UNIVERSIDAD DE BURGOS

TESIS DOCTORAL

Programa de Doctorado

Tecnologías Industriales e Ingeniería Civil

Estudio de factores humanos en la conducción mediante un simulador de realidad virtual. Análisis pormenorizados de la influencia de la música, el uso del smartphone y la carga mental, en entornos urbanos e interurbanos.

Autor

Carlos Alberto Catalina Ortega

Directores de Tesis

Dra. Susana García Herrero

Dr. Miguel Ángel Mariscal Saldaña

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RESUMEN

Los accidentes de tráfico siguen teniendo un gran impacto en nuestra sociedad provocando gran cantidad de pérdidas humanas cada año, tal es el impacto que este se encuentra dentro de los Objetivos de Desarrollo Sostenible 3.6 y 11.2 (Auert y Khayesi 2021) de la Organización Mundial de la Salud, que instan a reducir a la mitad el número de muertes por accidente de tráfico y a proporcionar acceso a sistemas de transporte seguros. Por estos motivos es importante estudiar los factores asociados con los accidentes de tráfico de modo que se puedan proponer nuevas medidas de seguridad activas o pasivas y nuevas políticas de tráfico. Esto favorecerá que se eviten las pérdidas humanas, referenciadas por estudios científicos que fundamenten medidas efectivas para la disminución de los accidentes.

En la presente Tesis doctoral se ha realizado dos experimentos con voluntarios y voluntarias usando un simulador de conducción. En el primer experimento se estudió el efecto de la música en conductores y conductoras, para lo cual se tuvo que modificar el simulador con el objetivo de obtener datos concretos. El segundo estudio realizado se diseñó para que permitiera analizar diversos factores con la misma experimentación, el cual necesitó que se preparara un sistema complejo (modificaciones más elaboradas en el simulador, uso de eye tracker, uso de smartphone con registro de actividad y cuestionarios de carga de trabajo).

El uso de simuladores permite realizar la experimentación de modo seguro aun generando situaciones inseguras, así como capturar una gran cantidad de datos de forma precisa. El uso de simuladores además es una evolución de la trayectoria del autor de la Tesis, que no solo participó en el desarrollo del simulador utilizado para el estudio (y en sus modificaciones para la realización de la Tesis), sino que durante su trayectoria profesional ha desarrollado y liderado proyectos de investigación principalmente en simulación, realidad virtual y realidad aumentada. 4 Proyectos Europeos, (3 H2020 y 1 AAL) WorkingAge («Smart Working environments for all Ages | WorkingAge Project | Fact Sheet | H2020 | CORDIS | European Commission» 2019) Simusafe («SIMULATOR OF BEHAVIOURAL ASPECTS FOR SAFER TRANSPORT | SimuSafe Project | Fact Sheet | H2020 | CORDIS | European Commission» 2017), Econfidence («Confidence in behaviour changes through serious games | e-Confidence Project | Fact Sheet | H2020 | CORDIS | European Commission» 2016), Nacodeal («DOMEO - AAL Programme» 2011), 12 Proyectos de investigación nacional y 4 proyectos de investigación regional, contando con varias publicaciones adicionales a las de la presente Tesis, entre las que se destaca un artículo JCR Q1 en la revista Comunicar titulado “Tecnología asistencial móvil,

con realidad aumentada, para las personas mayores" (Saracchini, Catalina y Bordoni 2015). Hay más información de los proyectos y publicaciones en la sección 4.6.

Las contribuciones de la presente Tesis están formadas por un total de cinco publicaciones: tres artículos JCR ya publicados, un congreso indexado en SCOPUS y otro artículo JCR en estado de revisión mayor. Para dichas contribuciones se han utilizado diversas técnicas de análisis de datos, siendo las principales las Redes Bayesianas, Random Forest, Paired t-test y Anovas.

El primer artículo crea un modelo conceptual analizado con redes bayesianas para estudiar el efecto de la música en conductores y conductoras. En este estudio se identificaron, entre otros, los efectos sobre las infracciones cometidas por exceso de velocidad, la experiencia al volante en relación con los efectos de la música y las consecuencias según el género de música que se escucha y los sentimientos que produce. La segunda publicación identifica diferencias de comportamiento del conductor o conductora, en parámetros de la mirada, cerca y dentro de las rotondas cuando están expuestos a distracciones. En el tercer artículo los resultados confirman las diferencias, entre conductores o conductoras jóvenes distraídos y no distraídos, su impacto en el rendimiento, en términos de control del vehículo. Además, esta misma publicación estudia cómo la carga de trabajo de conductores y conductoras aumenta con el uso de sus smartphones mientras conducen. La cuarta publicación utiliza redes bayesianas para desarrollar un modelo probabilístico global cuyos resultados indican que el uso de aplicaciones de redes sociales mientras se conduce aumenta la probabilidad de cometer una infracción de tráfico. El último artículo, en estado actual de revisión mayor, muestra la variabilidad de donde mira el conductor o la conductora en rotondas con y sin distracciones; a su vez, demuestra cómo, la experiencia del conductor o conductora se relaciona directamente con mirar al lado izquierdo y con el número de infracciones cometidas.

Palabras Clave: Accidentes de tráfico, factores humanos, simuladores, realidad virtual, eye tracker, workload.

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ESQUEMA GENERAL DE LA TESIS

La presente Tesis está organizada en cinco secciones que permiten dar una visión completa de los trabajos realizados y su estructura. En la primera se realiza una introducción al problema y relevancia de los accidentes de tráfico en nuestra sociedad, para continuar con la explicación de los objetivos de la Tesis.

En la segunda se hace una descripción de los materiales y métodos utilizados para llevar a cabo los distintos experimentos. Se detallan herramientas como el simulador de conducción adaptado, un smartphone con aplicaciones específicas instaladas y el eye tracker para hacer seguimiento de la mirada del usuario o usuaria. También se detallan los cuestionarios utilizados (demográfico y NASA-TLX), las bases de datos generadas y utilizadas, y el modo de sincronización de los datos. Igualmente se profundiza en el marco metodológico con una breve introducción a las distintas técnicas analíticas utilizadas en los distintos artículos. Se han llevado a cabo desde técnicas más clásicas como ANOVA o T-test, a técnicas más innovadoras como son las redes bayesianas o los random forest.

El documento de Tesis continua en su tercera sección con un breve resumen de las contribuciones científicas que han dado forma a esta Tesis, presentada por compendio de artículos, en la que se incluyen los datos más relevantes de los experimentos, herramientas y principales aportaciones. Se incluye un apartado adicional en el que se destacan algunas publicaciones en las que ha colaborado el autor de la Tesis pero que no están relacionadas directamente con la misma, destacando entre ellas otro JCR en Q1. En la cuarta sección se incluyen las 4 publicaciones científicas que forman la Tesis por compendio de artículos.

Finalmente, en la sección cinco se proponen las conclusiones generales de toda la investigación en su conjunto, tanto en cuanto a aportaciones científicas, como a posibles medidas activas o pasivas para las mejoras del tráfico y futuros estudios.

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INTRODUCCION

1 Introducción

Los accidentes de tráfico son responsables de 1,35 millones de muertes y siguen siendo una causa importante de lesiones y muertes (Organización Mundial de la Salud 2018). Esto ha llevado a que los países de todo el mundo den la máxima prioridad a la mejora de la seguridad vial, así como a dedicar esfuerzos considerables a la gestión de los perfiles de lesiones de los accidentes de tráfico. Como consecuencia, se han destinado grandes esfuerzos al desarrollo de un sistema de tráfico más seguro, el cual es conformado por la seguridad de los vehículos, la mejora de las infraestructuras viales, retos en la atención a los conductores y las conductoras, las normas y reglamentos de tráfico, las campañas de concienciación, etc.

De hecho, las estadísticas sobre accidentes de tráfico y lesiones relacionadas con ellos han demostrado que entre el 80% y el 90% de los incidentes de tráfico están causados por los errores operativos, los comportamientos incorrectos del conductor o conductora, la falta de atención, la fatiga y la distracción (Wang, Li y Lu 2013; Koesdwiady et al. 2017; Jørgensen y Hanssen 2019; Xing, Lv y Cao 2020; McEvoy, Stevenson y Woodward 2006).

Aunque existen numerosas fuentes potenciales de distracción en el vehículo, una amplia investigación (Horberry et al. 2006; Sullman 2012; Xiao y Shi 2015; Rashid et al. 2020) informó de que el uso de teléfonos móviles es uno de los principales factores que provocan accidentes de tráfico. A este respecto, se concluyó que, en 2015, había 4.700 millones de personas que utilizaban teléfonos móviles y se esperaba que esta cifra alcanzase los 5.600 millones en 2020. Además, el desarrollo de la industria de las telecomunicaciones y este creciente número de usuarios y usuarias hacen que el uso de los teléfonos móviles por parte de los conductores y conductores sea muy común.

El estudio de los factores que promueven dichos accidentes de tráfico, por parte de la comunidad científica debe ser una prioridad que permita salvar vidas. Dichos estudios dependen de la conducción en entornos o con condiciones de riesgo, por lo que el uso de simuladores de conducción es una herramienta perfecta para permitir que se lleven a cabo sin riesgos y con una gran versatilidad.

