaction time and global percentage of errors.

significant differences in the braking distance (F(2,74)=6.53; p=.002; η^2=.15), and pairwise comparisons with Bonferroni correction showed that participants started braking sooner in DF situations (29.7 m) than in BP (22.0 m; p=.004) or EP (22.4 m; p=.02) hazards. The analysis of approach speed change reveals no statistically significant difference (F(2,74)=.62; p=.54; η^2=.02) and an unconfirmed tendency was reported in the number of crashes (F(2,74)=2.83; p=.07; η^2=.07).

	Mean	St. Dev.
a) Approach Speed Change (km/h)		
Overall situations	18.5	4.7
BP hazards	17.8	6.7
EP hazards	18.0	9.5
DF hazards	19.6	7.5
b) Braking Distance (m)		
Overall situations	24.8	8.8
BP hazards	22.0	11.9
EP hazards	22.4	12.1
DF hazards	29.7	12.8
c) Crashes (number)		
Overall situations	0.8	1.0
BP hazards	0.1	0.4
EP hazards	0.3	0.6
DF hazards	0.3	0.5
Whole Route	1.4	1.0

Table 5.2: Summary of results for the driving performance measures taken from the Faros GB3 simulator (mean and standard deviation, St. Dev.): (a) Average approach speed change (km/h), (b) braking distance (m), and (c) number of crashes, computed overall for the nine hazardous situations and also for each category of hazard (Behavioural Prediction, BP, Environmental Prediction, EP, and Dividing and Focusing Attention, DF). Finally, the number of crashes for the whole route (including data from outside the hazard windows) is also reported.

3.3. Association between attentional functioning and driving performance

To analyse the relationship between the driving performance measures and the EC, AO, and PhA attentional functions, Pearson's correlation indices were inspected and are shown in Figure 5.3. Whenever the correlation analysis suggested the existence of a significant association, a linear regression analysis was computed to ascertain whether the driving measures could be effectively predicted by using the attentional indices.

3.3.1. Approach speed change

Correlations between the attentional network scores and overall approach speed change for all the hazards combined failed to reach statistical significance. However, separate analyses for the three hazard categories revealed that the AO score in RT was positively correlated with approach speed change, but only in EP situations (r=.50 ; p=.002), suggesting that those participants who were more intensely influenced by spatial cues in the ANTI–V were more likely to reduce their speed on approach to an EP hazard. A regression analysis confirmed that only AO score in RT was predictive of the approach speed change in EP situations (F(1,36)=11.66; p=.002; R^2=.22; $\beta_{AO\text{-}RT}$=.50).

3.3.2. Braking distance

Correlations between the attentional network scores and overall braking distances were non–significant, with the exception of the AO score in percentage of errors (r=.35; p=.03). This result suggests that a greater influence of spatial cues on allocating attention to specific locations in the ANTI–V may be associated with overall greater braking distance (i.e., earlier response) in the driver simulator. However, separate analyses for the three hazard categories showed that this overall correlation was explained mainly by BP situations (r=.41; p=.01) and perhaps also by EP situations (where an unconfirmed tendency was suggested, r=.31; p=.06), but clearly not by DF situations. Actually, a significant negative correlation between braking distance in the latter situations (DF) and AO score in RT was found (r=–.43; p=.007), suggesting that, in situations where multiple potential hazards are shown, a greater influence of spatial cues on focusing attention may indeed be associated with a reduced braking distance (i.e., delayed response). Separate regression analyses confirmed these results on attentional orienting,

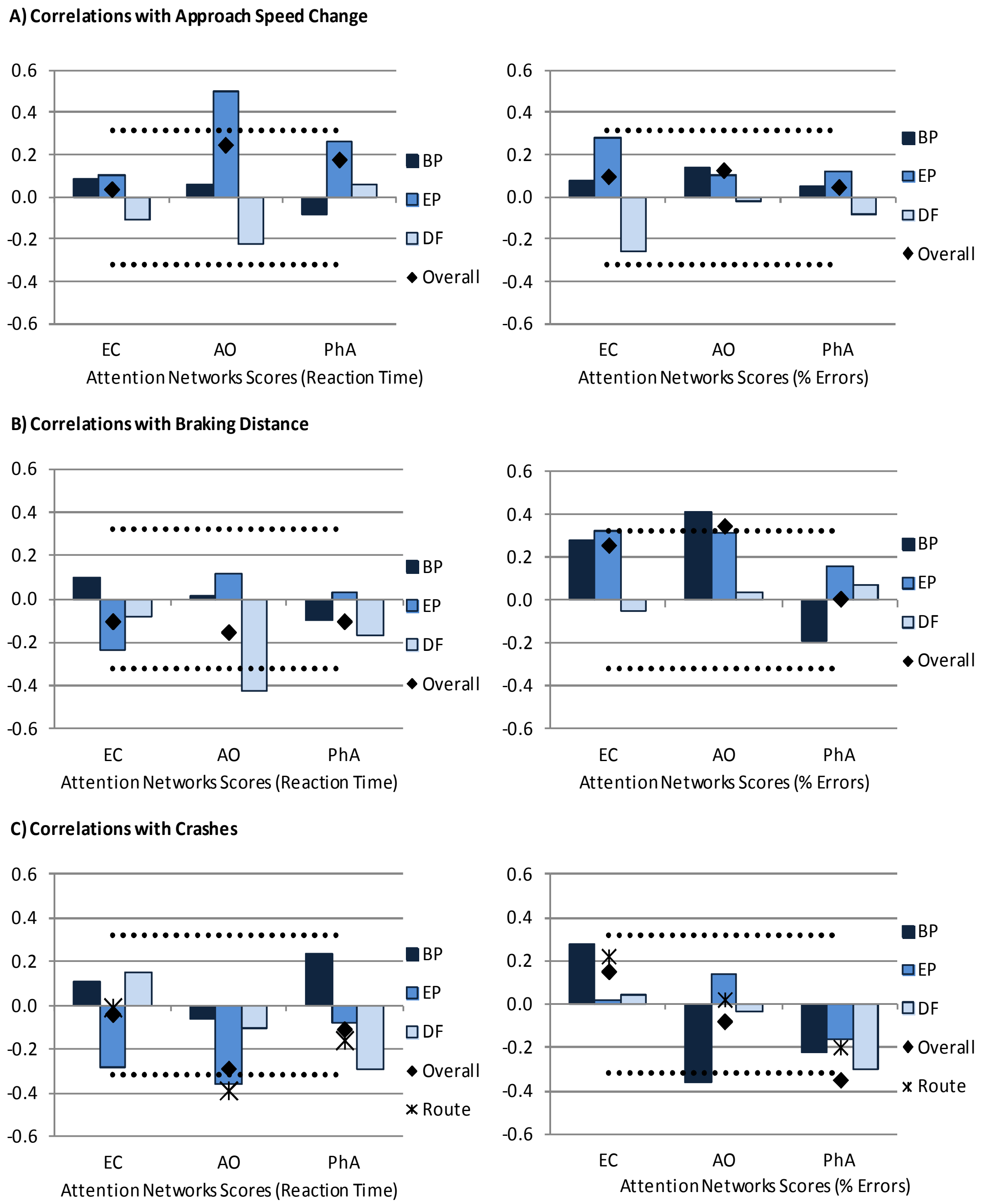


Figure 5.3: Correlations between the attentional networks scores (Executive Control, EC, Attentional Orientation, AO, and Phasic Alertness, PhA) and the driving performance measures: (A) Approach Speed Change; (B) Braking Distance; and (C) Crashes. On the left, attentional network scores in reaction time. On the right, attentional network scores in percentage (%) of errors. Separate results are shown for the three hazard categories (Behavioural Prediction, BP, Environmental Prediction, EP, and Dividing and Focusing Attention, DF), overall for the nine driving situations (Overall), and for the number of crashes along the whole route. The dotted lines (●●●●●) represent a correlation at the significance level (.05) for the null hypothesis of r = 0 and N = 38.

since AO score in ACC was predictive of overall braking distance ($F(1,36)=5.03$; $p=.03$; $R^2=.10$; $ß_{AO\text{-}\%error}=.35$) and braking distance in BP situations ($F(1,36)=7.08$; $p=.01$; $R^2=.14$; $ß_{AO\text{-}\%error}=.41$), and AO score in RT was predictive of braking distance in DF situations ($F(1,36)=8.28$; $p=.007$; $R^2=.16$; $ß_{AO\text{-}RT}=.-43$). No other attentional measure met the inclusion criteria in these regression analyses.

3.3.3. Crash frequency

First, a significant negative correlation was found between the number of crashes across the nine driving situations and the PhA score in percentage of errors ($r=-.35$; $p=.03$), and a regression analysis confirmed this association ($F(1,36)=4.87$; $R^2=.10$; $p=.03$; $ß_{PhA\text{-}\%error}=-.35$). These results suggest that participants who benefit most from warning signals in the ANTI–V may be less likely to crash in the hazardous situations. However, further analyses revealed that PhA score in percentage of errors failed to be individually correlated with any hazard category. Second, there was a significant negative correlation between the AO score in RT and the number of crashes over the whole route (i.e. inside and outside the hazard windows, $r=-.39$; $p=.02$) and an unconfirmed tendency was apparent with the number of crashes across the nine hazardous situations ($r=-.29$; $p=.08$). These results suggest that the greater influence of spatial cues in the ANTI–V may be associated with fewer crashes in the driving simulator. The regression analysis confirmed that the AO score in RT was predictive of the number of crashes over the whole route (and EC in percentage of errors also entered the final regression model; $F(2,35)=7.13$; $p=.003$; $R^2=.25$; $ß_{AO\text{-}RT}=-.52$; $ß_{EC\text{-}\%error}=.40$). The separate analyses for the hazard categories revealed that the overall correlations with AO score in RT could be mainly explained by the significant correlation in EP situations ($r=-.36$; $p=.03$), suggesting that those participants who were more intensely influenced by spatial cues in the ANTI–V had fewer crashes in EP situations. The regression model was also statistically significant ($F(1,36)=5.33$; $p=.03$; $R^2=.11$; $ß_{AO\text{-}RT}=-.36$). Finally, the AO score in percentage of errors was also correlated with the number of crashes in BP situations ($r=-.36$; $p=.03$), where a higher orienting score was associated with fewer crashes. The regression analysis confirmed the latter result (and overall percentage of errors and PhA in percentage of errors also entered the final model; $F(3,34)=7.29$; $p<.001$; $R^2=.34$; $ß_{overall\ \%error}=.48$; $ß_{AO\text{-}\%error}=-.36$; $ß_{PhA\text{-}\%error}=-.33$).

Regarding the relationship between the driving performance measures and the vigilance performance, Pearson's correlation indices are reported in

Figure 5.4. The percentage of hits and the sensitivity (*d'*) failed to be significantly correlated with the approach speed change, the braking distance or the number of crashes (although some notable tendencies were suggested, as can be viewed in Figure 5.4). The percentage of false alarms and the response bias were significantly correlated with the overall approach speed change (r=–.35; p=.03 and r=.37; p=.02, respectively). Separate analyses for each hazard category showed that the percentage of false alarms was significantly correlated with approach speed change in BP situations (r=–.42; p=.008), and there was a possible unconfirmed tendency with the response bias (r=.31; p=.06). Regression analyses revealed that the response bias was predictive of the overall approach speed ($F(1,36)=5.66$; p=.02; R^2=.11; $ß_{beta}$=.37) and the percentage of false alarms was predictive of the approach speed change in BP situations ($F(1,36)=7.91$; p=.008; R^2=.16; $ß_{beta}$=–.42).

3.4. Analysis of potential qualitative differences

Some of the results reported suggest the existence of potential qualitative differences in the relationship between the attention network scores and driving performance in the hazard categories, which means that a specific attentional score is positively correlated with one hazard category and negatively correlated with another. It should be noted that these qualitative differences, if confirmed, could partially explain the fact that overall correlations tend to be lower, since they summarise opposite tendencies.

To obtain some evidence of the potential existence of these qualitative differences, statistical tests for the difference of two correlations (H_0: r_1–r_2=0) were computed when: (a) the correlations between a specific attentional score and two different hazard categories had different signs; (b) at least one of the two correlations was statistically significant from zero (H_0: r=0).

For example, the correlations between AO score in RT and the approach speed change in EP and DF situations met these criteria (see Figure 5.3A), and their difference was statistically significant (r_1–r_2=.72; p=.001). Also, the correlation between AO score in RT and the braking distance in EP and DF situations was compared (see Figure 5.3B), and the difference was statistically significant (r_1–r_2=.55; p=.02). In addition, the differences in the correlations between AO score in percentage of errors and the number of crashes in BP and EP situations (see Figure 5.3C) were also statistically significant (r_1–r_2=.50; p=.03).