OBJETIVOS

2 Objetivos

El objetivo final de la Tesis es proponer medidas de seguridad vial tanto técnicas como políticas o de mejoras en la formación de conductores y conductoras, que ayuden a cumplir con los Objetivos de Desarrollo Sostenible 3.6 y 11.2 de la Organización Mundial de la Salud, disminuyendo las muertes y lesiones por accidentes de tráfico. Para lograrlo, se hace imprescindible entender los efectos de distintas distracciones durante la conducción (música, uso de smartphones, redes sociales…) tanto en entornos urbanos como en interurbanos, y analizar sus efectos (control del vehículo, efecto en infracciones…) mediante distintas herramientas. De ese modo se podrán proponer medidas basadas en datos que tengan un impacto real sobre el número de víctimas mortales en carretera.

De forma concreta se quieren investigar los siguientes aspectos acerca de la conducción teniendo en cuenta las variables de distracción, las cuales permiten obtener conclusiones que lleven a medidas de seguridad vial:

- Analizar el efecto de distintos tipos de distracciones durante la conducción para ver cómo afecta a las infracciones que se comenten al volante. El tipo de distracciones incluye la música y el uso de smartphone tanto en su uso general (llamadas y WhatsApp) como uso de redes sociales.
- Estudiar dónde fija la mirada el usuario o usuaria durante la conducción, tanto en una situación con distracciones como en otra sin distracciones, para explicar el incremento de infracciones.
- Comprender el impacto de factores sociales, tales como la sobrecarga mental y la experiencia de conductores y conductoras, para proponer medidas de seguridad vial más efectivas.

Cada una de las publicaciones de la presente Tesis ayuda a profundizar en algunos de los aspectos anteriormente descritos, y arrojan luz sobre el problema global, proporcionando evidencias que permiten entender el conjunto de la conducción con distracciones. Cada uno de los artículos tiene igualmente otras aportaciones, de alto valor científico, que se han encontrado en el proceso de análisis de datos.

MARCO METODOLÓGICO

3 Marco Metodológico

Para la presente Tesis ha sido necesario realizar dos experimentos en los que se han utilizado distintos equipos, fuentes de datos y herramientas de análisis. Dichos experimentos han permitido obtener los datos necesarios para realizar los análisis de datos y extraer los resultados descritos en las diferentes publicaciones. Se describen a continuación los equipos y herramientas, los experimentos realizados, las bases de datos generadas y, finalmente, la metodología de análisis de datos que se ha llevado a cabo.

3.1 Equipos y herramientas

A continuación, se pueden ver los distintos elementos utilizados para la elaboración de la Tesis.

3.1.1 Equipamiento

Simulador de conducción:

Para las distintas publicaciones de la presente Tesis, se ha utilizado un simulador de conducción DriveSim adaptado, propiedad de la UBU (Ilustración 1). El simulador está formado por tres pantallas conectadas, cada una de ellas de 39” y con una resolución de 1920×1080 para proporcionar un amplio campo de visión del tráfico simulado, el entorno de la carretera y las condiciones meteorológicas. Los frames de simulación se generan en tiempo real con una frecuencia de actualización de 40 a 60 Hz gracias a las capacidades del hardware. La variación de frames depende de la carga gráfica en el entorno de realidad virtual (número de vehículos, peatones, objetos en escena…). El simulador está equipado con un volante, palanca de cambios y pedales (acelerador, freno y embrague), palancas de intermitentes, luces y llave de contacto.

El simulador además cuenta con tráfico y peatones y peatonas con inteligencia artificial para simular condiciones reales de tráfico, así como generar una variabilidad aun repitiendo rutas.

Ilustración 1 – Simulador de conducción.

En su experimentación más compleja, se han integrado otros dispositivos: (1) un eye tracker, (2) un marcador de tiempo y (3) smartphone colocado a la derecha del volante (Ilustración **2**).

Ilustración 2 – Simulador con smartphone y eye tracker.

Para los distintos experimentos ha sido necesario realizar modificaciones a medida sobre la versión comercial. Estas modificaciones, exclusivas para fines de la investigación, se han podido realizar gracias a que el Doctorando es uno de los desarrolladores originales del simulador. La empresa Drivesim (DRIVESIM SIMULATION S.A.) es propietaria del producto y el ITCL («ITCL Centro Tecnológico | I+D | inteligencia artificial | realidad virtual | energia») es el desarrollador del mismo.

A continuación, se detallan las modificaciones realizadas:

- Se añadió en la telemetría la velocidad máxima de la vía en cada instante para poder medir en cuanto se sobrepasa la velocidad máxima.
- Creación de una ruta específica pasando por el máximo de rotondas posible.
- Añadido de distintos triggers que permitan saber cuándo el conductor o la conductora se encuentra cerca o dentro de la rotonda (50 metros antes de la línea de detención, previo y posterior a la línea de detección, línea de detención y línea de salida) (Ilustración 3).

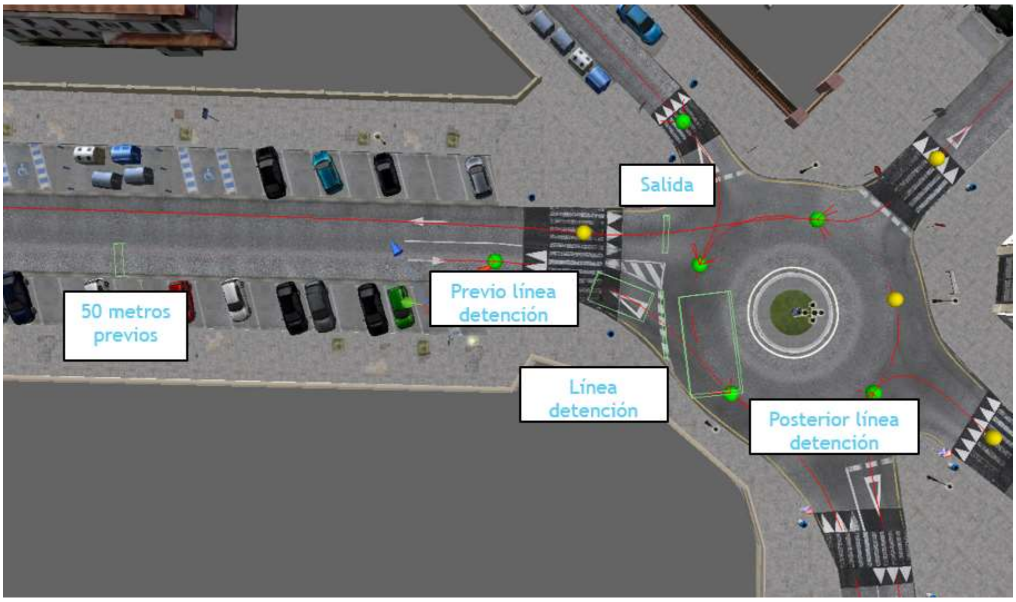


Ilustración 3 - Triggers rotondas.

- Aumento de la frecuencia de registro de telemetría a 1 registro cada frame en vez de cada 5 frames.
- Integración de reloj que exponga en todo momento el timestamp del simulador (Dia, hora, minutos, segundos y milisegundos)
- Cambios de la textura del vehículo para mejorar el seguimiento con dispositivo externo eye tracker.

Eye tracker Tobii

Para seguir los movimientos oculares de los participantes se utilizó un Tobii Pro Grasses 2 (Ilustración 4). Este sistema está compuesto por varias cámaras, giroscopio y acelerómetros que permiten realizar un seguimiento de la mirada del usuario o usuaria con alta precisión y frecuencia (100 Hz), estando diseñadas especialmente para estudios científicos y de producto.

Ilustración 4 - Eye tracker Tobii Pro 2.

Otro equipamiento

Igualmente ha sido necesario utilizar otros equipos más estándar. En ambos experimentos se hizo uso de smartphones para la generación de distracciones. En el primero de los experimentos se utilizó el smartphone para reproducir las canciones. En el segundo, el usuario o usuaria interactuó con el smartphone mientras conducía, respondiendo una llamada, además de utilizarlo para el acceso a aplicaciones de uso frecuente tales como Facebook, WhatsApp e Instagram.
También se han utilizado en todo el proceso de esta Tesis varios ordenadores siendo una herramienta esencial en este trabajo, empezando por la ejecución del simulador, el uso del equipamiento Tobii, pasando por la sincronización de datos, el análisis de los mismos y, desde luego, para la redacción de la Tesis.

3.1.2 Principal software utilizado:

A continuación, se describen los principales softwares utilizados para el desarrollo de la Tesis.

Matlab:

Matlab es un software de cálculo numérico que cuenta con un entorno de desarrollo con un lenguaje de programación propio que le permite programar análisis de datos muy avanzados. El software además cuenta con gran cantidad de librerías y extensiones que permite aplicar técnicas como Random Forest, Bayesian Networks… de un modo eficiente. Esta ha sido la principal herramienta de análisis de datos de la Tesis.

Tobii Pro Lab:

El eye tracker incluye un software propietario que permite analizar los datos que captura el equipo para proporcionar información de la mirada del usuario o usuaria por cada ojo. El proceso de análisis requiere cargar los datos de cada experimento, configurar el proyecto indicando las AOIs (Areas Of Interests en inglés), snapshots, eventos… y poner a procesar cada experimento por parte del software. Una vez procesado, el software permite exportar las métricas para su posterior análisis con otros programas como Excel o Matlab, entre otros.

Para los trabajos de esta Tesis fue necesario utilizar Tobbi Pro Lab con el objetivo de mapear el mundo real (entorno del simulador) y las AOIs con la mirada del usuario o usuaria. Para asegurar la calidad de seguimiento del sistema se añadieron varios marcadores en el marco de las pantallas. Esto es debido a que el eye tracker Tobbii utiliza principalmente referencias visuales para conectar el mundo real con el entorno de referencia. El entorno de RV del simulador cambia en cada fotograma por lo que no se puede utilizar como referencia para el seguimiento, ya que el entorno real externo no tenía suficiente detalle. En la Ilustración **5** se puede ver cómo el software relaciona la imagen del eye tracker con la visión (círculo rojo) en el retrovisor izquierdo, con el entorno completo del simulador. Esto junto con las AOIs nos permite saber dónde mira el usuario o usuaria en todo momento, respecto al montaje de laboratorio completo (retrovisores, volante, ventanillas…).

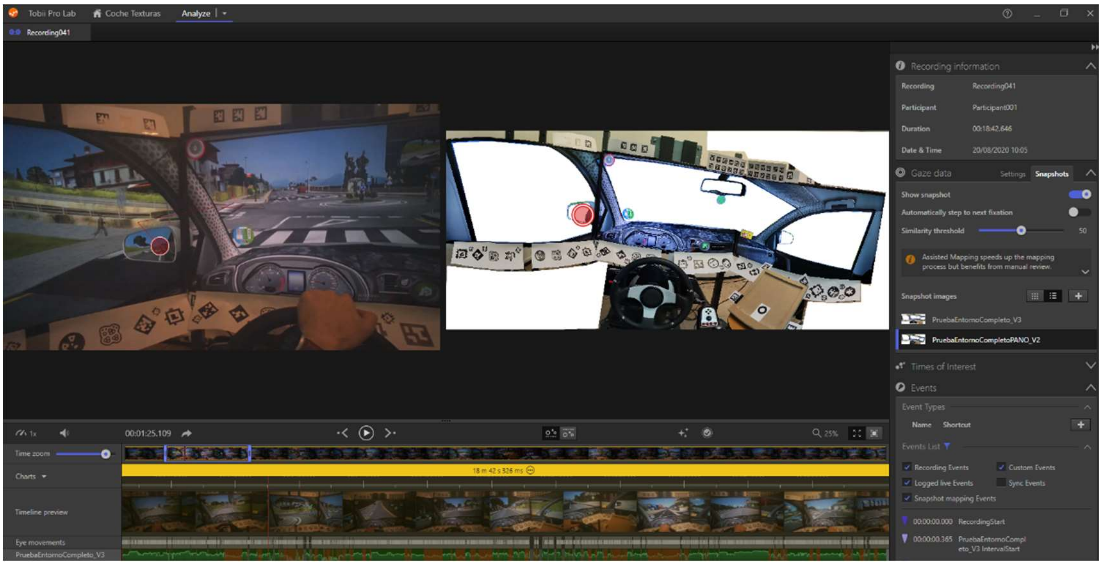


Ilustración 5 - Tobii visión del usuario o usuaria respecto al entorno real.

De acuerdo con los objetivos de las investigaciones se configuraron y agruparon principalmente 9 AOIs: ventanas (frontal, izquierda y derecha), espejos (frontal, izquierda y derecha), volante, salpicadero y smartphone (Ilustración **6**). Para el objetivo de la investigación se enfocó el análisis de datos principalmente en la fijación de mirada, que según el fabricante Tobbi *"Las fijaciones son aquellos momentos en los que nuestros ojos esencialmente dejan de escanear sobre la escena, manteniendo la visión foveal central en su lugar para que el sistema visual pueda tomar información detallada sobre lo que se está mirando* (Tobii AB 2022).

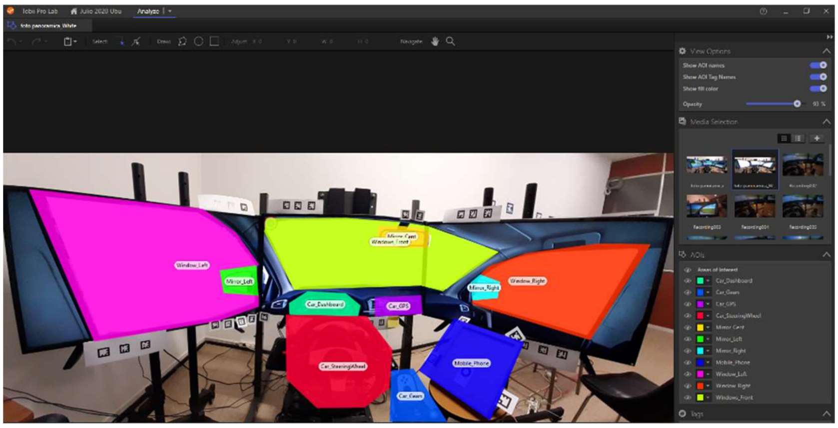


Ilustración 6 - AOIs definidas en el Eye Tracker.

DB Browser:

La base de datos del simulador utiliza SQLite como gestor de base de datos relacional, para poder visualizar, hacer consultas y extraer datos de dicha base de datos se utilizó en diversas ocasiones este visualizador gratuito.

Aplicaciones para el smartphone:

Se instalaron aplicaciones de uso frecuente para generar distracciones realistas mientras los usuarios conducían: Facebook, WhatsApp, Instagram y Spotify. También se utilizó una aplicación que permite registrar los instantes de tiempos de actividad de cada una de las aplicaciones, de modo que se pudiera sincronizar el uso de aplicaciones con otros eventos como, por ejemplo, las infracciones de tráfico.

Otros:

Igualmente ha sido necesario utilizar aplicaciones de ofimática para distintas fases de la tesis tales como Word, Office, Power Point y Mendeley Desktop.

3.2 Ejecución de los experimentos

Para la Tesis se han llevado a cabo dos experimentos que han generado las bases de datos utilizadas en los distintos artículos publicados. Los estudios han sido desarrollados siguiendo las guías de la Declaración de Helsinki y aprobadas por el Comité Ético de la Universidad de Burgos.

Primer experimento

El primer experimento se diseñó en varias fases. En la primera, todos los participantes rellenaron un cuestionario sobre información demográfica, posteriormente se informó a los y las participantes sobre los objetivos del estudio, sobre los diferentes pasos y se les dieron instrucciones para llevar a cabo el experimento. A continuación, los y las participantes realizaron una práctica de conducción durante varios minutos para familiarizarse y sentirse cómodos y cómodas con el entorno virtual y los diferentes dispositivos. Esta fase permite también descartar posibles participantes que se vean afectados por mareo en el simulador. En la fase de experimentación los y las participantes realizaron la misma ruta estándar del simulador "Vías de alto rendimiento", que transcurre por autovías, con y sin música de distintos tipos, iniciando con canciones de tristeza/relajantes y continuando con músicas que promueve agresividad/felicidad.

Segundo experimento

El segundo experimento fue más complejo y se diseñó para poder realizar varios estudios, explicados en distintas publicaciones. Al igual que con el primer experimento los y las participantes rellenaron un cuestionario demográfico y pasaron por una fase de habituación al simulador y al equipamiento.

En la segunda fase, todos los y las participantes condujeron el mismo escenario genérico en las mismas condiciones en el simulador de conducción, con tiempo despejado, conducción diurna y flujo de tráfico estable. El escenario de conducción consistía en conducir por una ruta guiada por vía interurbana y urbana que contiene cinco rotondas (Ilustración 7). Debido a que uno de los focos del segundo experimento eran las rotondas, el trazado completo se diseñó teniéndolo en cuenta. Por ello, según el mapa disponible en el simulador, se diseñó un trazado incluyendo nueve pasos por rotondas.

Ilustración 7 – Vista superior de la ruta.

Cada participante realizó dos experiencias de conducción utilizando el Eye Tracker Tobii. La primera experiencia fue una situación de conducción normal durante la cual los y las participantes condujeron por la carretera virtual. La segunda experiencia fue una condición de conducción con distracciones, en la cual los y las participantes debían realizar distintas acciones con el smartphone (responder mensajes, hacer llamada, publicar contenidos…).

Adicionalmente, después de cada fase de conducción, los y las participantes completaron el test de Nasa-TLX para computar la carga de trabajo de ambas experiencias de conducción.

3.3 Fuentes de datos. Recogida, tratamiento y sincronización:

Base de datos del simulador

La base de datos del simulador almacena distintos datos necesarios para las investigaciones realizadas. Los datos que almacena el simulador son:

- Aquellos relacionados con usuario y ejecuciones: Estudiante, fecha de ejercicio, id del ejercicio.
- Telemetría del vehículo de forma constante hasta 60 veces por segundo: Velocidad, posición y aceleración del vehículo, estado de los controles (volante, pedales, marcha, intermitentes, luces), estado del motor, revoluciones del motor y velocidad máxima de la vía.
- Infracciones: Instante y tipo de infracciones cometidas. Existen un total de 93 infracciones registradas por el simulador, desde muy graves como una fuerte colisión o saltarse un stop, a muy leves como calar el vehículo.