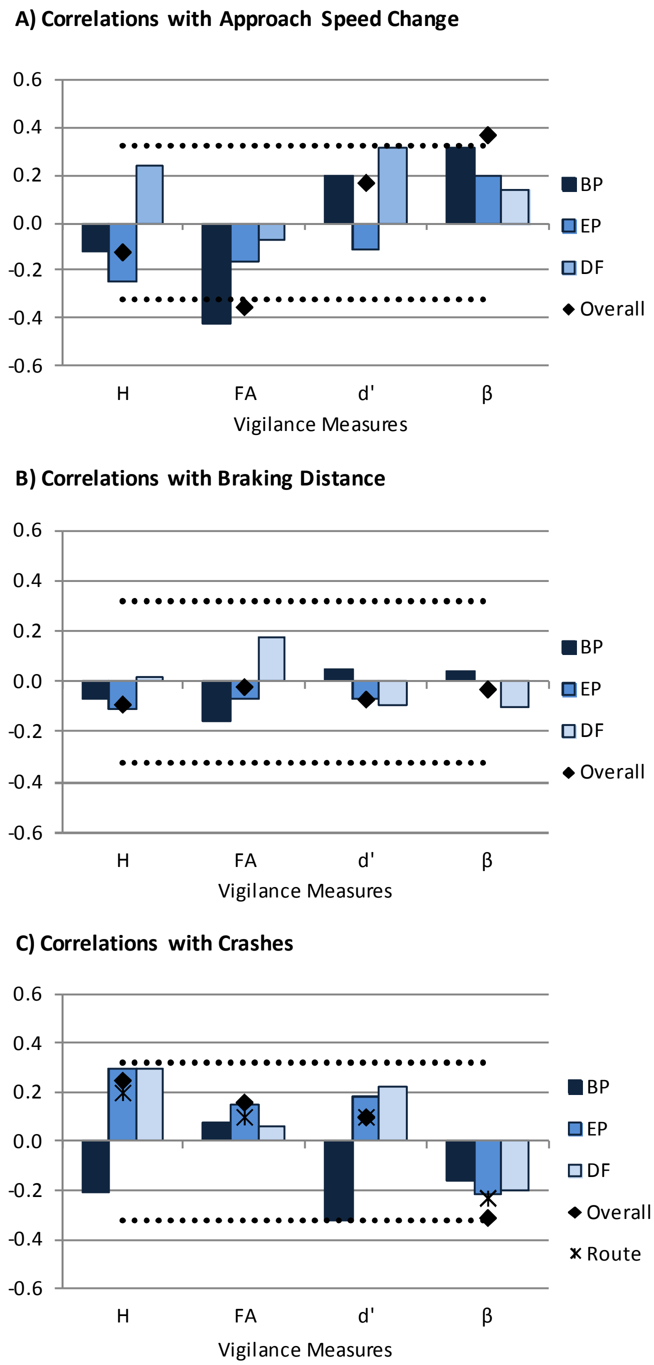


Figure 5.4: Correlations between the vigilance measures (hits, H, false alarms, FA, sensitivity, *d'*, and response bias, β) and the driving performance measures: (A) Approach Speed Change; (B) Braking Distance; and (C) Crashes. Separate results are shown for the three hazard categories (Behavioural Prediction, BP, Environmental Prediction, EP, and Dividing and Focusing Attention, DF), overall for the nine driving situations (Overall), and for the number of crashes along the whole route (Route). The dotted lines (●●●●●) represent a correlation at the significance level (.05) for the null hypothesis of $r = 0$ and N = 38.

4. DISCUSSION

The main objective of the present study was to analyse the relationship between individual differences in the functioning of the three attentional networks (executive control, attentional orienting and alerting) and drivers' behaviour. With this aim, individual measures of attentional functioning were obtained by using a single computer–based neurocognitive test (i.e., the Attention Networks Test for Interactions and Vigilance) and these were then compared with the participants' performance in a driving simulator where some common hazardous situations were found (for example, an unexpected car or a pedestrian crossing the driver's trajectory). In summary, whereas previous studies failed to find specific associations between the attentional functions and overall driving measures (Weaver et al., 2009), the correlation and linear regression analyses in the current work reveal some significant associations, for example, between attentional orienting and approach speed change, braking distance and the number of crashes while driving through the hazardous situations. Interestingly, some qualitative differences in the relationship of this attentional network and driving performance are suggested when considering the different types of hazardous situation (Behavioural Prediction, Environmental Prediction and Dividing and Focusing Attention hazards). In addition, partial evidence of a relationship between crash occurrence and the functioning of both the executive control and the alerting networks has been reported. According to these results, driving simulators presenting hazardous situations can be considered useful tools to study driving behaviour, and particularly the drivers' attentional functioning.

Overall, the data provided by the present study suggest that attentional orienting is the attentional score from the ANTI–V most clearly associated with driving performance when participants have to deal with the simulated hazardous situations. Using correlation and linear regression analyses, the AO score in RT was positively associated with the approach speed change in EP situations, and negatively with the number of crashes, both over the whole route and in EP situations. Also, the AO score in percentage of errors was positively associated with the braking distance, both overall and in BP situations, and negatively with the number of crashes in BP situations. In contrast, the AO score in RT was negatively associated with the braking distance in DF situations. As a consequence, these data suggest that those participants who were more intensely influenced by spatial cues in the ANTI–V tended to show safer driving behaviour when approaching EP hazards (greater speed reduction and fewer crashes) and BP hazards (earlier braking and less crashes), whereas their behaviour in DF situations could be more dangerous (delayed braking). In BP situations, the hazard source is visible before it becomes an actual hazard (for example, we can see the child before he steps outs in front of the car), and thus it can be used as a precursor, or a visual cue, to the location of the forthcoming hazard. In EP situations, the hazard source is concealed by a precursor in the environment (for example, an ice–cream van hiding a pedestrian about to cross), and it is also possible to identify this precursor as a visual cue to the location of the forthcoming hazard. Therefore, it is suggested that those participants with a higher ability to use their attention to give processing priority to events occurring in spatially cued areas may also use this ability in the traffic environment to quickly detect and more efficiently avoid a hazard source anticipated by a precursor. On the other hand, in DF situations there are multiple hazard sources and it is impossible to anticipate which one is going to become the actual hazard (for example, there are several cars approaching the crossroads but only one fails to give way). Thus, giving processing priority to a specific element in the traffic environment (for example, a car approaching from the left) will imply partially neglecting other potential hazard sources (for example, a car approaching from the right), and therefore more dangerous driving behaviour will be observed (for example, a delay in braking, as found in the current study). These results for the attentional orienting network are in agreement with previous studies on the role of visual attention while driving. For example, certain studies have shown that a computer–based test on visual attention (the Useful Field of Vision or UFoV) is sensitive in predicting risk for crash involvement, especially in older drivers (e.g., Ball et al., 1993; Ball et al., 2006). More specifically, Bédard et al. (2006) analysed the relationship between driving performance and the inhibition of return (IOR), a reflexive visual attention mechanism that prevents attention being re–allocated to a recently scanned location or object (see Klein, 2000, or Lupiáñez, Klein, & Bartolomeo, 2006, for reviews). They observed that IOR was associated with a measure of drivers' ability to scan the traffic environment effectively (the higher the IOR, the fewer the scanning errors). The IOR is observed only when there are long delays between the orienting cue and the relevant target and can be considered a result of the habituation of the attentional capture by the cue, so that the entire environment can be rapidly explored (Dukevich, 2009; Lupiáñez, 2010). Thus, our data are complementary to Bédard et al.'s study and suggest that orienting attention to potential hazard precursors makes it possible to cope with them in a better way, thus showing safer performance in the driving task. However, paying attention to all the potential precursors of hazards, when only one or some of them will in fact become hazards, could be more distracting than helpful to the driver. In these situations, it is still important to attend to the potential hazards, but it is also critical to habituate the attentional capture when they do not become a real risk. This would explain why both better attentional orienting (as in this study) and larger IOR (i.e., more habituation of attentional orienting, as in Bedard et al.'s study) are associated with safer driving performance. In addition, Underwood et al. (2011) reviewed different studies using eye–tracking technology in hazard perception situations and found convergent evidence to support that certain types of hazard are associated with a general reduction in the spread of visual search, with hazardous events eliciting longer fixations and less scanning of the traffic environment. Consistently with the findings in the current study, they claimed that, when a participant identifies a hazardous area, it is important that the information in this region is processed in depth and therefore there may be advantages in monitoring that location (as found in BP and EP situations); but there is also a potential danger in restricting visual search in situations where over–focusing the attention may prevent the viewer from noticing and processing potential hazards elsewhere in the traffic environment (as suggested for DF situations).

Partial evidence of a relationship between the functioning of the alerting network and crash occurrence has been found. First, the PhA score in percentage of errors was negatively associated with the number of crashes overall in the nine hazardous situations, and specifically in BP situations (although to find this association, the influence of the overall percentage of errors and the AO score had to be first controlled). These results, if further confirmed, may suggest that participants showing a higher alerting effect in the ANTI–V may be more able to avoid crashes in the driving simulator, especially in BP situations. The PhA score represents the benefit in performance obtained by using the warning signal to prepare to respond. Therefore, drivers approaching a BP situation might use the precursor (i.e., the vehicle waiting in a side road) as a warning signal that a hazardous event may arise. However, these results should be considered with caution, since no other driving performance indicator (such as the approach speed or the braking distance) was consistently associated with the PhA score. Previous evidence has shown the effectiveness of different driver warning devices, such as lane departure or collision avoidance warning systems to prevent road traffic accidents (for a review see May & Baldwin, 2009). For example, Lee, McGehee, Brown, & Reyes (2002) found that early warnings helped both distracted and undistracted drivers to show a quicker reaction and avoid more rear–end collisions than did late warnings or no warnings. Second, in relation to vigilance performance, no association was found in the current study between the percentage of hits or sensitivity and the driving performance measures. Vigilance is considered as an attentional component with a great influence on driving performance: a low–vigilance state has been previously associated with a worse driving performance and increased crash risk, for example, after sleep loss (e.g., Åkerstedt et al., 2011; Lal & Craig, 2001), or during prolonged driving, especially in monotonous driving situations (e.g., Campagne et al., 2004; Larue et al., 2011). Moreover, a worse vigilance performance in the ANTI–V has been significantly associated with a higher tendency to suffer attentional failures while driving as measured by the attentional lapses subscale in the DBQ (Roca, Lupiáñez et al., 2011). However, it should be noted that the participants in the current study were driving in a wakeful state (for example, they were neither sleep–deprived nor fatigued) and also that the driving task was very short (about 11 minutes) and in some ways stimulating (as several hazards were being encountered along the route). Therefore, it is probable that other studies manipulating the participants' state or using alternative driving situations (such as longer and monotonous itineraries) would be more appropriate to find an effect of individual differences in vigilance functioning on the driving measures.

Regarding the number of false alarms and the response bias in the ANTI–V, a significant association was found between these indices and the overall approach speed change, especially in BP situations. The participants with a more conservative response bias tend to be those changing their approach speed to a greater extent. According to Horne, Anderson and Wilkinson (1983), the response bias index can be considered as the "unwillingness" to respond positively to the vigilance task (the infrequent stimuli), and is usually interpreted as a motivational factor. Thus, we may say that the participants' behaviour in both tasks (the ANTI–V and the driving simulator task) could also be influenced by some motivational factors induced by the experimental setting.

In relation to the executive control network, partial evidence of a relationship between this attentional function and crash occurrence was found. The regression analysis computed from the attentional scores to predict the number of crashes over the whole route suggested a positive association with the EC score in percentage of errors, once the AO in RT had been introduced in the model. This result, if confirmed in further studies, may suggest that participants showing a higher congruency effect (and thus less cognitive control to ignore distracters) will tend to have more crashes in the driving simulator. However, as has also been claimed in relation to the alerting network, these results should be considered with care, since no other driving performance indicator was significantly associated with the EC score. Previous evidence has shown that individual differences in executive functions are associated with driving performance, both in younger (Mäntylä et al., 2009) and in older drivers (Adrian et al., 2011; Daigneault et al., 2002). For example, Mäntylä et al. (2009) evaluated different components of the executive function (response inhibition, working memory updating, and mental shifting) in fifty young participants (15–19 years old) and compared their performance in a simulated driving task (Lane Change Task). Their results revealed that participants with low performance in some of the executive function tests (i.e., working memory updating) also made greater errors in the simulated driving. However, the response inhibition tests (i.e., Stroop and *stop signal* tasks) were not consistently associated with driving performance, whereas in the current study we have observed that the EC score (measured as a congruency effect, which is a response inhibition task) was related to the number of crashes in a driving simulator task. Adrian et al. (2011) analysed the degree of association between executive function and on–road driving performance in a sample of older drivers (60 or over). Significant correlations were found between poor driving performance and low scores on tests assessing shifting and updating executive functions, but again inhibition was not related to driving performance. According to Adrian et al. (2011), a potential explanation for the lack of a significant association between inhibition and driving performance is that this executive function component is more related to specific situations like having to take emergency action. Thus, the hazardous situations used in the current study might be more appropriate to evaluate the relationship between inhibition and driving performance. Accordingly, Daigneault et al. (2002) compared executive functioning in two groups of older drivers, accident–free and with 3 or more accidents in the last 5 years, and found that participants in the latter group committed more errors in tasks reflecting mental rigidity (perseverative errors, flexibility problems, etc.) and had a poorer ability to plan for and solve problems. In particular, performance in the *Stroop Color World Test* was diminished in the accident group, suggesting that a lower ability to inhibit incongruent responses was associated with a higher accident involvement, which is consistent with our results with the EC score.

Previous evidence using the ANT found that overall RT was significantly associated with a driving performance measure (i.e., the Manitoba Road Test), but failed to find evidence of any association with the three attentional functions (Weaver et al., 2009). In contrast, the current study has successfully found specific associations between the attentional scores and different driving performance measures. We propose that this diverging evidence may be explained by analysing the differences between the two studies. First, the Manitoba Road Test used by Weaver et al. (2009) is a demerit–point system providing a general score by assessing infractions falling into five general categories (starting, stopping and reversing; signal violations, right of way, and inattention; moving onto a roadway; overtaking and speed; and turning). Consequently, it is possible that: (a) the driving performance measure obtained from the Manitoba Road Test was too general and unspecific to find a clear effect (since opposed tendencies in different driving situations might be lost after averaging); and (b) the traffic infractions observed were more clearly influenced by motivational or driving style factors than by the attentional functioning (for example, drivers who exceed speed limits are not generally distracted, but actually want to drive in that way). The current study, however, required the participants to drive through several specific hazardous situations in which the attentional functioning was an immediate factor in avoiding a crash, and therefore it should be considered more appropriate to evaluate the role played by the attentional system. Indeed, evidence supporting both aspects has been found. First, some qualitative differences in the relationship between the attention network scores and the hazard categories were suggested. This means that a specific attentional score can be positively associated with one hazard category and negatively associated with another, and thus a general (average) measure may hide or minimise a significant relationship, by summarising opposite tendencies. For example, the AO scores in EP and DF situations, for both the approach speed change and the braking distance, showed this pattern of association (opposed tendencies) and the differences between these correlations were statistically significant. As a consequence, it could be claimed that the relationship of the attentional networks might not be unidirectional in every possible traffic situation, and therefore an individual tendency to apply a specific attentional function (e.g., a higher attentional orienting score) could be helpful in some specific situations (e.g., EP hazards), whereas in some other cases it could be associated with a worse performance (e.g., DF hazards). Second, in spite of the existence of some qualitative differences, the current study also found some general associations between the attentional scores and overall driving performance measures (for example, between AO and both the number of crashes over the whole route and the overall braking distance, and also between PhA and the overall number of crashes), which suggests that the hazardous situations used in the current study, taken overall, were still sensitive to individual differences in attentional functioning. As a consequence, it is suggested that future studies exploring the role played by the attentional networks in driving behaviour would benefit from the use of simulated hazardous situations instead of measuring indices based on traffic infractions. Also, some previous studies have been successful in obtaining associations between attentional functioning and driving performance by analysing the drivers' ability to scan the traffic environment in real non-hazardous situations (Bédard et al., 2006).

Finally, the data obtained in the current study provide further evidence of the validity of hazard detection-based driver simulators, such as the FAROS GB3 used in this study. Underwood et al. (2011) reviewed different eye-tracking studies and found similar patterns of behaviour in participants driving on the road, watching hazard perception movies, and also in driving simulators presenting hazardous traffic situations. For example, in these three research contexts, more experienced drivers searched the roadway more and had shorter eye fixations than less experienced drivers. This provided evidence for relative validity (i.e., similar patterns of behaviour, as proposed by Godley, Triggs, & Fildes, 2002; whereas absolute validity would imply, for example, driving at similar speeds in both real and simulated situations). In addition, the associations reported in the present study between the attentional indices from the ANTI–V and performance in the driving simulator suggest that the latter is able to tackle important cognitive components of real driving (i.e. the attentional functions of executive control, attentional orienting and alertness, as discussed above). As a consequence, it might be suggested that driving simulators presenting hazardous situations can be considered useful tools to study driving behaviour and, particularly, drivers' attentional functioning.

4.1. Conclusions and future directions

The present study has been successful in obtaining evidence to show that individual measures in attentional functioning (executive control, attentional orienting, phasic and tonic alertness) could be associated with simulated driving performance. In particular, a higher score in attentional orienting has been associated with a safer driving performance in situations where there is a single precursor anticipating the hazard source (Behavioural Prediction and Environmental Prediction hazards), whereas in situations where there are multiple potential hazards (and thus it is not clear which one is going to be the actual hazard) higher orienting scores are associated with delayed braking (Dividing and Focusing Attention hazards). In consequence, it is suggested that participants with a higher ability to use their attention to prioritise events occurring in spatially cued areas may also use this ability in the traffic environment to quickly detect and more efficiently avoid a hazard source anticipated by a precursor. On the other hand, in complex hazardous situations, giving processing priority to a specific element in the traffic environment will imply partially neglecting other potential hazard sources. Future research to establish a direct link between attentional orienting functioning and the detection of a hazard in these driving situations would be useful, since the current study was mainly aimed at analysing the associations between individual differences. Also, partial evidence of a relationship between crash occurrence and the functioning of both the executive control and the alerting networks has been reported, and these results should be further explored, for example, using alternative driving situations where these attentional functions are essential to avoid crashing. Finally, it is suggested that future studies aimed at analysing drivers' attentional behaviour should avoid overall performance measures and focus their analyses on specific driving situations, such as common hazardous situations, as in the current work. With respect to this, it should be noted that the hazard taxonomy proposed by Crundall and collaborators (Crundall et al., 2010, in press) was not initially intended to analyse attentional functioning. Therefore it is possible that alternative situations or different categories to those used in the current study would be more effective to observe the effects of the attentional functions on driving performance. Further research aimed at identifying such driving situations and categories would be helpful to better understand the role that each attentional network (executive control, attentional orienting and alerting) play in safe driving, and thus to develop efficient countermeasures to reduce attention–related crashes.

CAPÍTULO 6 CHAPTER

DISCUSIÓN GENERAL

GENERAL DISCUSSION

The main objectives of this doctoral dissertation are first to develop a version of the Attention Networks Test that includes a direct measure of vigilance and then to analyse the influence of the different attentional functions (executive control, attentional orienting and both phasic and tonic alertness) on driving behaviour. Overall, the evidence gathered in the four studies described above suggests that these objectives may have been fulfilled, since research with the task developed (the Attention Network Test for Interactions and Vigilance or ANTI–V) showed that it was suitable for obtaining valid vigilance indices in addition to the usual attentional scores and particularly because these measures have been associated with different driver behaviour outcomes (such as the self–informed Driver Behaviour Questionnaire and performance in a driving simulator presenting hazardous traffic situations). In this last section, the main results will be summarised and discussion will be extended transversally, by topic rather than by study, raising some further points beyond those discussed individually in each of the previous studies. In addition, some considerations about potential applications of the results and future research topics will be highlighted.

1. MEASURING ATTENTIONAL FUNCTIONING WITH THE ANTI-V

1.1. The attentional scores

Overall, data in this doctoral dissertation supports the idea that it is possible to measure the functioning of the three attentional networks (executive control, attentional orienting and alertness) using a quick and easy computer task (e.g., Callejas, Lupiáñez & Tudela, 2004; Fan, McCandliss, Sommer, Raz & Posner, 2002). Usable indices of the functioning of executive control, attentional orienting, phasic and tonic (vigilance) alertness have been obtained in the four studies. To facilitate comparison with other researchers' data, Table 6.1 summarises the attentional scores in these studies. In addition, since the four studies used a comparable ANTI–V version and a similar sample composition (mainly young university students), all the participants' data have been aggregated to increase the robustness of the ANTI–V results with a bigger sample size (n = 216; see Appendix C).

Evidence supporting the validity of the executive control, attentional orienting and phasic alertness scores has been provided elsewhere for the ANT and the ANTI (see, for example, Fan et al., 2002; Fan, McCandliss, Fossella, Flombaum & Posner, 2005; Posner, 2008). Regarding the vigilance performance indices in the ANTI–V, we observed in Study 2 that they are affected in the expected direction by 24–hour sleep deprivation: the percentage of hits and the sensitivity (*d'*) were significantly lower after sleep loss. These results were accompanied by slower RT and an increased percentage of errors, which suggests that the change in the vigilance indices was not explained better by participants' use of a different strategy to perform the task (e.g., some

	Study 1	Study 2	Study 3	Study 4	Weighted mean
a) Attentional scores: RT (ms)					
Executive control	66 (23)	51 (24)	59 (29)	73 (41)	62 (30)
Attentional orienting	44 (26)	39 (20)	45 (27)	42 (34)	44 (27)
Phasic alertness	34 (30)	30 (31)	44 (39)	40 (38)	39 (36)
b) Attentional scores: % errors					
Executive control	1.5 (2.8)	1.5 (2.9)	1.6 (2.2)	1.5 (2.3)	1.5 (2.4)
Attentional orienting	1.0 (3.0)	1.1 (2.5)	1.2 (2.2)	0.8 (2.8)	1.1 (2.6)
Phasic alertness	1.3 (3.3)	1.2 (3.4)	1.8 (3.7)	1.7 (3.1)	1.6 (3.4)
c) Vigilance measures (SDT)					
Hits (%)	55 (20)	55 (19)	59 (18)	56 (16)	57 (18)
False Alarms (%)	3.4 (3.4)	2.8 (2.9)	3.7 (3.9)	2.6 (2.7)	3.3 (3.5)
Sensitivity (*d'*)	2.1 (0.5)	2.1 (0.6)	2.2 (0.5)	2.2 (0.4)	2.2 (0.5)
Response Bias (β)	7.6 (4.7)	8.4 (4.1)	7.6 (4.6)	9.0 (4.6)	7.9 (4.6)
d) Global results					
ANTI RT (ms)	636 (88)	638 (78)	689 (101)	655 (82)	664 (95)
ANTI % errors	2.2 (2.0)	3.2 (3.1)	2.2 (1.9)	1.7 (1.7)	2.2 (2.1)
Sample size (N)	53	25	99	39	216

Table 6.1: Summary of the attentional measures in the four studies that constitute the current doctoral dissertation: Mean and standard deviation (between parentheses) are shown for: a) Attentional scores in reaction time (executive control, attentional orienting, and phasic alertness); b) Attentional scores in percentage of errors; c) Vigilance measures (hits, false alarms, sensitivity–*d'*, and response bias–β); and d) Global results (reaction time, percentage of errors, and sample size). Also, data in the four studies have been aggregated (see Appendix C for detailed information) and overall results are shown in the last column (weighted mean).

participants might have responded more slowly to be more accurate, and thus fewer errors would have been observed). Besides, results in this study confirm that sleep deprivation succeeded in reducing the vigilance level (e.g., slower RT, more errors, increased RT variability and higher subjective vigilance). Therefore, we would claim that hits and sensitivity in the ANTI–V should be considered valid vigilance indices, and could thus be helpful to researchers interested in measuring vigilance as well as the usual executive control, attentional orienting and phasic alertness scores.

In addition, some of the results in this doctoral dissertation discourage the use of other indirect vigilance indices previously proposed for the ANT or the ANTI tasks, such as global RT, no–cue RT or the difference between global RT in the last and the first blocks. As discussed in Study 1, none of the alternative vigilance indices were closely correlated with the direct vigilance measure in the ANTI–V. Only global indices (overall RT and ACC, and overall RT obtained from no tone and no cue conditions) were moderately correlated with hits and sensitivity. But the tendency of these correlations (positive for reaction time and negative for errors) suggested that the indices might indeed be reflecting different strategies to perform the task (e.g., some participants tend to respond more slowly in order to be more accurate in both subtasks, i.e. the ANTI and the vigilance task). This is consistent with Posner (2008), who claimed that reaction time and accuracy should be inspected carefully when comparing groups with the ANT, for the same reasons adduced here.

Additionally, the main correlations of Study 1 were found again in Study 2 and also in the complementary analysis with the whole sample (see Appendix C, Table C2): Correlations with a direct measure of vigilance were only moderate for the global measures, the same tendencies in the correlations were observed and, after partialling out the influence of the global RT and ACC, no other alternative index was associated with hits or sensitivity.