Base de datos del eye tracker

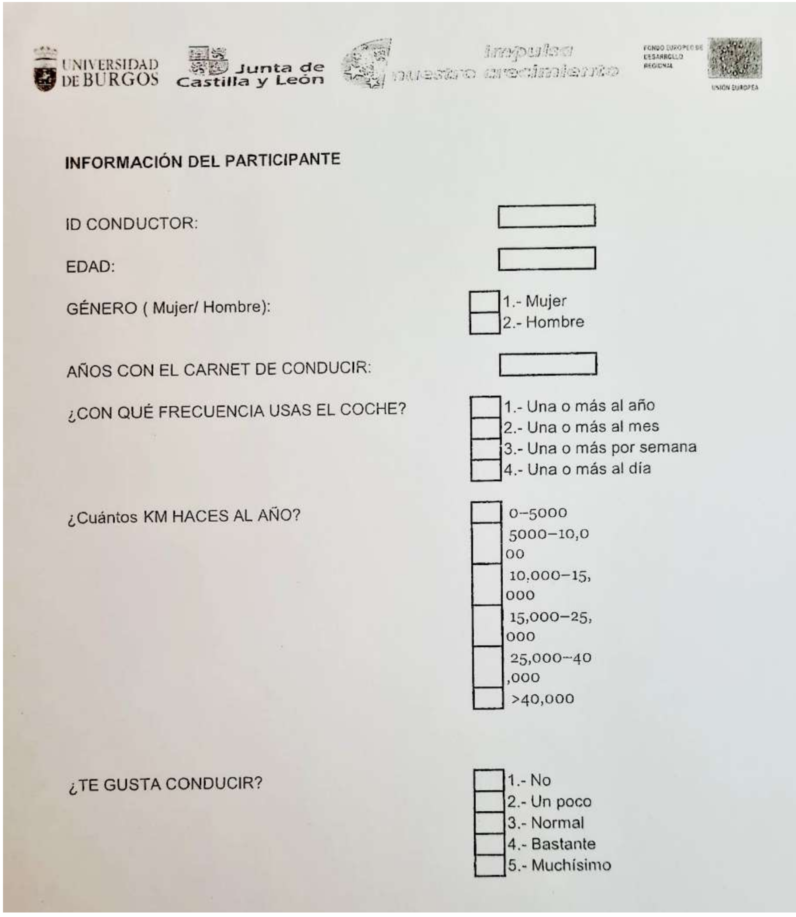
El Eye tracker Tobii proporciona datos relativos a la mirada del usuario o usuaria pudiendo relacionarlos con una imagen o imágenes de referencia mediante exportado a ficheros CSV. Los datos utilizados del tracker son principalmente:

- Datos de Fijación: Fijación de la mirada del usuario o usuaria en un punto, se produce en el momento en el que se deja de analizar el entorno y se centra en un punto. También se ha utilizado en las publicaciones el tiempo de fijación.
- Datos de AOIs: zona de interés definida en el software, en la que el usuario o usuaria ha fijado su mirada en un instante concreto.
- Datos de tamaño de la pupila.

- Videos grabados con tiempos (para la sincronización).

Cuestionario demográfico

El primer cuestionario utilizado permite obtener datos demográficos con la edad del conductor o conductora, género, años de carné de conducir, frecuencia de uso del coche (una o más al año, al mes, a la semana o al día), km al año (0-5.000; 5.000-10.000; 10.000-15.000; 15.000-25.000; 25.000-40.000; >40.000) y si al usuario o usuaria le gusta conducir (no, un poco, normal, bastante, muchísimo).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INFORMACIÓN DEL PARTICIPANTE

ID CONDUCTOR: ☐

EDAD: ☐

GÉNERO (Mujer/ Hombre): ☐ 1.- Mujer ☐ 2.- Hombre

AÑOS CON EL CARNET DE CONDUCIR: ☐

¿CON QUÉ FRECUENCIA USAS EL COCHE? ☐ 1.- Una o más al año ☐ 2.- Una o más al mes ☐ 3.- Una o más por semana ☐ 4.- Una o más al día

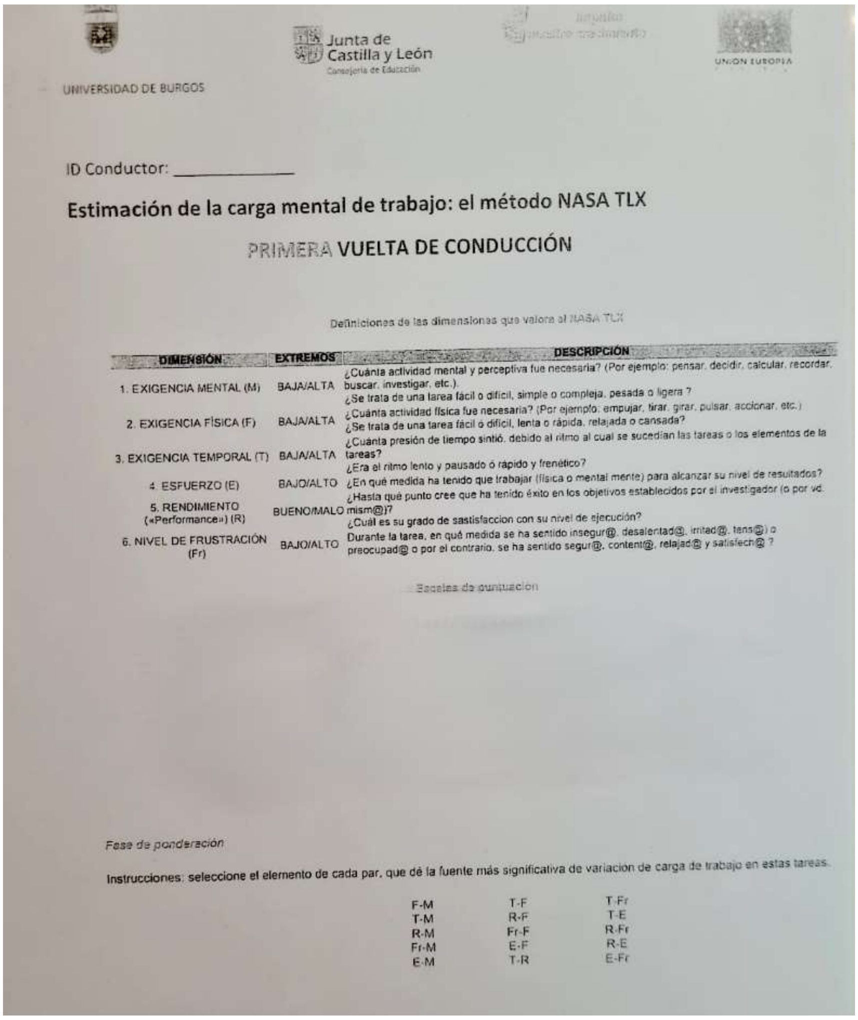
¿Cuántos KM HACES AL AÑO? ☐ 0–5000 ☐ 5000–10,000 ☐ 10,000–15,000 ☐ 15,000–25,000 ☐ 25,000–40,000 ☐ >40,000

¿TE GUSTA CONDUCIR? ☐ 1.- No ☐ 2.- Un poco ☐ 3.- Normal ☐ 4.- Bastante ☐ 5.- Muchísimo

Ilustración 8 – Foto del cuestionario demográfico original.

Cuestionario Nasa-TLX

El segundo cuestionario utilizado es el conocido test de carga de trabajo Nasa-TLX (National Aeronautics and Space Administration Task Load Index) que permite analizar la carga de una cierta tarea en cuanto a exigencia menta, física, temporal, de esfuerzo, de rendimiento y nivel de frustración. En el caso de la presente Tesis se utilizó para comparar la carga de dos tareas similares como conducir utilizando y no utilizando el smartphone



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Consejería de Educación

UNION EUROPEA

ID Conductor: ____________

Estimación de la carga mental de trabajo: el método NASA TLX

PRIMERA VUELTA DE CONDUCCIÓN

Definiciones de las dimensiones que valora el NASA TLX

DIMENSIÓN	EXTREMOS	DESCRIPCIÓN
1. EXIGENCIA MENTAL (M)	BAJA/ALTA	¿Cuánta actividad mental y perceptiva fue necesaria? (Por ejemplo: pensar, decidir, calcular, recordar, buscar, investigar, etc.). ¿Se trata de una tarea fácil o difícil, simple o compleja, pesada o ligera ?
2. EXIGENCIA FÍSICA (F)	BAJA/ALTA	¿Cuánta actividad física fue necesaria? (Por ejemplo: empujar, tirar, girar, pulsar, accionar, etc.) ¿Se trata de una tarea fácil o difícil, lenta o rápida, relajada o cansada?
3. EXIGENCIA TEMPORAL (T)	BAJA/ALTA	¿Cuánta presión de tiempo sintió, debido al ritmo al cual se sucedían las tareas o los elementos de la tareas? ¿Era el ritmo lento y pausado ó rápido y frenético?
4. ESFUERZO (E)	BAJO/ALTO	¿En qué medida ha tenido que trabajar (física o mental mente) para alcanzar su nivel de resultados?
5. RENDIMIENTO («Performance») (R)	BUENO/MALO	¿Hasta qué punto cree que ha tenido éxito en los objetivos establecidos por el investigador (o por vd. mism@)? ¿Cuál es su grado de sastisfaccion con su nivel de ejecución?
6. NIVEL DE FRUSTRACIÓN (Fr)	BAJO/ALTO	Durante la tarea, en qué medida se ha sentido insegur@, desalentad@, irritad@, tens@) o preocupad@ o por el contrario, se ha sentido segur@, content@, relajad@ y satisfech@ ?

Escalas de puntuación

Fase de ponderación

Instrucciones: seleccione el elemento de cada par, que dé la fuente más significativa de variación de carga de trabajo en estas tareas.