1.2. Main effects and network interactions

Main effects of congruency, visual cue and warning signal were significant in the four studies using the ANTI–V. Also, a similar pattern of interactions was found (Warning signal X Visual cue and Visual cue X Congruency interactions were statistically significant, whereas Warning signal X Congruency and the second order interaction were not), although some minor differences were reported (see, for example, Study 2 and Study 3). In this respect, the complementary analysis that aggregates data in the four studies confirms the pattern of main effects and interactions described, with the exception of Validity x Warning (F(1,215)=0.10; p=.76; η^2<.001) and the Warning X Congruency interaction (F(1,215)=7.17; p=.008; η^2=.32), both in percentage of errors. The latter interaction is statistically significant in this analysis, suggesting that the congruency effect is smaller after a warning tone (0.95%) as compared to the no tone condition (1.90%).

It should be noted that, using the ANTI, a higher congruency effect is generally observed when a warning signal has been presented (e.g., Callejas et al., 2004). However, as argued in Study 1, the vigilance task embedded in the ANTI–V may have increased the need for cognitive control, and thus the congruency effect is lower with and without a warning signal (as compared, for example, with the ANTI). In addition, the complementary analysis described here reveals that the warning signal in the ANTI–V may even help the participants ignore the incongruent flankers, since they commit fewer errors after the tone. In this regard, the different pattern of results points to some important differences in the way the ANTI and ANTI–V manipulate phasic alertness. Generally, after a warning signal that increases participant alertness, a trade–off between speed and accuracy is found (faster reaction time but more errors; Posner & Petersen, 1990), and this effect has been observed with both the ANT (Fan et al., 2002) and the ANTI (Callejas et al., 2004). In contrast, in the four studies with the ANTI–V, presenting a warning tone produced faster reaction times and fewer errors (an average reduction of 39 ms and 1.6% of errors was found, see Table 6.1). The ANTI–V is a more demanding task than the ANT or the ANTI, and overall reaction time is usually slower. As a consequence the participants take more time to correctly classify the target stimuli, even when a warning tone has been presented. Thus the phasic alertness manipulation in the ANTI–V is probably reflecting a *temporal preparation* to respond rather than an increase in the participant's alertness level (and thus performance in both reaction time, RT, and accuracy, ACC, may be improved). This suggestion might account for some of the differences in results reported between the ANTI–V and earlier versions of the task in relation to the phasic alertness manipulation and its interactions (for example, the above–mentioned interactions in percentage of errors). Future researchers may be interested in further analysing the different aspects of phasic alertness covered by the ANT, the ANTI and the ANTI–V, for example, by manipulating the difficulty of the task, the predictiveness of the warning signal and/or the

SOA between the warning signal and the target (especially with predictive signals).

2. THE THREE ATTENTIONAL NETWORKS

2.1. The executive control network

Executive control functioning is assessed in the ANTI–V by analysing the congruency effect, which is observed after presenting trials with congruent and incongruent stimuli, and then analysing the difference in average RT and ACC (e.g., Callejas et al., 2004; Fan et al., 2002). When an incongruent trial is presented, cognitive control is required to ignore the flanking distracters and respond to the central target. In consequence, a higher executive control score (incongruent minus congruent trials) represents greater interference (less cognitive control). From the data in this doctoral dissertation, some significant results involving executive control have been found, and they will now be summarised.

First, in Study 1, the executive control score was apparently associated with vigilance performance, since there was a positive correlation with hits using RT data and a negative correlation with sensitivity using ACC. However, this association vanished after using partial correlations to control for the influence of global RT and ACC. Similar results were found in the complementary analysis using the whole sample (see Appendix C, Table C3). Therefore, these results are consistent with the idea that global measures reflect different attitudes toward the task (some participants tend to respond more slowly so as to make fewer errors, and thus they take more time to discard the distracters and also identify the vigilance target more efficiently) and suggest that global RT and ACC have to be carefully considered when using the ANTI–V (and perhaps also when using other versions of the test such as the ANT or the ANTI).

The second study in this doctoral dissertation failed to find a sleep deprivation effect on the executive control score using the ANTI–V. The literature on the influence of sleep loss on this network has shown inconsistent results (see, for example, Killgore, 2010). Our results suggest that sleep deprivation has no influence on the congruency effect measured by the ANTI–V, and this may be inconsistent with previous studies using the ANT (Martella, Casagrande & Lupiáñez, 2011), where a higher congruency effect (more interference) was found after sleep loss. However, the ANTI–V, when compared to the ANT, requires a further attentional component (the vigilance task) and the need for cognitive control is increased to adequately distinguish the different types of stimuli (as discussed in Study 1). Therefore, the increased demands on cognitive control as a result of the extra vigilance task may have partially compensated for the effect of sleep deprivation on the executive control score, so that larger interference was no more observed (consistently, Baulk, Reyner & Horne, 2001, found that adding a secondary reaction time task provided more activity and stimulation for sleepy drivers during a monotonous drive, and as a consequence their performance was improved). Also, these results could be ascribed to a high inter-subject variability in the effects of sleep loss (Banks & Dinges, 2007; Bell-McGinty et al., 2004; Van Dongen, Baynard, Maislin & Dinges, 2004). Further research would be useful to clarify the influence of sleep loss and executive functions.

No significant correlations were found between the executive control scores in the ANTI-V and the Driver Behaviour Questionnaire (DBQ) or the Cognitive Failures Questionnaire (CFQ), which suggests that the psychological constructs measured by these self-informed scales may be unrelated to (or only loosely associated with) the executive function. However, there was an unconfirmed tendency in the correlation of executive control score in errors with the DBQ-Violations subscale, and the (non-significant) correlation indices with DBQ-Aggressiveness were above .20, which suggest that stronger correlations might still be found in future studies using, for example, alternative executive control measures (such as mental set shifting and information updating tasks, or measures of inhibition with stop-signal paradigms), other driving behaviour measures (e.g., hazardous traffic situations) or perhaps by applying more powerful statistical analyses. In fact, partial evidence of a relationship between this attentional function and crash occurrence in the driving simulator was found in Study 4. Regression analysis suggested a positive association between the executive control score in percentage of errors and the number of crashes over the driving itinerary (the higher the congruency effect, the more crashes). However, these results should be considered with care, since no other driving performance indicator (such as approach speed or braking behaviour) was significantly associated with the executive control score in this study.

Previous evidence has shown that individual differences in some executive functions (for example, shifting and updating tasks) are associated with driving performance, both in younger (Mäntylä, Karlsson & Marklund, 2009) and older drivers (Adrian, Postal, Moessinger, Rascle & Charles, 2011). However, the response inhibition tests (such as Stroop and *stop signal* tasks) were not consistently associated with driving performance in these studies. According to Adrian et al. (2011), a potential explanation for the lack of a significant association between inhibition and driving performance in their study is that this executive function component is more related to specific situations like having to take emergency action. Thus, the hazardous situations used in the current study might be more appropriate to evaluate the relationship between inhibition and driving performance. Consistently with our results with the executive control score, Daigneault, Joly and Frigon (2002) observed that a higher accident involvement in older drivers was associated with a lower ability to inhibit incongruent responses. Also, López–Ramón, Castro, Roca, Ledesma and Lupiáñez (2011), using the ANTI, found a reduced congruency effect (less interference of incongruent stimuli) in drivers with a higher proneness to attentional lapses while driving (although this result was only observed with valid peripheral cues, suggesting a different modulation between orienting and executive control functions in these drivers).

2.2. The attentional orienting network

The attentional orienting function is assessed in the ANTI–V by presenting non–predictive peripheral spatial cues (valid, invalid and no cue conditions with equal probability) and then observing the difference in average RT and ACC between these experimental conditions. Valid spatial cues help the participants to automatically focus their attention on the forthcoming target, and thus the difference in performance between valid and no cue conditions is considered a measure of the benefits of orienting attention. Invalid spatial cues automatically focus the participants' attention on a wrong location, and thus the difference between invalid and no cue conditions is used as a measure of the costs of reorienting attention. Finally, the difference between invalid and valid conditions is generally used to assess the participants' orienting functioning, including both costs and benefits: a higher score means a greater influence of non–predictive peripheral (thus automatic) spatial cues.

The attentional orienting score was associated with vigilance in Study 1. A positive correlation with sensitivity was revealed using RT data, once the influence of the global measures was partialled out. Participants with a higher orienting score were slightly more able to detect the infrequent stimuli in the vigilance task. Note that detecting the displaced target in the ANTI–V requires attention, and therefore participants better at orienting their attention might benefit when detecting the infrequent displaced targets. However, these results should be considered with caution, since the complementary analysis using the whole sample failed to find a significant correlation between attentional orienting and vigilance (see Appendix C, Table C3). If confirmed, these results may suggest that boosting attentional orienting could potentially be a way to increase vigilance performance, which may be useful in some applied research contexts. For example, different driving behaviour studies (see May & Balwin, 2009; Tejero–Gimeno, Pastor–Cerezuela & Chóliz–Montañés, 2006, for reviews) have analysed the effect of increasing the alertness level to improve performance in drivers with reduced vigilance (e.g., drowsy drivers) by using warning signals, secondary tasks or stimulant drugs (mainly caffeine). According to our results in Study 1, improving the functioning of the attentional orienting system could be a complementary way to improve vigilance performance, since it may help drivers to successfully scan the traffic environment and use their remaining attentional resources on identifying immediate hazards.

Evidence in Study 2 supports the latter suggestion and further explores the interactions between the orienting score and tonic alertness. In this study, the reorienting costs of having an invalid spatial cue (invalid minus no cue trials) were reduced under sleep deprivation, whereas the benefits of presenting a valid spatial cue (valid minus no cue trials) tended to be slightly higher (although this difference was not statistically significant). After considering these data and the evidence in previous research (e.g., Casagrande, Martella, DiPace, Pirri & Guadalupi, 2006; Lasaponara, Chica, Lecce, Lupiáñez & Doricchi, 2011; Martella et al., 2011; Trujillo, Kornguth & Schnyer, 2009; Versace, Cavallero, De Min Tona, Mozzato & Stegagno, 2006), it was proposed that using peripheral valid cues is more helpful after sleep loss, compensating for the general increase in RT. Thus, a reduced tonic alertness may be more detrimental to the voluntary, endogenous components of attentional orienting (usually associated with central cues and, according to Lasaponara et al., 2011, also with reorienting costs) while the automatic, exogenous components (peripheral cues and orienting benefits) will be more resistant.

Results in Study 3 showed that participants with a greater tendency to make minor mistakes in everyday life (i.e., a higher CFQ score) were associated with increased reorienting costs: all the participants showed a similar performance after valid spatial cues (thus similar benefits), but those with a higher CFQ found more problems in disengaging from the erroneous spatial location and moving their attentional focus towards the target location when presented with invalid cues (thus costs were more affected) (see also Ishigami & Klein, 2009). As a consequence, it can be suggested that potential countermeasures against the vigilance decrement based on the attentional orienting function may be more effective if automatic exogenous orienting, rather than voluntary endogenous orienting, is applied or facilitated.

Finally, the evidence gathered in Study 4 extends the previous suggestions on attentional orienting and tonic alertness to other driving situations and also raises an important caveat to be considered. In this study, normal (non sleep–deprived) participants drove through an itinerary where nine hazardous situations were triggered. Data suggest that those participants who were more influenced by spatial cues in the ANTI–V (higher orienting score) tended to show safer driving behaviour when approaching Environmental Prediction hazards (greater speed reduction and fewer crashes) and Behavioural Prediction hazards (earlier braking and fewer crashes), whereas their behaviour in Dividing and Focusing situations could be more dangerous (delayed braking). In the former hazardous situations (Environmental and Behavioural Prediction), there is a single precursor that might be used as a visual cue for the location of the forthcoming hazard, whereas in the latter situation (Dividing and Focusing) there are multiple hazard sources and it is impossible to anticipate which is going to become the actual hazard (and thus focusing attention on one element in the traffic environment will imply partially neglecting other potential hazard sources). Although a direct link between attentional behaviour and the detection of a hazard in these driving situations would be useful to complement these findings, the results are in agreement with previous studies on the role of visual attention while driving (for example, as will be discussed later in this section, Underwood, Crundall & Chapman, 2011; Bédard et al., 2006). As a consequence, a higher attentional orienting score may be associated with safer driving behaviour in a number of traffic situations, but it could also lead to driver distraction in complex situations where the most immediate hazard cannot be clearly identified. Therefore, the use of potential countermeasures to improve driving performance, based on the orienting system (e.g., with low–

vigilance drivers or in hazardous situations) should be carefully considered, but these would have to be applied quite specifically. For example, an Advanced Driver Assistance System (ADAS) could use video image processing and/or other sensors to help drivers allocate their attention to particular dangers in specific situations, such as a preceding vehicle braking hard or a distracted pedestrian about to invade the driver's trajectory (see Figure 6.1). With regard to this, if, as discussed above, automatic exogenous orienting might be more effective to compensate the vigilance decrement, then we should consider this kind of ADAS using peripheral cues (e.g., spatial cues shown on the windshield or in a head-up display) rather than central cues (e.g., a particular sign on the dashboard giving spatial information). Future research would be useful to confirm or discard the possibilities offered by these suggestions.