F-M	T-F	T-Fr
T-M	R-F	T-E
R-M	Fr-F	R-Fr
Fr-M	E-F	R-E
E-M	T-R	E-Fr

Ilustración 9 – Foto del cuestionario NASA-TLX original.

Sincronización de datos

La sincronización de datos es esencial para un correcto análisis de los datos. La configuración más compleja incluye tres sistemas distintos e independientes sobre los que se necesita dar una precisión de sincronización por debajo del segundo. Por ello se diseñó el siguiente sistema de sincronización que asegura una fiabilidad en los datos registrados.

Los eventos que se procesaron, principalmente los del eye tracker, tienen una precisión necesaria de milisegundos, por lo que para una sincronización precisa se añadió en el simulador un reloj que muestra en tiempo real el tiempo interno del simulador con milisegundos (el que se refleja posteriormente en la base de datos del simulador). En los casos en los que se utiliza el smartphone, siempre se inicia el experimento mirando con el eye tracker al smartphone mostrando la hora interna del mismo también con milisegundos. Estos datos quedan grabados en las imágenes del Eye Tracker Tobii. Para sincronizar los datos, cada vez que se va a procesar una grabación se busca una imagen en la que se vean ambos relojes de forma nítida y se apuntan junto con el tiempo del eye tracker, de modo que los tiempos de los 3 sistemas estén sincronizados. En la se puede ver en la Ilustración **10** sistema de sincronización con los tres relojes con alta precisión, ya que para estos experimentos los milisegundos son importantes debido al tipo de eventos procesados.

Ilustración 10 – Proceso de sincronización de datos.

En el caso del experimento de música se utiliza una aplicación instalada en el smartphone para sincronizar la reproducción de las canciones con los eventos de la base de datos y los tiempos relativos entre simulador y smartphone.

3.4 Metodología de análisis

A continuación, se hace una breve descripción de los principales métodos de análisis utilizados. No es el objetivo de esta sección describir cada método con profundidad sino dar una introducción a dichos métodos para facilitar la lectura de la Tesis y resultados. La información sobre Redes Bayesianas y Validación cruzada proviene del artículo “Music Distraction among Young Drivers: Analysis by Gender” (Catalina, García-Herrero, Cabrerizo, et al. 2020), y la información sobre Decisión Trees y Random Forest proviene del artículo “Effects of Mobile Phone Use on Driving Performance: An Experimental Study of Workload and Traffic Violations” (Catalina et al. 2021), ambos artículos forman parte de la presente Tesis. Otras herramientas de análisis estadístico utilizadas en la presente Tesis, y no descritas en este apartado, porque son más conocidas, son las siguientes: ANOVA, T-Test paired y one side, Mann-Whitney U-test.

3.4.1 Redes Bayesianas

Las Redes Bayesianas Discretas (BNs Bayesian Networks), son altamente reconocidas como técnica de aprendizaje automático con la que se aprende eficientemente la Distribución de Probabilidad Conjunta (JPD – Joint Probability Distribution) (Ecuación **1**) de un problema multivariante que involucra variables aleatorias discretas X= {X_1,…,X_n } (Ecuación **2**), donde X_i es cada variable considerada en el modelo. El modelo creado permite estimar la probabilidad de cada variable (inferencia) a partir del conocimiento del estado de una o varias del resto de las variables (evidencia).

Las Redes Bayesianas son modelos que combinan las teorías de la probabilidad y de grafos para aprender eficientemente la JPD de las variables aleatorias consideradas (Xi):

$$p(X_1, \ldots, X_n)$$

Ecuación 1 – JPD

En particular, las BNs se basan en Grafos Acíclicos Dirigidos (Ilustración **11**) (DAG Direct Acyclic Graph) que representan la dependencia probabilística, directa o condicional, entre las variables y, utilizando la regla de Bayes, permiten factorizar la JPD

$$p(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} p(x_i|\pi_i)$$

Ecuación 2 – Función de probabilidad conjunta de la red bayesiana

Donde x_i corresponde a una realización de la variable aleatoria X_i y π_i es el conjunto de padres del nodo X_i en el grafo, es decir, el conjunto de nodos enlazados con X_i por una flecha que apunta a este nodo. A modo de ejemplo, en el grafo de la Ilustración **11** se puede ver la factorización resultante del artículo sobre los efectos de la música (Catalina, García-Herrero, Cabrerizo, et al. 2020). En él se puede ver, como Speed es la variable core, localizada en el centro del grafo, con dependencias con sus padres (Gender, Driver experience y Braking) y con sus hijos (Infraction, Acceleration, RPM y Music)

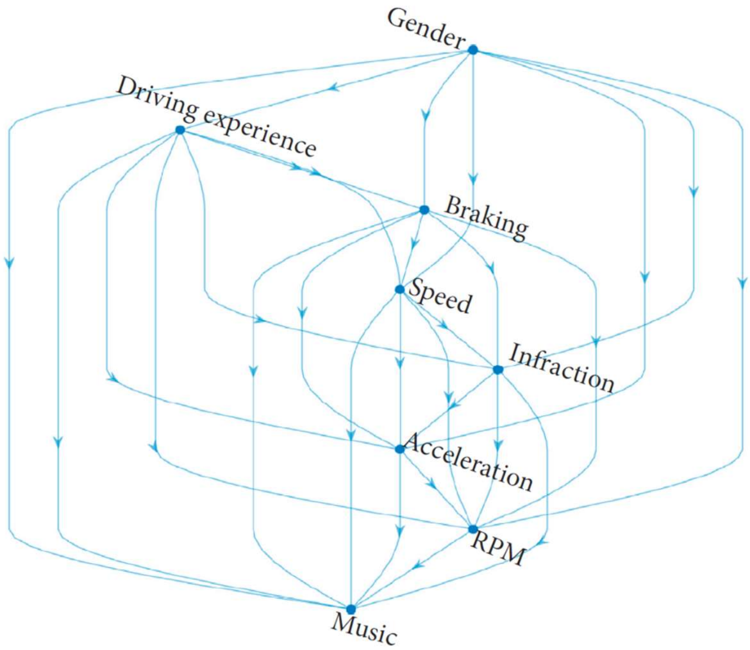

Ilustración 11 – DAG de la Red Bayesiana sobre distracciones relacionadas con la música

En consecuencia, primero se obtiene el DAG aplicando el algoritmo de aprendizaje basado en parámetros de bondad de ajuste definido por (Buntine 1991) y, a continuación, se estiman por máxima verosimilitud, los parámetros asociados a las diferentes tablas de probabilidad definidas en la factorización como los que mejor explican los datos observados.

3.4.2 Validación cruzada

Una vez obtenido el modelo e identificada la variable objetivo se puede definir un modelo de clasificación para ésta a partir de las probabilidades que devuelve la red bayesiana para cada uno de los estados de la variable objetivo. La evaluación de los modelos se realiza a través de una validación cruzada basada en dividir la muestra en 10 conjuntos disjuntos (10-fold), creando una partición aleatoria de la base de datos en diez submuestras, utilizando así el 90% para entrenar y el 10% restante para evaluar, y repitiendo este proceso para los 10 subconjuntos, con el fin de conocer la capacidad de nuestro modelo de generalizar a nuevos datos y para evitar el sobreajuste. Como resultado se obtienen 11 muestras-test, una por submuestra y la última considerando la predicción de la muestra completa obtenida al unir las 10 submuestras.

La evaluación de cada modelo se puede realizar utilizando el área bajo la curva ROC (Receiver Operating Characteristic) (AUC) (Fawcett 2006), que es un parámetro estándar para clasificadores probabilísticos y binarios que varía de 0,5 (conjetura aleatoria) a 1 (rendimiento perfecto), el cual es considerado como una medida de la precisión global del modelo (Hanley y McNeil 1982).

3.4.3 Decision Trees

Tanto en este caso como en el de Random Forest, que veremos a continuación, se trabajan modelos de clasificación, Y = f(X), donde la variable dependiente u objetivo (variable que queremos predecir o explicar) Y es una variable categórica y las variables independiente o explicativas (X, variables que nos deben permitir predecir la variable objetivo) pueden ser categóricas o cuantitativas.

Los métodos basados en Trees (Breiman et al. 2017), o árboles en castellano, definen un árbol en el cual cada nodo corresponde a un test sobre una variable explicativa (Ej: Distracciones por uso del smartphone), cada rama corresponde a un valor de dicha variable (Ej: Distracción por uso del móvil = Sí o No), y cada hoja o nodo terminal representa un valor final (Ej: Infracción = Sí) que se asigna a la submuestra que cumple las diferentes condiciones del camino para llegar desde la parte superior del árbol a dicha hoja. De este modo, las sucesivas subdivisiones definidas por cada nodo dan lugar a una partición del espacio de las variables explicativas. Cada división se define obteniendo la mejor división, determinada por un criterio de pureza (Ecuación 3), elegido sobre la variable objetivo (ej: infracciones sí o no), en base a cuan homogénea o heterogénea sean los nodos terminales obtenidos realizando dicha división. En particular, el índice de Gini se utiliza para problemas de clasificación (Ecuación **3**) y la suma de los residuos cuadrados (RSS Residual Sum of Squares) en el caso de problemas de predicción.

$$\text{GINI} = 1 - \sum_{i=1}^{n} p_i^2$$

Ecuación 3 – Índice Gini

Estos métodos presentan varias ventajas e inconvenientes bien conocidos. En primer lugar, los árboles tienen una representación gráfica fácil de asimilar e interpretar. En comparación con otros métodos, los árboles de decisión pueden construirse con relativa rapidez y no requieren de una muestra muy grande para obtener resultados competitivos. En segundo lugar, algunas variables explicativas podrían no seleccionarse para hacer crecer el árbol, ya que son secundarias en términos del incremento de la pureza global de la partición obtenida. Por este motivo, pueden utilizarse también como método de selección de variables explicativas en un preproceso para otros algoritmos de aprendizaje. En tercer lugar, funcionan tanto con predictores cuantitativos como cualitativos (es decir, discretos). Como desventaja, para un árbol suficientemente complejo (es decir, grande o profundo), aunque todas las instancias podrían clasificarse correctamente, esto suele dar lugar a modelos sobreajustados.