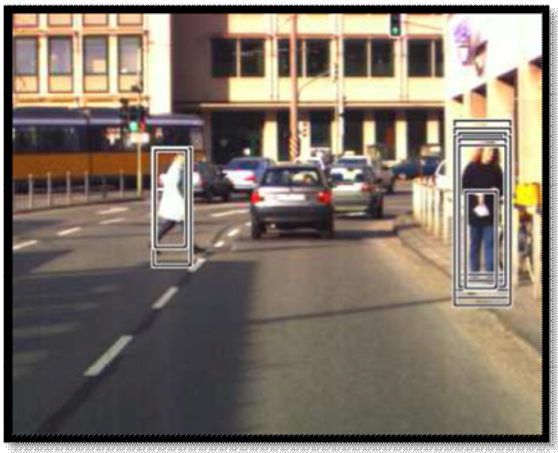


Figure 6.1: Digital video image processing can be used to identify moving pedestrians within a traffic scene. Adapted from Papageorgiou and Poggio (2000).

2.3. The alerting network

The ANTI–V takes two complementary measurements of the functioning of the alerting network. First, as in the original ANT version, phasic alertness is analysed by comparing performance (average RT and ACC) with a warning signal to when the signal is absent. In particular, the ANTI–V uses a strategy similar to that of the ANTI, where a warning tone is used as a warning signal (instead of a visual cue), and thus the alerting and the orienting indices can be assessed more independently (see Callejas et al., 2004). A higher phasic alertness score (no tone minus tone conditions) implies a greater benefit from having a warning signal. In addition, some authors have highlighted the importance of examining tonic alertness or vigilance when assessing the functioning of the three attentional networks (e.g., López–Ramón et al., 2011; Posner, 2008; Weaver, Bédard, McAuliffe & Parkkari, 2009). Following these suggestions, a secondary vigilance task was embedded in the ANTI–V. As described in Study 1 and Study 2, this task required the participants to detect some infrequent, uncertain, unpredictable stimuli in some of the trials while doing the standard ANTI in the remaining most frequent trials. The Signal Detection Theory indices of sensitivity (d') and response bias (β) were then computed from hits (proportion of correct identifications of infrequent targets) and false alarms (proportion of incorrect identifications of infrequent targets).

The influence of the phasic and tonic components of the alerting network were analysed in the sleep deprivation study (Study 2). In both sleep conditions, a warning signal induced faster reaction times and fewer errors. However, after sleep loss, the phasic alertness effect was smaller in RT (17 ms vs. 35 ms) but clearly higher in errors (5.2% vs. 0.72%). Previous research with the ANT (Martella et al., 2011; Trujillo et al., 2009) failed to find a sleep deprivation effect on the phasic alertness indices. However, the ANTI–V uses an auditory signal instead of a visual warning and it has been suggested that auditory alerting cues produce more automatic alerting than do visual cues and thus they might serve to aid the reliability of the alerting manipulation (Fan et al., 2002). In addition, we have already discussed the fact that automatic components of attentional orienting may be more resistant to the effects of sleep deprivation (and thus they are more effective after sleep loss), and something similar may occur with automatic alerting. Therefore, the results with auditory warning signals indicate that, under reduced vigilance, a warning tone might be helpful to increase participants' alertness, which would result in a slightly faster RT and, particularly, in fewer errors. In addition, it should be noted that in this doctoral dissertation, the complementary analyses using the whole sample revealed an unconfirmed negative tendency in the correlation between sensitivity and phasic alertness score in RT ($r = -.13$, $p = .06$, after controlling for the effect of the global measures; see Appendix C, Table C3). Participants showing lower sensitivity in the vigilance task may tend to obtain higher phasic alerting scores, which would be consistent with the suggestion that warning signals could be more effective with reduced tonic alertness and partially compensate for its negative effects (see for example, López Ramón et al., 2011; Miró et al., 2011).

No significant correlations were found between the phasic alertness scores in the ANTI–V and the Driver Behaviour Questionnaire (DBQ) or the Cognitive Failure Questionnaire (CFQ) in Study 3. Previous evidence using the

ANTI and an alternative questionnaire to measure drivers' failures of attention (ARDES) suggested that this measure was associated with the alerting network, since participants with higher ARDES scores also obtained a higher phasic alertness effect (López–Ramón et al., 2011). An association with the alerting network was also found using the DBQ–Lapses factor (particularly with tonic alertness, as discussed below), but the correlation with phasic alertness was non–significant (the indices in RT were above .20 for DBQ–Lapses and DBQ–Errors, but they failed to reach the significance level). Also, Ishigami and Klein (2009) used the ANTI and found that the CFQ–Total was associated with the phasic alertness score. The ANTI–V manipulates phasic alertness in a similar way to the ANTI (using a warning tone), and thus similar patterns of correlation with DBQ and CFQ were expected. However, as discussed above, it is also possible that the phasic alertness manipulation in the ANTI and the ANTI–V tackle slightly different aspects of attentional alerting: the usual trade–off in alertness between speed and accuracy is generally observed with the ANTI (and a warning tone produces faster RT but more errors), whereas it is absent in the ANTI–V (faster RT and fewer errors). Thus, the phasic alertness manipulation in the ANTI–V is probably reflecting more the controlled aspect of alertness (i.e. *temporal preparation* to respond) rather than an overall increase in the participant's alertness level and this may account for some of the differences in results reported between the ANTI–V and some other versions of the task.

Finally, some evidence of an association between individual differences in the phasic alertness score and driving performance was found in Study 4. The phasic alertness score in percentage of errors was negatively associated with the number of crashes overall in the nine hazardous situations, and specifically in Behavioral Prediction situations. These results may suggest that participants showing a higher alerting effect in the ANTI–V (and thus obtaining greater benefit from a warning signal) may be better able to avoid crashes in the driving simulator, especially in BP situations (perhaps because they use the precursor as a warning signal). However, these results should be considered with caution, since no other driving performance indicator was consistently associated with the phasic alertness score. Yet, previous evidence has shown the feasibility of different driver warning devices, such as lane departure or collision avoidance warning systems, to prevent road traffic accidents (see, for example, Fort et al., 2011; Lee, McGehee, Brown & Reyes, 2002; May & Baldwin, 2009). As a consequence, it might be suggested that future studies should analyse the role of phasic alertness using alternative driving situations where a greater influence of phasic alertness would be expected (e.g., a braking light indicating that a lead vehicle is suddenly stopping).

Regarding tonic alertness, one of the main results in this doctoral dissertation is that the ANTI–V was successful in obtaining a vigilance measure in addition to the usual executive control, attentional orienting and phasic alertness scores. As previously discussed in this section, usable vigilance indices were obtained in the four studies and these indices were influenced in the expected direction by sleep deprivation. The results were not explained better by a difference in attitude towards the task and, moreover, some findings discourage the use of other indirect vigilance indices previously proposed for the ANT or the ANTI tasks, such as global RT, no–cue RT or the difference between global RT in the last and first blocks.

The relationships between the vigilance indices and the executive control, attentional orienting and phasic alertness scores have been discussed in the previous sections corresponding to each network (for example, some evidence suggesting that low vigilance may be associated with a higher phasic alerting score has been provided above). In addition, a significant association between the vigilance indices and the DBQ was found in Study 3. A higher score in the attentional lapses subscale of the DBQ was negatively correlated with hits and sensitivity in the vigilance subtask from the ANTI–V. This suggests that a higher self–informed tendency to suffer attentional lapses while driving is associated with a worse attentional performance, specifically with a reduced tonic alertness or vigilance. Consequently, the results support the idea that the DBQ–Lapses factor may be related to driving inattention which, if confirmed in further studies, suggests that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour.

In contrast, no association was found in Study 4 between the percentage of hits or the sensitivity and performance measures from the driving simulator. Vigilance is considered to be an attentional component with a strong influence on driving performance (e.g., Åkerstedt, Philip, Capelli & Kecklund, 2011; Campagne, Pebayle & Muzet, 2004; Lal & Craig, 2001; Larue, Rakotonirainy & Pettitt, 2011). However, it should be noted that the participants in this study were driving in a wakeful state (for example, they were neither sleep–deprived nor fatigued) and also that the driving task was very short (about 11 minutes) and in some ways stimulating (as several hazards were being encountered along the route). Therefore, it is probable that other studies manipulating the participants' state or using alternative driving situations (such as longer and monotonous itineraries) would be more appropriate to find an effect of individual differences in vigilance functioning on the driving measures.

3. THE DRIVING BEHAVIOUR MEASURES

3.1. The Driver Behaviour Questionnaire

The Driver Behaviour Questionnaire (DBQ) is one of the most widely used research tools available to traffic researchers to obtain information about drivers' aberrant behaviour. The original version (Reason, Manstead, Stradling, Baxter & Campbell, 1990) includes an attentional lapses subscale that can be applied by road traffic researchers and practitioners to analyse the driver distraction and inattention phenomenon and its potential countermeasures. The current doctoral dissertation provides some useful data to discuss the construct validity of the DBQ–Lapses subscale by analysing its potential association with attentional functioning (ANTI–V) and cognitive failure (Cognitive Failures Questionnaire, CFQ). In particular, it was found in Study 3 that those participants who reported more attentional lapses while driving (higher DBQ–Lapses score) tended to be those with a worse vigilance performance (fewer hits and lower sensitivity in the ANTI–V) and with more self–reported cognitive failures in everyday life (higher CFQ score). Other DBQ subscales (errors, violations and aggressive behaviours) were not related to vigilance or any other attentional index in this study, and their relationship with cognitive failure was more moderate (with the exception of the DBQ–Errors factor, which was also highly correlated). As has been discussed above, the ANTI–V is based on a solid neurocognitive model of human attention and thus we think it is more appropriate for evaluating the participants' attentional performance (compared, for example, to some self–informed attentional questionnaires that have been also related to DBQ scores, such as the Differential Attention Processes Inventory; see Wickens, Toplak & Wiesenthal, 2008). Nonetheless, further research would be useful to clarify whether or not the DBQ factors are influenced by other attentional and cognitive functions.

Overall, the results with the DBQ are consistent with the idea that the attentional lapses subscale is related to driver distraction and inattention. If confirmed in further studies, it may suggest that this subscale could be a useful tool in road safety research to study vigilance–related driving behaviour. However, the DBQ–Lapses factor has failed to be consistently associated with self–reported accidents. Further evidence would therefore be helpful to clarify whether a higher proneness to having attentional lapses while driving is associated with road traffic crashes, for example, by using improved versions of the DBQ (with new items asking about more dangerous inattention behaviour), alternative attentional lapses questionnaires (such as the ARDES, which has recently been associated with traffic collisions; see Ledesma, Montes, Poó & López–Ramón, 2010) or particular groups of drivers (e.g., a relatively high DBQ–Lapses score is predictive of both active and passive accidents in older drivers; see Parker, McDonald, Rabbitt & Sutcliffe, 2000).

3.2. Driving performance in simulated hazardous situations

The driving simulator used in the current doctoral dissertation presented the participants with a route where nine hazardous situations were triggered when they approached. According to Crundall and his collaborators (Crundall, Andrews, van Loon & Chapman, 2010; Crundall et al., in press), three categories of hazards can be differentiated: “Behavioural Prediction” (BP), “Environmental Prediction” (EP), and “Dividing and Focusing Attention” (DF) hazardous situations. First, BP hazards could be avoided if the driver anticipated the behaviour of a visible traffic factor (i.e. a child pedestrian who is standing visibly between two parked cars and suddenly steps out in front of the participant’s car). Second, in EP situations the source of the hazard is hidden by a part of the environment and is not visible before the hazard is triggered (e.g., a man carrying a box steps out from behind a parked truck). Third, DF situations require the drivers to monitor multiple sources of potential risk before selecting one as the actual hazard (e.g., when driving over a crossroads, a car from the right fails to give way, while a hazard from the left would have been equally plausible.

Evidence has been obtained showing that individual measures in attentional functioning (from the ANTI–V) can be associated with performance in a driving simulator presenting common hazardous traffic situations. In particular, the results in Study 4 revealed that participants who were more influenced by visual spatial cues in the ANTI–V (higher attentional orienting score) tended to show safer driving behaviour when approaching EP hazards (greater speed reduction and fewer crashes) and BP hazards (earlier braking and fewer crashes), whereas their behaviour in DF situations could be more dangerous (delayed braking). As discussed above, in both BP and EP situations, there is a precursor that may be used as a visual cue for the location of the forthcoming hazard, whereas in DF situations there are multiple potential hazards, and thus it is not clear which one is going to be the actual hazard. Consequently, it is suggested that participants with a higher ability to use their attention to prioritise events occurring in spatially cued areas may also use this ability in the traffic environment to quickly detect and more efficiently avoid a hazard source anticipated by a precursor. On the other hand, in complex hazardous situations, giving processing priority to a specific element in the traffic environment will imply partially neglecting other potential hazard sources. These findings are in agreement with previous studies on the role of visual attention while driving. For example, Underwood et al. (2011) proposed that certain types of hazard are associated with a general reduction in the spread of visual search, with hazardous events eliciting longer fixations and less scanning of the traffic environment. Also, results on the attentional orienting effect in the ANTI–V are complementary to Bédard et al.'s study (2006). They observed that the inhibition of return (IOR) was associated with a measure of drivers' ability to scan the traffic environment effectively (the higher the IOR, the fewer the scanning errors). It can be claimed that both components of attention (i.e. attentional orienting and IOR) are relevant to safe driving: in various traffic situations, it is important to allocate our attention to the location where a potential hazard is about to appear (as suggested in Study 4), but in other complex situations, it is also critical to habituate the attentional capture when a particular precursor does not indicate a real risk (as in Bédard et al., 2006). This would explain why both better attentional orienting and greater IOR may be associated with safer driving performance. Additionally, as discussed in previous sections, partial evidence of a relationship between crash occurrence and the functioning of both the executive control and the alerting networks has been reported. These results could be further explored, for example, by using alternative driving situations where these attentional functions are essential to avoid crashing.

Previous evidence using the ANT failed to find evidence of associations between the three attentional functions and overall driving performance measures (the Manitoba Road Test; Weaver et al., 2009). In contrast, the current doctoral dissertation has been successful in finding associations between specific attentional scores and different driving performance measures. It is possible that the driving performance measure obtained from the Manitoba Road Test (a demerit–point system providing a general score by assessing traffic infractions) was too general to find a clear effect, since opposed tendencies in different driving situations might be lost after averaging (as suggested by the qualitative differences found between hazard categories in Study 4). Also, traffic infractions (such as speeding) may be more clearly influenced by motivational or driving style factors than by attentional functioning (whereas attention is an immediate factor to avoid crashing in the hazardous situations used in Study 4). Therefore, we think that future studies aimed at analysing drivers' attentional behaviour should avoid overall scores and focus their analyses on performance measures that are more specific regarding both the attentional components and the driving situations. For example, as utilised in the current doctoral dissertation, the ANTI–V and a driving simulator presenting hazardous situations may be considered useful tools to study driving behaviour and, particularly, drivers' attentional functioning.

4. Further applications and future research

A single task providing usable indices of the functioning of multiple attentional components (such as the ANTI–V) can be a helpful tool in different basic and applied research contexts. In this last section, some suggestions as to its potential applications and some issues for future research will be highlighted.

4.1. Interactions between the attentional networks

First, as is currently being done with the ANT and the ANTI, a great variety of experimental manipulations could be performed to analyse how the attentional components influence each other in cognitive and experimental psychology studies. For example, Callejas, Lupiáñez, Funes and Tudela (2005) and Fuentes and Campoy (2008) manipulated the temporal course of cue–target intervals in the ANTI to analyse how the alerting network influences the orienting network. With the ANTI–V, specific predictions about vigilance and its interactions with other attentional functions could also be tested.

Also, the ANTI–V could be adapted to the requirements of a neuroimaging study (as Fan et al., 2005, did with the ANT) to test hypotheses in cognitive neuroscience and related areas. In particular, measuring both the phasic and tonic aspects of attention within a single task, such as the ANTI–V, may be useful to disentangle these two components in imaging studies (and, for example, to analyse the exact reasons for the differences in laterality found with tonic and phasic studies, which, according to Posner, 2008, are still unknown).

4.2. Attentional functioning in different groups of participants

Including a measure of vigilance can expand what we already know from developmental psychology studies (e.g., Rueda et al., 2004) about the attentional networks and their interactions and also from clinical and neuropsychological research on, for example, dementia (e.g., Fernández et al., 2011; Fuentes et al., 2010), depression (e.g., Gruber, Rathgeber, Bräunig & Gauggel, 2007), attention–deficit hyperactivity disorder in children (e.g., Adólfsdóttir, Sørensen & Lundervold, 2008) and anxiety (e.g., Pacheco–Unguetti, Acosta, Callejas & Lupiáñez, 2010). All these studies highlight the fact that the ANT and its variations use non–verbal stimuli and thus it is quite easy to adapt the test to participants of different ages and levels of ability.

In particular, some studies have found higher phasic alertness scores in particular groups of participants, such as patients with fibromyalgia (Miró et al., 2011), morning chronotype participants measured in the evening (Matchock & Mordkoff, 2009) and drivers prone to having attentional lapses (López–Ramón et al., 2011). The larger alerting effects in these groups of participants were interpreted as either a better phasic alertness functioning (higher reactivity to warning signals) or a reduced tonic alertness (making the warning signal more effective). Performing similar studies with the ANTI–V may provide useful information to evaluate these interpretations, since both components of alertness (phasic and tonic) are measured using this task.

4.3. Driver behaviour evaluation

Regarding Traffic and Transport Psychology, two studies in this doctoral dissertation (Studies 3 and 4) can be considered examples of the potential applications of the ANTI–V. First, this experimental task could be used to provide construct validity for driving behaviour tests, supplying both convergent validity with attention–related questionnaires (such as the DBQ–

Lapses or the ARDES) and discriminant validity when assessing whether a test measures a psychological construct that is independent from the attentional components (e.g., DBQ–Violations or the Useful Field of Vision test).

Moreover, as the ANTI–V tackles some important basic abilities for safe driving (i.e., attentional performance), it can be argued that this test should be considered for driver evaluation purposes (for example, it could be proposed for inclusion in the battery of medical and psychological tests required to obtain a driving licence). Although the evidence in the current doctoral dissertation associates the ANTI–V with some driving outcomes, we think there is still a long way to go before we know whether the test is suitable for these purposes. For example, the attentional scores should first be proved predictive of accident involvement in a large–scale study (using a large sample and considering relevant issues concerning the representativeness of the target population). Also, the reliability of each of the attentional measures should maintain a high standard (see discussion about reliability below). In addition, before considering the ANTI–V in driver evaluation programmes, some other social, political and technical issues should be raised, but a discussion of this goes beyond the scope of the current doctoral dissertation.

4.3.1. Reliability of ANTI-V measures

MacLeod et al. (2010) reviewed 15 studies applying the ANT to healthy individuals and all the samples were aggregated in a single reliability analysis (n = 1,129). Only the executive control score showed a moderate level of reliability using split–half correlation (r = .65), and both attentional orienting and phasic alertness measures obtained lower values (r = .32 and r = .20, respectively). In the case of the ANTI–V, a similar pattern of results was observed using the aggregated analysis (see Appendix C, Table C4): split–half correlations were moderate for executive control (.48 and .63, respectively for RT and ACC scores) while attentional orienting (.25 in RT and .20 in ACC) and phasic alertness (.22 in RT and .14 in ACC) showed lower reliability. Interestingly, the reliability of the vigilance measures in the ANTI–V was considerably stronger, since split–half correlation indices were equal to .99 (hits), .95 (false alarms), .94 (sensitivity, d') and .81 (response bias, β). Additionally, the Spearman–Brown prophesy formula was applied to extrapolate test–retest reliability from split–half reliability (see, for example, MacLeod et al., 2010) and the results are shown in Appendix C (Table C4).

In addition, MacLeod et al. (2010) discussed the relationship between statistical power, reliability and the variance components of the ANT scores (executive control showed the lowest within–subjects variance followed by orienting and then phasic alertness; but the opposite pattern was found for between–subjects variance), and they concluded that: (a) in the case of a between–subjects design, if there was enough power to detect significant effects in the executive network, then significant same–magnitude effects should have been found on all networks; but (b) it is possible that studies that obtained selective within–subjects differences in the executive network may have simply failed to achieve sufficient power to find coexisting true differences in the orienting and alerting networks. To overcome these limitations, it was suggested that researchers using the ANT should aggregate multiple measures (repeated administration) and/or increase the duration of the task (more trials). Actually, Ishigami and Klein (2010) showed that repeated administration was effective to increase split–half reliability up to acceptable levels. However, these strategies may not be acceptable in a number of situations (such as driver evaluation programmes or many research settings), where it is only possible to apply the test in a single session and where time constraints are a relevant issue. Therefore, future research would be useful to refine the phasic alertness and attentional orienting scores, so that reliability is increased without losing their proven capability to measure the efficiency of the attentional components (as shown by convergent evidence in different disciplines, including the previously described neuroimaging, behavioural and neuropsychological studies).

An issue related to the reliability of the ANTI–V measures is consideration of the components of attention as neuropsychological traits or states. As discussed in Study 1, MacLeod et al. (2010) claimed that executive control should be considered more trait–like while phasic alertness and attentional orienting may be more state–like because: (a) executive control scores were more stable across multiple–measurements (higher reliability); (b) executive control scores showed low within–subject variance and high between–subjects variance, whereas a reverse pattern was reported for phasic alertness and orientation; and (c) there is evidence from genetic studies for a high heritability in executive network efficiency, but not for the alerting and orienting networks. In addition, Pacheco–Unguetti et al. (2010) found that executive control was related to anxiety–trait, whereas both alertness and orienting were somewhat related to anxiety–state.

With regard to the vigilance measure in the ANTI–V, this attentional function has been traditionally defined as a *state* or a *temporary level* (for example, Posner, 2008; Sturm & Willmes, 2001).Moreover, it is accepted that maintaining vigilance over time is managed by the alerting neural network (e.g., Posner, 2008), which is also involved in the (state–like) phasic alertness function. In addition, we have shown in Study 2 that sleep deprivation (which is a manipulation of alertness state) had an effect on the vigilance indices in the ANTI–V, and thus this measure was associated with the changing level of alertness. However, it is also possible that a general ability to maintain vigilance over time may be better defined as a trait (i.e., a more stable cognitive control ability), whereas the momentary level of vigilance would be better defined as a state. Actually, Robertson, Manly, Andrade, Baddeley and Yiend (1997) claimed that, when rare targets occur in a sustained attention task, controlled processing must be triggered to overcome automatic responses, and therefore they proposed the Sustained Attention to Response Task, or SART, as a continuous performance test where frequent targets and rare non–targets required alternative responses from the participants (in a similar way to the vigilance subtask in the ANTI–V). In addition, the suggestion that vigilance might be better considered as a trait is consistent with our finding that the vigilance indices in the ANTI–V have quite a high split–half reliability (.99 and .94 for hits and sensitivity, respectively), and thus could be more stable across measurements. Further research would be useful to clarify the role of vigilance as a trait or a state. For example, the ANTI–V could be modified to include two complementary measures of vigilance, one aimed at assessing the more stable trait–like components of vigilance and the other to evaluate the changing states of alertness, and then to look for potential dissociations between these measures.

4.4. Attention-related driving situations

A further potential application of the scores in the ANTI–V, as shown in Study 4, is to explore the attentional components involved in particular traffic situations. If individual differences in the ANTI–V are associated with drivers' performance when dealing with specific traffic situations, then it can be argued that such attentional components may be relevant to driving safely in those situations. However, it should be highlighted that a lack of significant results should not be taken as evidence against a potential association (which could still be found using other strategies, such as direct experimental manipulations or other performance measures). Significant results can, however, be taken as evidence, suggesting further testable predictions and hypotheses, especially if a consistent pattern of results is found using multiple measures and multiple performance indicators.

A good understanding of how the attentional networks influence common driving situations could be useful in various ways. For example, as raised by Weaver et al. (2009), each neural network is mainly influenced by a specific neurotransmitter. Therefore, it is possible to anticipate the possible impact of some medications on drivers' performance in particular situations. For example, drugs modulating the dopamine system will have the greatest impact on situations related to the executive control network, and similar effects on orienting– and alerting–related situations would be expected of the cholinergic and noradrenergic systems. The results presented in Study 4, for example, suggest that modulating the cholinergic system (using either agonists or antagonists) will have a different impact on Dividing and Focusing situations, on the one hand, and Behavioral Prediction and Environmental Prediction situations, on the other hand, since the relationship between the orienting network and performance in these situations followed a qualitatively different pattern. A parallel argument can be put forward for clinical conditions that selectively affect the attentional networks and/or those neurotransmitter systems, such as Parkinson's disease or schizophrenia (dopamine), Alzheimer's disease (acetylcholine) or attention–deficit hyperactivity disorder (noradrenaline and dopamine). Additionally, as also proposed by Weaver et al. (2009), it might be possible to use the ANTI–V to obtain individual patterns of attentional dysfunction (e.g., from clinical populations or from subclinical elderly drivers), and then create driving rehabilitation programmes customised to their needs. For example, someone who shows an impaired executive control performance, but a preserved alerting and orienting functioning, might particularly benefit from practice in driving situations involving cognitive conflict or, at least, could be taught to identify (and then avoid or cope with) these high–risk situations (e.g., where multiple incompatible manoeuvres may be required, as at complex crossroads or when joining a motorway with a high level of traffic).