3.4.4 Random forest

Random Forest (Breiman 2001) es un algoritmo de aprendizaje automático basado en árboles que se utiliza para construir modelos predictivos. Para ello se utiliza una combinación de técnicas de Bootstrap y de bagging (boosting aggregation) para crear un conjunto de árboles independientes, de ahí el apelativo de bosque.

La técnica se basa en la construcción de un gran número de árboles independientes, para lo cual cada árbol es entrenado con un subconjunto aleatorio de variables y una muestra aleatoria del conjunto de datos de entrenamiento. De este modo, se obtiene un conjunto de predicciones, cada una de ellas asociada a un árbol. Una vez que se han construido todos los árboles, se utiliza un promedio ponderado de sus predicciones para clasificar nuevos objetos o predecir nuevas respuestas Ilustración 12.

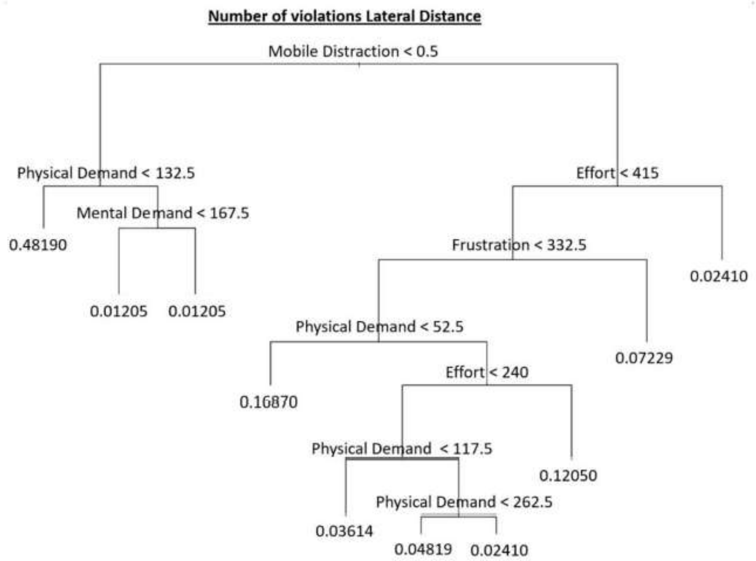

Ilustración 12 - Ejemplo de Regression Tree generado por el método de Random forest relativo el número de infracciones relacionadas con la distancia lateral. (Catalina et al. 2021)

Puesto que se generan múltiples árboles independientes, se producen distintas predicciones para el mismo conjunto de datos. Para obtener una única predicción final se utilizan técnicas de combinación de predicciones. Para la clasificación se suele utilizar el método de la mayoría de los votos, de modo que se toma la predicción más frecuente de todas las instancias como predicción final de la muestra. Para la regresión se suele utilizar el promedio de todas las predicciones obtenidas por todos los árboles independientes. Podemos ver en este árbol de regresión, cuyo objetivo es determinar los factores que contribuyen a las infracciones que comete el conductor relacionadas con distancia lateral, como la variable explicativa Mobile Distraction aparece en el primer nodo, con el resto como hijos suyos. Esto refleja la capacidad de esta variable para aislar muestras homogéneas y con diferencias significativas en cuanto al número de penalizaciones entre las submuestras con y sin distracciones móviles. Igualmente podemos ver en cada nodo hoja la predicción de porcentaje de número de penalizaciones según los valores que tomen las variables explicativas.

Obsérvese que, a pesar del sobreajuste de cada árbol en particular, la media de múltiples arboles independientes evita el sobreajuste del Random Forest. Sin embargo, la representación gráfica del bosque aleatorio no es posible y, en consecuencia, su interpretación es más difícil. Para superar parcialmente este problema se utiliza la importancia de cada variable explicativa en términos de la reducción de error obtenida cuando esta variable objetivo es elegida en un nodo, que suele representarse en modo de diagrama de barras Ilustración 13. Esta medida puede utilizarse como una estimación de la contribución de cada variable al objetivo del modelo.

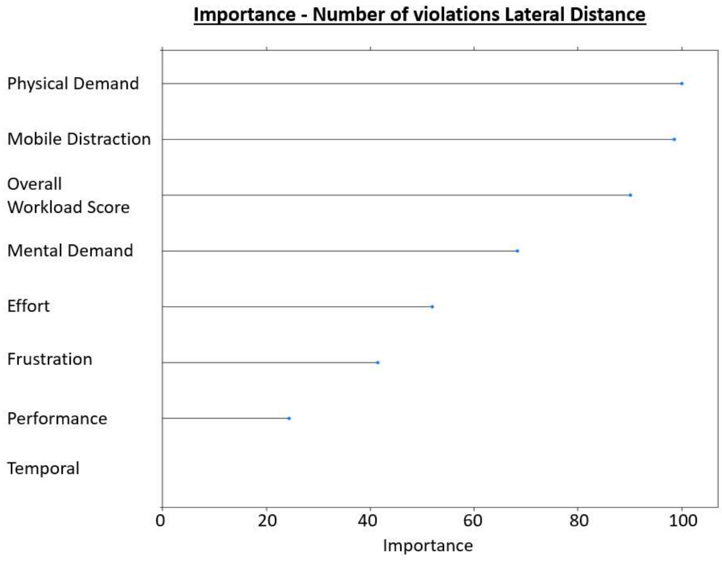

Ilustración 13 – Gráfico de importancia de cada variable relativo al número de infracciones relacionadas con distancia lateral.

RESUMEN DE CONTRIBUCIONES CIENTÍFICAS

4 Resumen de contribuciones y resultados

4.1 Music Distraction among Young Drivers: Analysis by Gender and Experience (Catalina et al. 2020)

Título: Music Distraction among Young Drivers: Analysis by Gender and Experience	
Revista: Journal of Advanced Transportation	**DOI:** https://doi.org/10.1155/2020/6039762
Citaciones: 8	Site: https://www.hindawi.com/journals/jat/2020/6039762/
Fecha de envío: 19-9-2019	**Fecha de publicación:** 14-8-2020
Base de datos de indexación: JCR (WOS)	
Categoría: ENGINEERING, CIVIL	**Índice de impacto:** 2020 2.419
Posición que ocupa la revista: 70	**Número de revistas en el área:** 137
Quartil: Q3	**Año:** 2020
Categoría: TRANSPORTATION SCIENCE & TECHNOLOGY	**Índice de impacto:** 2020 2.419
Posición que ocupa la revista: 22	**Número de revistas en el área:** 37
Quartil: Q3	**Año:** 2020
Base de datos de indexación: SJR (SCOPUS)	
Categoría: Economics, Econometrics and Finance	**Índice de impacto:** SJR 0.569
Posición que ocupa la revista: 149	**Número de revistas en el área:** 661
Quartil: Q1	**Año:** 2020
Categoría: Engineering	**Índice de impacto:** SJR 0.569
Posición que ocupa la revista: 24	**Número de revistas en el área:** 95
Quartil: Q1	**Año:** 2020
Citar como: Carlos A. Catalina, Susana García-Herrero, Elvira Cabrerizo, Sixto Herrera, Santiago García-Pineda, Fatemeh Mohamadi, M. A. Mariscal, "Music Distraction among Young Drivers: Analysis by Gender and Experience", Journal of Advanced Transportation, vol. 2020, Article ID 6039762, 12 pages, 2020. https://doi.org/10.1155/2020/6039762	

Citas recibidas:

Babić, D., Babić, D., Sucha, M., Stanić, V., & Toman, M. (2021). The influence of music genres on the driving behaviour of young drivers and their visual scanning of the environment. *Transportation research part F: traffic psychology and behaviour*, *81*, 396-407.

García-Herrero, S., Febres, J. D., Boulagouas, W., Gutiérrez, J. M., & Mariscal Saldaña, M. Á. (2021). Assessment of the influence of technology-based distracted driving on drivers' infractions and their subsequent impact on traffic accidents severity. *International journal of environmental research and public health*, *18*(13), 7155.

Karageorghis, C. I., Payre, W., Howard, L. W., Kuan, G., Mouchlianitis, E., Reed, N., & Parkes, A. M. (2022). Influence of music on driver psychology and safety-relevant behaviours: a multi-study inductive content analysis. *TheoreTical issues in ergonomics science*, *23*(6), 643-662.

Molero, G. D., Poveda-Reyes, S., Malviya, A. K., García-Jiménez, E., Leva, M. C., & Santarremigia, F. E. (2021). Computational Solutions Based on Bayesian Networks to Hierarchize and to Predict Factors Influencing Gender Fairness in the Transport System: Four Use Cases. *Sustainability*, *13*(20), 11372.

Bates, L., Alexander, M., Van Felius, M., Seccombe, J., & Bures, E. (2021). What is known about distracted driving?.