We also think that ordinary (non–clinical) drivers could benefit too from a good understanding of how the attentional networks influence driving performance. For instance, identifying driving situations where a particular attentional component is associated with safer behaviour may suggest effective strategies to successfully resolve the potential hazard. This will be the case, for example, in traffic situations where a higher phasic alertness was related to safer driving (e.g., a brake light indicating that a lead vehicle has slowed down), and thus we can facilitate the driver's temporal preparation for a correct manoeuvre by using Advanced Driver Assistance Systems (ADAS) providing warning signals (e.g., a forward collision warning system; Fort et al., 2011; Lee et al., 2002). A second example could be identifying situations where a worse vigilance performance was associated with lower safety (e.g., driving long hours or late at night) and thus proposing specific countermeasures, such as alerting devices, secondary tasks or stimulant drugs (see May & Balwin, 2009, or Tejero–Gimeno et al., 2006, for reviews). Also, with regard to attentional orienting–related situations, we could help drivers (especially learner drivers) to correctly scan the traffic environment and identify useful hazard precursors, so that they can successfully allocate their attention to the immediate hazards. Similarly, in complex driving traffic situations (e.g., a big roundabout where many cars and some motorbikes are on the road), safer strategies could be promoted to help drivers distinguish immediate hazards from other potential hazards or make them aware that multiple hazards might be triggered (for example, to prevent the common failure to notice motorbikes). In fact, Crundall et al. (2010) showed that a group of learner drivers receiving on–road commentary training (focused on identifying hazards, ordering them in importance and inferring potential hazards) had a beneficial effect on a posterior simulated driving session, especially in those situations that required either Behavioural Prediction or Dividing and Focusing Attention skills. In this context, the ANTI–V may provide independent evidence to develop an attention–based category of hazardous situations and thus to suggest specific countermeasures.

4.5. Driving simulator validation

As a final point, it is also suggested that the current work may aid researchers in the field of driving simulation, provided that a simulator can be shown to relate to attentional functioning in predictable ways. The potential associations between the attentional indices from the ANTI–V and performance in the driving simulator would suggest that the latter is able to tackle important cognitive components of real driving (i.e. the attentional functions). Therefore, the current research may also benefit the developers and users of simulator technology, providing a possible alternative route to obtaining evidence for simulator validation.

5. Conclusions

In the four studies that were integrated in this doctoral dissertation, a new version of the Attention Networks Test has been developed (i.e., the ANTI–V), aimed at obtaining a direct measure of vigilance in addition to the usual attentional scores (executive control, attentional orienting and phasic alertness), and these attentional measures have been associated with different driver behaviour outcomes, such as the self–informed Driver Behaviour Questionnaire and performance in a driving simulator presenting hazardous traffic situations.

Several issues regarding characterisation and the mutual influences between the attentional networks have been discussed, and further evidence to analyse the role that the different attentional functions play in explaining driving behaviour in common traffic situations has been presented. Therefore, to conclude, we suggest that the current research may benefit both theorists on attention, since some insights into the grounding of the measures of the attentional networks have been provided, and applied psychologists in the field of driving, since evidence to improve our understanding of the driving task has been presented.

However, many questions have been raised in the current research and these still remain open. If we bear in mind that driver distraction and inattention is considered to be a major contributing factor in road traffic accidents, which are one of the main causes of premature death and financial loss in the world, hopefully the current doctoral dissertation will encourage further and deeper analysis to increase our knowledge of human attention and its influence on driving behaviour.

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Apéndice A

Appendix A

Two slightly different variations of the ANTI–V task have been used in Study 1. A half of the participants (27) completed a shorter version (ANTI–V$_a$) while the others (28) were presented with a longer version (ANTI–V$_b$). The ANTI–V$_a$ comprised 7 blocks (54 trials each) and there was ~11% of infrequent trials. The participants had to perform the task and remain vigilant continuously for more than 22 minutes, while completing the experiment typically required about 30 minutes. In the ANTI–V$_b$ an extra experimental block was added and the percentage of infrequent targets was increased up to ~25% (16 of 64 trials per block). The participants had to perform the task continuously for 31 minutes, whereas completing the experiment required about 40 minutes. This second variation of the ANTI–V task was introduced to improve the estimation of the vigilance measures. To compare the performance between both tasks, mean correct RT, accuracy, and vigilance–performance data from Study 1 were submitted to ANOVAs with experimental task (ANTI–V$_a$ and ANTI–V$_b$) as a between–participants factor (see Table A1). The results revealed some differences in average RT (being 60 ms slower in ANTI–V$_b$; $F(1,51)=6.94$; $p<.05$; $\eta^2=.12$) and in the percentage of false alarms (which was 2% higher in ANTI–V$_b$; $F(1,51)=4.90$; $p<.05$, $\eta^2=.09$). No other attentional score, vigilance index or global measure was found significantly different between both tasks.

	ANTI-V$_a$	ANTI-V$_b$
a) Attentional scores: RT (ms)		
Phasic alertness	38 (29)	29 (32)
Orientation	48 (21)	40 (31)
Executive Control	69 (23)	63 (24)
b) Attentional scores: % errors		
Phasic alertness	1.1 (2.8)	1.6 (3.9)
Orientation	0.8 (3.0)	1.2 (3.0)
Executive Control	0.9 (2.7)	2.2 (2.7)
c) Vigilance measures (SDT)		
Hits (%)	51 (22)	59 (19)
False alarms (%)	2.5 (2.3)	4.5 (4.1)
Sensitivity (d')	2.1 (0.6)	2.1 (0.4)
Response Bias (β)	8.6 (4.6)	6.6 (4.6)
d) Global results		
ANTI RT (ms)	607 (77)	667 (90)
ANTI % errors	1.9 (2.1)	2.4 (1.9)

Table A1: Comparison of ANTI–V$_a$ and ANTI–V$_b$ tasks used in Study 1. Mean and standard deviation are shown for: (a) the attention network scores (phasic alertness, orientation and executive control) for reaction time (ms), and (b) for accuracy (percentage of errors) data; (c) the Signal Detection Theory (SDT)–based vigilance measures (hits, false alarms, sensitivity, and response bias); and (d) the global reaction time (RT, ms) and global accuracy results (ACC, percentage of errors).

APÉNDICE B

APPENDIX B

Scatter plots of main correlations in Study 1 have been inspected to look for non–linear functional relationships and are shown in Figure B1. As suggested by observing some of the scatter plots, complementary analyses have been conducted to test the significance of quadratic models. The results showed that:

(A) Regarding global RT, hits were significantly predicted by using either a linear model (F(1,51)=34.58; p<.001; R^2=.40) or a quadratic model (F(2,50)=20.09; p<.001; R^2=.45). However, the quadratic coefficient (global RT^2) in the latter failed to reach statistical significance ($ß$=−2.1; p=.06) and thus the linear model seem to be a more efficient explanation of the data. Besides, sensitivity–d' was significantly predicted by global RT, using either a linear model (F(1,51)=9.05; p=.004; R^2=.15) or a quadratic model (F(2,50)=8.88; p=.001; R^2=.26). In the latter, the quadratic coefficient (global RT^2) was statistically significant ($ß$=−2.75; p=.008).

(B) Similar results were found with NTNC RT: hits were significantly predicted with a linear model (F(1,51)=32.49; p<.001; R^2=.39) and a quadratic model (F(2,50)=18.53; p<.001; R^2=.43). The quadratic coefficient (NTNC RT^2) in the latter was close to reach statistical significance ($ß$=−1.72; p=.08). Sensitivity–d' was also significantly predicted by NTNC RT, using either a linear model (F(1,51)=9.31; p=.004; R^2=.15) or a quadratic model (F(2,50)=8.40; p=.001; R^2=.25). The quadratic coefficient (global RT^2) was statistically significant in the latter model ($ß$=−2.55; p=.01).

In summary, these results suggested a possible quadratic relationship between some the variables (at least with sensitivity–d'). However, the quadratic pattern was not clearly found in other relevant relationships, and thus we think that these results are not conclusive. Furthermore, the inspection of the scatter–plots may suggest a possible ceiling effect that may be more clearly found with longer RT and hits/sensitivity–d'. However, it should be noted that longer RT are not considered informative in the ANT or ANTI tasks, and are usually filtered out as confounding factors. Thus, we may suggest that the most simple and efficient explanation for our data in the usual scale of the variable is the linear model.

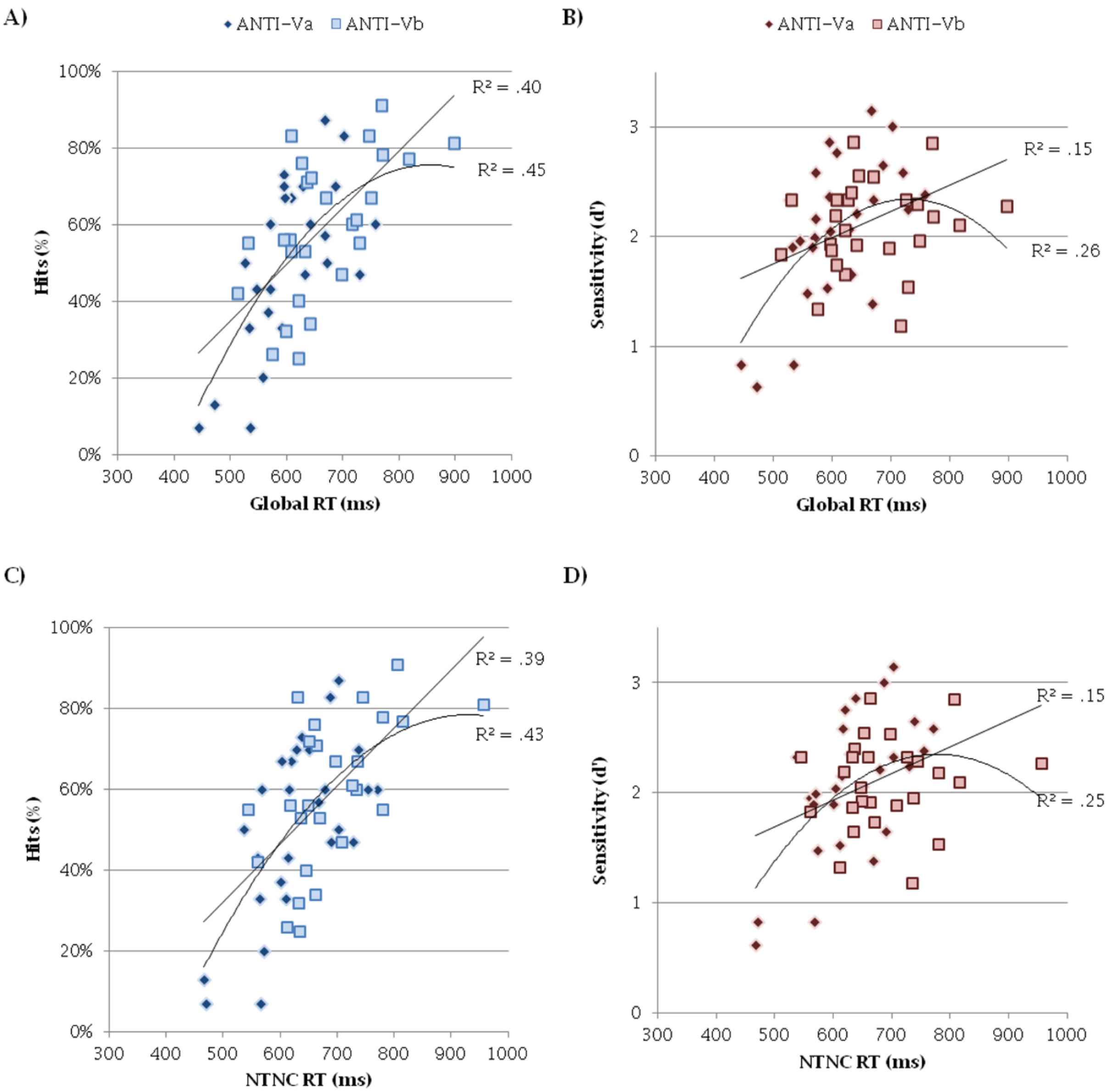

Figure B1: Scatter plots of main correlations in Study 1: (A) Global RT and hits; B) Global RT and sensitivity-d'; (C) NTNC RT and hits; (D) NTNC RT and sensitivity-d'. Linear and quadratic fit lines with their associated R^2 are shown in each graph. Different dots have been used to identify the participants in the ANTI-V_a and the ANTI-V_b tasks (see Appendix A for more information).