Mesquitela, J. C. P. S. M. (2021). *A data-driven approach to road accidents in the municipality of Lisbon* (Doctoral dissertation).

ABADI, D. F. (2022). Analisis Pengaruh Mendengarkan Podcast Terhadap Performansi Pengemudi Menggunakan Driving Simulator Dan Muse Brain Sensing Headband.

Metodología Resumida:

- 19 participantes de entre 20 y 28 años.
- Test demográfico.
- Ruta corta habituación al simulador para descartar participantes sensibles al mareo.
- Ruta sin música (10 min).
- Ruta con música 10 min, primero tristes/relajación y luego agresividad/felicidad seleccionada por cada usuario de lista de 20.

Herramientas:

- Simulador de conducción adaptado con datos de telemetría.
- Smartphone con música y herramienta de telemetría de uso del móvil.
- Test demográfico.

Métodos de estudio analítico:

- Redes bayesianas.
- Análisis de tabulación cruzada.

Principales contribuciones:

- Modelo conceptual que incluye variables relacionadas con la música, con datos demográficos y de experiencia en la conducción, de telemetría (infracciones, aceleración, RPMs, frenadas y aceleraciones) y de adecuación de la velocidad. Modelo validado con todas las AUCs (Areas Under Curve) superiores a 0,7.
- Gráfico de red Bayesiana con la velocidad como variable principal localizada en el centro del mismo con links directos con todas las variables consideradas en el modelo.
- Influencia de la música en la probabilidad de cometer una infracción de velocidad teniendo en cuenta distintos factores como la existencia o no de música, el tipo de música, género del conductor o conductora y experiencia.

4.2 Analysis of Drivers' Eye Movements on Roundabouts: A Driving Simulator Study (Azimian et al. 2021)

Título: Analysis of Drivers' Eye Movements on Roundabouts: A Driving Simulator Study	
Revista: Sustainability	**DOI:** https://doi.org/10.3390/su13137463
Citaciones: 5	**Site:** https://www.mdpi.com/2071-1050/13/13/7463
Fecha de envío: 1-6-2021	**Fecha de publicación:** 4-6-2021
Base de datos de indexación: JCR (WOS)	
Categoría: ENVIRONMENTAL SCIENCES	**Índice de impacto:** 2021 3.889
Posición que ocupa la revista: 133	**Número de revistas en el área:** 279
Quartil: Q2	**Año:** 2021
Categoría: ENVIRONMENTAL STUDIES	**Índice de impacto:** 2021 3.889
Posición que ocupa la revista: 57	**Número de revistas en el área:** 128
Quartil: Q2	**Año:** 2021
Base de datos de indexación: SJR (SCOPUS)	
Categoría: Social Sciences	**Índice de impacto:** SJR 2021 0.664
Posición que ocupa la revista: 110	**Número de revistas en el área:** 704
Quartil: Q1	**Año:**
Categoría: Environmental Science	**Índice de impacto:** SJR 2021 0.664
Posición que ocupa la revista: 18	**Número de revistas en el área:** 104
Quartil: Q1	**Año:**
Citar como: Azimian, A., Catalina Ortega, C. A., Espinosa, J. M., Mariscal, M. Á., & García-Herrero, S. (2021). Analysis of drivers' eye movements on roundabouts: A driving simulator study. *Sustainability*, *13*(13), 7463.	
Citas recibidas: Ren, R., Li, H., Han, T., Tian, C., Zhang, C., Zhang, J., ... & Feng, Y. (2023). Vehicle crash simulations for safety: Introduction of connected and automated vehicles on the roadways. *Accident Analysis & Prevention*, *186*, 107021. Hsieh, Y. L., Lee, M. F., Chen, G. S., & Wang, W. J. (2022). Application of Visitor Eye Movement Information to Museum Exhibit Analysis. *Sustainability*, *14*(11), 6932.	

Al Aufi, A., Schmidt, C., Goetz, J., & Haleem, K. (2022). Investigating “Texting while Driving” Behavior at Different Roadway Configurations Using a Driving Simulator Setting. *Transportation research record*, *2676*(3), 183-200.

Xu, W., Feng, L., & Ma, J. (2022). Understanding the domain of driving distraction with knowledge graphs. *PLoS one*, *17*(12), e0278822.

Li, G., Wu, X., Eichberger, A., Green, P., Olaverri-Monreal, C., Yan, W., ... & Li, Y. (2023). Drivers’ EEG Responses to Different Distraction Tasks. *Automotive Innovation*, 1-12.

Metodología resumida:

- 45 participantes de entre 19 y 56 años.
- Test demográfico.
- Ruta corta habituación al simulador (descarga posibles personas sensibles al mareo).
- Ruta sin distracciones.
- Test Nasa TLX
- Ruta con distracciones.

Herramientas:

- Simulador de conducción adaptado.
- SmartPhone.
- Tobii Pro Glasses 2.
- Test demográfico y Nasa-TLX.

Métodos de estudio analítico:

- Paired T-test.
- One Side T-test.
- Mann-Whitney U-test.

Principales contribuciones:

- Se aprecian diferencias significativas en fixation del eye tracker en todas las AOIs (Area Of Interest) con distracciones por uso del smartphone. Según la zona de la rotonda (desde 50 metros antes de la misma hasta la salida) se obtienen distintas diferencias siendo no significativas en algunos de los casos, esto permite hacer hipótesis sobre el comportamiento de los conductores y las conductoras con distracciones.

- El estudio muestra que el tamaño de la pupila se incrementa significativamente. Este resultado es consistente con la literatura y con otras investigaciones similares.
- No se encuentran diferencias por género.

4.3 Effects of Mobile Phone Use on Driving Performance: An Experimental Study of Workload and Traffic Violations (Catalina et al. 2021)

Título: Effects of Mobile Phone Use on Driving Performance: An Experimental Study of Workload and Traffic Violations	
Revista: International Journal of Environmental Research and Public Health	**DOI:** https://doi.org/10.3390/ijerph18137101
Citaciones: 9	Site: https://www.mdpi.com/1660-4601/18/13/7101
Fecha de envío: 1 June 2021	**Fecha de publicación:** 2 July 2021
Base de datos de indexación: JCR (WOS)	
Categoría: ENVIRONMENTAL SCIENCES	**Índice de impacto:** 2021 4.614
Posición que ocupa la revista: 100	**Número de revistas en el área:** 279
Quartil: Q2	**Año:** 2021
Categoría: PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	**Índice de impacto:** 2021 4.614
Posición que ocupa la revista: 71	**Número de revistas en el área:** 210
Quartil: Q2	**Año:** 2021
Base de datos de indexación: SJR (SCOPUS)	
Categoría: Medicine	**Índice de impacto:** SJR 2021 0.814
Posición que ocupa la revista: 139	**Número de revistas en el área:** 562
Quartil: Q1	**Año:** 2021
Categoría: Environmental Science	**Índice de impacto:** SJR 2021 0.814
Posición que ocupa la revista: 57	**Número de revistas en el área:** 144
Quartil: Q2	**Año:** 2021
Citar como: Ortega, C. A. C., Mariscal, M. A., Boulagouas, W., Herrera, S., Espinosa, J. M., & García-Herrero, S. (2021). Effects of mobile phone use on driving performance: an experimental study of workload and traffic violations. *International journal of environmental research and public health*, *18*(13), 7101.	

Citas recibidas:

Boboc, R. G., Voinea, G. D., Buzdugan, I. D., & Antonya, C. (2022). Talking on the phone while driving: A literature review on driving simulator studies. *International journal of environmental research and public health*, *19*(17), 10554.

Voinea, G. D., Boboc, R. G., Buzdugan, I. D., Antonya, C., & Yannis, G. (2023). Texting while driving: a literature review on driving simulator studies. *International journal of environmental research and public health*, *20*(5), 4354.

Ali, Y., & Haque, M. M. (2023). Modelling braking behaviour of distracted young drivers in car-following interactions: a grouped random parameters duration model with heterogeneity-in-means. *Accident Analysis & Prevention*, *185*, 107015.

Li, G., Wu, X., Eichberger, A., Green, P., Olaverri-Monreal, C., Yan, W., ... & Li, Y. (2023). Drivers' EEG Responses to Different Distraction Tasks. *Automotive Innovation*, 1-12.

Liu, R., Qi, S., Hao, S., Lian, G., Li, Y., & Yang, H. (2023). Drivers' Workload Electroencephalogram Characteristics in Cognitive Tasks Based on Improved Multiscale Sample Entropy. *IEEE Access*.

Mishra, S., & Mehran, B. (2022). Traffic safety culture of drivers in Canada: implications for new traffic law implementation to enhance traffic safety. *IATSS research*, *46*(1), 82-92.

Mareška, A., Kordová, T., & Havlík Míka, M. (2022). Production of head-up display windshield and its relation with the image quality. *Transactions on transport sciences*, *13*(2), 63-70.

Madani, K. E. Driving and using mobile phone among medical students at Al-Majmaah University. *World*.

Sutantio, K. A., & Widyanti, A. Literature Review on Acceptance of Technology for Reducing Distracted Driving.

Metodología resumida:

- 39 participantes de entre 19 y 32 años.
- Test demográfico.
- Ruta corta habituación al simulador para descartar participantes sensibles al mareo.
- Ruta sin distracciones.
- Test Nasa TLX.
- Ruta con distracciones usando el smartphone.

Herramientas:

- Simulador de conducción adaptado con datos de telemetría.
- Smartphone.
- Test demográfico y Test NASA TLX.