APÉNDICE C

APPENDIX C

Data from the ANTI–V in the four studies that constitute the current doctoral dissertation have been aggregated in a single analysis to increase the robustness of the results and thus provide additional evidence to support some of the points raised in the global discussion. The four studies used comparable versions of the ANTI–V (see methods sections for further details) and similar sample composition (mainly young university students, as shown in Table C1). Data processing and extreme values filtering were applied following the criteria described for each study in the corresponding chapters. Also, only the initial experimental session in Study 2 was considered in the aggregated analysis, since neither of the following two sessions (with and without sleep deprivation) was comparable with data in the other studies.

Mean correct–trial reaction time (RT, ms) and accuracy data (ACC, percentage of errors) from the ANTI–V task were submitted to a 2 (Congruency: congruent / incongruent flankers) x 3 (Validity: valid / no cue / invalid cue) x 2 (Warning: Tone / No tone) repeated–measures ANOVA. The significance level was set at .05 and the Bonferroni adjustment was applied in pairwise comparisons. Degrees of freedom were adjusted using the Greenhouse–Geisser method when sphericity could not be assumed. RT results revealed that the participants were faster: (a) When the central and the flanker cars were congruent, as compared to when they were incongruent (633 ms and 695 ms, respectively; $F(1,215)=908.30$; $p<.001$; $\eta 2=.81$). (b) When a valid cue

Study	Sample size[a]	Males / Females	Age	Recruitment location
1	53	25% / 75%	21 (3)	University of Granada (Spain)
2	25	47% / 53%	21 (2)	University of Murcia (Spain)
3	99	7% / 93%	21 (4)	University of Granada (Spain)
4	39	52% / 48%	22 (4)	University of Nottingham (UK)
Overall	**216**	**25% / 75%**	**21 (3)**	

[a] Participants with extreme values have been excluded according to the criteria described in each of the four studies.

Table C1: Sample composition in the complementary analysis integrating the four studies that constitute the current doctoral dissertation. Sample size, percentage of males and females, mean age (and standard deviation) and the location where the participants were recruited is shown for each study. Overall data are also reported in the last line of the table.

was presented in comparison to no cue and invalid conditions (639 ms, 670 ms, and 683 ms, respectively; $F(1.9,415.4)=341.23$; $p<.001$; $\eta 2=.61$); pairwise comparisons confirmed the differences between these three conditions (all $p<.001$). (c) When a warning tone was presented as compared to when it was absent (650 ms and 689 ms, respectively; $F(1,215)=248.72$; $p<.001$; $\eta 2=.54$). Following Callejas, Lupiáñez, Funes & Tudela (2005), Validity x Warning ($F(1,215)=49.75$; $p<.001$; $\eta 2=.19$) and Validity x Congruency ($F(1,215)=114.76$; $p<.001$; $\eta 2=.35$) interactions were analysed after excluding no–cue trials (where no spatial orienting was measured) and they were both statistically significant. In addition, as is usual with the ANTI–V, the Warning x Congruency interaction was not statistically significant ($F(1,215)=0.69$; $p=.80$; $\eta 2<.001$). No second–order interaction was found ($F(1.9,417.5)=2.31$; $p=.10$; $\eta 2=.01$).

The analysis of the percentage of errors (%) revealed that participants were more accurate: (a) When the central and the flanker cars were congruent as compared to when they were incongruent (1.4% and 3.0%, respectively; $F(1,215)=86.46$; $p<.001$; $\eta 2=.29$). (b) When a valid cue was presented in comparison to no cue and invalid conditions (1.6%, 2.2%, and 2.7%, respectively; $F(1.7,370.5)=22.39$; $p<.001$; $\eta 2=.09$); planned pairwise comparisons with Bonferroni correction confirmed the differences between these three conditions (all $p<.015$). (c) When a warning tone was presented as compared to when it was absent (1.4% and 3.0%, respectively; $F(1,215)=46.41$; $p<.001$; η $2=.18$). Also, Validity x Warning ($F(1,215)=0.10$; $p=.76$; $\eta 2<.001$) and Validity x Congruency ($F(1,215)=45.23$; $p<.001$; $\eta 2=.17$) interactions were analysed after excluding no–cue trials. The Warning x Congruency interaction was significant in this analysis ($F(1,215)=7.17$; $p=.008$; $\eta 2=.03$). No second–order interaction was found ($F(2,430)=2.09$; $p=.13$; $\eta 2=.01$).

Attentional network scores were computed as a subtraction from specific average conditions (Executive Control = incongruent – congruent; Attentional Orienting = invalid – valid; and Phasic alertness = no tone minus tone, considering only no–cue trials). Regarding the vigilance performance, the percentages of hits and false alarms were obtained and Signal Detection Theory (SDT) indices for sensitivity (d’) and response bias (ß) were computed. Participants’ average results are shown in Table 6.1 (see general discussion section). The attentional measures were submitted to separate one–way ANOVAs, in which Study (1 / 2 / 3 / 4) was manipulated between–participants. Overall, these analyses show that the attentional measures are quite homogeneous across the studies (as also was the sample composition). However, some differences in the data have been found, probably reflecting small differences among the participants. The ANOVA on global RT revealed some overall differences ($F(3,212)=4.81$; $p=.003$; $\eta 2=.06$) and post-hoc analysis with Bonferroni correction showed that average RT was higher in Study 3 than in Study 1 (689 and 636 ms, respectively; $p=.006$). The ANOVA on global errors was also significant ($F(3,212)=3.76$; $p=.04$; $\eta 2=.04$), and this time a difference was found between Study 2 and Study 4 (3.2% and 1.7%, respectively; $p = .03$). Finally, the ANOVA on Executive Control score in RT also revealed some differences ($F(3,212)=3.32$; $p=.02$; $\eta 2=.05$) between Study 2 and Study 4 (51 and 73 ms, respectively; $p = .04$).

To further evaluate the robustness of the main correlations observed in Study 1 (between the direct vigilance measure and some other vigilance indices proposed for the ANT or the ANTI, such as global RT or no tone and no cue RT), the correlation indices were then obtained using the whole sample and are reported in Table C2. As found in Study 1, the global measures (both overall and considering only no tone and no cue trials) were only moderately associated with the direct vigilance indices. Global RT was positively correlated with hits and sensitivity, whereas Global ACC was negatively correlated with these vigilance indices. Also, after partialling out the influence of Global RT and Global ACC, no other correlation with hits or sensitivity was found to be statistically significant.

The association between the vigilance indices and executive control, attentional orienting and phasic alertness scores was inspected by computing Pearson correlations with the whole sample. As shown in Table C3, some potential associations were revealed (for example, between attentional orienting and false alarms, and among the three indices in percentage of errors and sensitivity). However, partial correlations were computed to control for the influence of Global RT and Global ACC measures (which could be reflecting different attitudes toward the task). A single significant correlation was found between attentional orienting in RT and false alarms ($r = -.18$; $p = .008$), and there were also unconfirmed tendencies towards correlations between sensitivity and both phasic alertness in RT ($r = -.13$; $p = .06$) and attentional orienting in ACC ($r = -.13$; $p = .07$). No other statistically significant correlation was found ($p > .10$).

	Hits	False alarms	Sensitivity (d')	Response bias (β)
Reaction time (ms)				
Global RT	.47***	.35***	.24***	-.30***
NTNC RT	.44***	.35***	.21**	-.32***
BD RT	.03	.17*	-.05	-.08
BD NTNC	.07	.13¹	-.01	-.12¹
Accuracy (% errors)				
Global ACC	-.23**	.13¹	-.33***	-.12¹
NTNC ACC	-.17*	.06	-.21**	-.01
BD ACC	.01	.10	-.03	-.06
BD NTNC ACC	-.03	.08	-.03	.01

Note: NTNC = No tone and no cue condition. BD = Last block minus first block difference. BD NTNC = Last block minus first block difference in no tone and no cue condition.

Note: After partialling out the influence of the global measures (Global RT and ACC), the only significant correlations were: BD RT and False alarms (r =.14; p = .04) and NTNC ACC and response bias (r = .15; p = .03). Also, there were unconfirmed tendencies between NTNC ACC and hits (r = -.11; p = .10) and between BD NTNC ACC and False alarms (r = .13; p = .07). No other statistically significant correlation was found (p > .10).

¹ p<.10; * p<.05; ** p<.01; *** p<.001

Table C2: Correlations between the direct vigilance indices (hits, false alarms, sensitivity-*d'*, and response bias-ß) and other vigilance or tonic alertness indices proposed for the ANT or the ANTI, both for reaction time (RT-ms) and accuracy (ACC-percentage of errors) data.

Finally, the reliability of the attentional measures in the ANTI-V was evaluated by analysing split-half correlations. With this aim, separate pairs of attentional scores for each participant were obtained from odd and even trials in the ANTI-V and correlations were then computed between these pairs. Additionally, the Spearman-Brown prophesy formula was applied to extrapolate test-retest reliability from split-half reliability (see, for example, MacLeod et al., 2010).

	Hits	False alarms	Sensitivity (d')	Response bias (β)
Reaction time (ms)				
Executive control	.09	.09	.06	.00
Attentional orienting	–.04	–.19**	.07	.13¹
Phasic alertness	–.03	.11¹	–.09	–.09
Accuracy (% errors)				
Executive control	–.12¹	.08	–.21**	–.12¹
Attentional orienting	–.13¹	.03	–.18**	–.09
Phasic alertness	–.13¹	–.02	–.14*	.04

Note: After partialling out the influence of the global measures (Global RT and ACC), the only significant correlation was: RT– Orienting and False alarms (r = –.18; p = .008). Also, there were unconfirmed tendencies between RT–Phasic alertness and Sensitivity (r = –.13; p = .06) and between ACC–Orienting and Sensitivity (r = –.13; p = .07). No other statistically significant correlation was found ($p > .10$).

¹ $p<.10$; * $p<.05$; ** $p<.01$; *** $p<.001$

Table C3: Correlations between the direct vigilance indices (hits, false alarms, sensitivity–*d*', and response bias–ß) and the attention networks scores (executive control, attentional orienting and phasic alertness), both for reaction time (ms) and accuracy (percentage of errors) data.

As shown in Table C4, split–half correlations were moderate for the executive control scores (.48 and .63, respectively for RT and ACC) while the correlations for the attentional orienting (.25 in RT and .20 in ACC) and phasic alertness scores (.22 in RT and .14 in ACC) were lower. Interestingly, the reliability of the vigilance measures in the ANTI–V was considerably stronger, since split–half correlations were equal to .99 (hits), .95 (false alarms), .94 (sensitivity, d') and .81 (response bias, β). As previous versions of the ANT lacked a direct measure of vigilance, this is the first time that the reliability of the vigilance indices embedded in the ANTI–V has been inspected.

	Split-half correlation	Spearman-Brown prophesy test-retest reliability
a) Attentional scores in reaction time		
Executive Control	.48	.65
Attentional Orienting	.25	.41
Phasic Alertness	.22	.36
b) Attentional scores in percentage of errors		
Executive Control	.63	.77
Attentional Orienting	.20	.33
Phasic Alertness	.14	.25
c) Vigilance measures		
Hits	.99	.99
False Alarms	.95	.98
Sensitivity (*d'*)	.94	.97
Response Bias (β)	.81	.89
d) Global results		
ANTI RT	.99	.99
ANTI % errors	.98	.99

Table C4: Reliability analysis of the attentional measures in the ANTI–V: Split–half correlations (obtained by using separate pairs of attentional scores for each participant, extracted from odd and even trials) and Spearman–Brown prophesy test–retest reliability (which is estimated from split–half correlations) are shown for: a) Attentional scores in reaction time (executive control, attentional orienting, and phasic alertness); b) Attentional scores in percentage of errors; c) Vigilance measures (hits, false alarms, sensitivity–*d'*, and response bias–β); and d) Global results (reaction time, RT, and percentage of errors, %).

“*Un hombre que pueda conducir con seguridad mientras besa a una mujer hermosa, simplemente no está dedicando al beso la atención que merece*”
~Albert Einstein

“*Any man who can drive safely while kissing a pretty girl is simply not giving the kiss the attention it deserves*”
~Albert Einstein