Métodos de estudio analítico:

- Análisis de varianza (ANOVA).
- Random Forest.
- Classification and regression trees.

Principales contribuciones:

- El análisis de los datos encontró diferencias significativas en las infracciones relacionadas con la posición lateral con y sin distracción. Concretamente el grupo de infracciones de distancia lateral tiene p-value <0.001 lo cual es consistente con la literatura relacionada con distracciones por smartphone.
- El estudio de carga de trabajo encontró diferencias significativas en la carga mental, física, de esfuerzo, rendimiento y en el cómputo global. Mostrando que, aun siendo una tarea muy común entre los conductores y conductoras, estos son conscientes de que requiere esfuerzo en muchos aspectos.
- El estudio realizado mediante la técnica de Random Forest muestra la distracción por el móvil y la carga mental global, como primer nodo en la división en las infracciones relacionadas con distancia lateral. Esto permite evidenciar la importancia de ambos factores en el estudio. Adicionalmente, estos factores son de gran importancia también en otras infracciones, siendo el primero o segundo en importancia en 3 categorías agrupadas de infracciones y 22 infracciones individuales.

4.4 Estimating the Probability of Committing Traffic Infraction due to Mobile Use: Driving Simulator Study (Catalina et al. 2020)

Título: Estimating the Probability of Committing Traffic Infraction due to Mobile Use: Driving Simulator Study	
Editorial: Research Publishing, Singapore	**DOI:** 10.3850/978-981-14-8593-0_4116-cd
Congreso: Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference, PSAM 2020 **ISBN** :978-981148593-0	Site: http://rpsonline.com.sg/proceedings/9789811485930/html/4116.xml
Fecha de envio: 12 febrero 2020	**Fecha de publicación:** 5-11-2020
Base de datos de indexación: SCOPUS	
https://www.scopus.com/record/display.uri?eid=2-s2.0-85110394504&origin=resultslist&sort=plf-f&src=s&st1=Estimating+the+Probability+of+Committing+Traffic+Infraction+due+to+Mobile+Use%3a+Driving+Simulator+Study&sid=8732a77a40b020794b68d40a25df63a1&sot=b&sdt=b&sl=117&s=TITLE-ABS-KEY%28Estimating+the+Probability+of+Committing+Traffic+Infraction+due+to+Mobile+Use%3a+Driving+Simulator+Study%29&relpos=0&citeCnt=0&searchTerm=	
Citar como: Catalina Ortega, C.A.; García-Herrero, S.; Azimian, A.; García, A.; Mariscal, M.A. *Estimating the Probability of Committing Traffic Infraction due to Mobile Use: Driving Simulator Study*; Research Publishing Services: Chennai, India, 2020; pp. 2585–2591	

Metodología resumida:

- 20 participantes con edades comprendidas entre 20 y 28 años.
- Test demográfico.
- Ruta corta habituación al simulador para descartar participantes sensibles al mareo.
- Ruta con distracciones usando el smartphone.
- Cuestionario para verificar que se ha prestado atención a las tareas.

Herramientas:

- Simulador de conducción adaptado.
- Smartphone.
- Aplicaciones móviles usadas: Facebook, WhatsApp e Instagram.
- Aplicación móvil para medir tiempos de uso.

Métodos de estudio analítico:

- Redes Bayesianas.

Principales contribuciones:

- El aumento de probabilidad de infracción aumenta en gran medida sea cual sea el tiempo de uso de la aplicación, siendo la franja con mayor probabilidad la que va entre los 15 y 30 segundos.
- La probabilidad de infracción aumenta con todas las aplicaciones (Facebook, WhatsApp e Instagram).
- Los conductores y conductoras experimentados tienen un porcentaje menor de probabilidad de infracción.

4.5 Effects of Mobile Phone-Related Distraction on Driving Performance: Eye Movements Tracking Perspective

Título: Effects of Mobile Phone-Related Distraction on Driving Performance at Roundabouts: Eye Movements Tracking Perspective	
Revista: TRANSPORTATION RESEARCH PART F-TRAFFIC PSYCHOLOGY AND BEHAVIOUR	**DOI: Artículo en revisión**
Fecha de envío: 20 Enero 2023	**Fecha de publicación: Artículo en revisión**
Base de datos de indexación: JCR (WOS)	
Categoría: PSYCHOLOGY, APPLIED	**Índice de impacto: 2021** 4.349
Posición que ocupa la revista: 28	**Número de revistas en el área:** 83
Quartil: Q2	**Año:** 2021
Categoría: TRANSPORTATION	**Índice de impacto: 2021** 4.349
Posición que ocupa la revista: 15	**Número de revistas en el área:** 37
Quartil: Q2	**Año:** 2021
Base de datos de indexación: SJR (SCOPUS)	
Categoría: Engineering	**Índice de impacto**: SJR 2021 1.462
Posición que ocupa la revista: 38	**Número de revistas en el área:** 326
Quartil: Q1	**Año:** 2021
Categoría: Social Sciences	**Índice de impacto:** SJR 2021 1.462
Posición que ocupa la revista: 23	**Número de revistas en el área:** 117
Quartil: Q1	**Año:** 2021
Citar como: Under Review	

Metodología resumida:

- 43 participantes de entre 19 y 56 años.
- Test demográfico.
- Ruta corta habituación al simulador para descartar participantes sensibles al mareo.
- Ruta sin distracciones.
- Ruta con distracciones usando el smartphone.

Herramientas:

- Simulador de conducción adaptado con datos de telemetría.
- Smartphone.
- Tobii Pro Glasses 2.

Métodos de estudio analítico

- Análisis de varianza (ANOVA).
- T-test, Z-test.

Principales contribuciones:

El artículo se centra en estudiar la mirada del usuario o usuaria en las distintas AOIs con y sin distracciones en rotondas y su relación con las infracciones cometidas.

El artículo cuenta con una ruta en la que se pasa por rotondas en 7 ocasiones y detalla entradas y salidas.

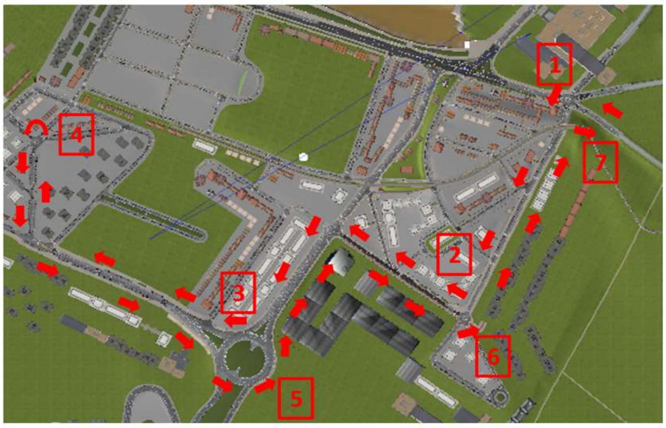

Figure 7. Top view of the virtual urban road

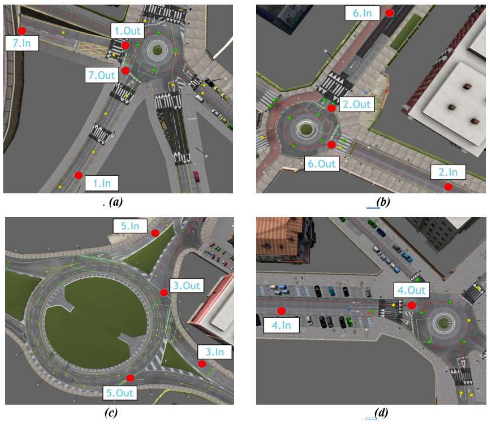

Figure 8. Detailed information about the In and Out of each roundabout in the route where data was collected: (a) roundabouts 1 and 7 of the route; (b) roundabouts 2 and 6 of the route; (c) roundabouts 3 and 5 of the route; and (d) roundabout 4.

- Se observan diferencias de fijación de mirada en la ventanilla y retrovisor izquierdo en rotondas grandes y pequeñas.
- Relacionado con la distracción por uso de Smarphone se observa que el usuario o usuaria mira más a la ventanilla y retrovisor izquierdo cuando no hay distracciones.
- A nivel sociológico se observa que más años de experiencia en la conducción contribuye a que los participantes observen más la ventanilla y el retrovisor izquierdo en las rotondas.
- Hay relación significativa entre mirar más a la ventanilla y al retrovisor izquierdo y cometer menos infracciones.

4.6 Otras publicaciones científicas y proyectos de investigación del autor.

La carrera de investigación del autor empieza en 2006 participando en proyectos de investigación regional y evoluciona los siguientes años hasta trabajar en varios proyectos e incluso liderar varios de ellos. En total el investigador ha trabajado en 4 Proyectos Europeos (1 AAL y 3 H2020), 12 Proyectos de investigación nacional y 4 proyectos de investigación regional. Fruto de dichos proyectos se cuenta con varias publicaciones previas que no forman parte de esta Tesis, pero dan una visión de la evolución de su carrera como investigador.

Indexado JCR
Revista Científica de Comunicación y Educación Comunicar
DOI: https://doi.org/10.3916/C45-2015-07
SJR:1.257
JCR-JIF 1.438 Q1
Fecha: 1-7-2015
Citaciones: 41
SARACCHINI, R., CATALINA, C.A. y BORDONI, L., 2015. A mobile augmented reality assistive technology for the elderly. *Comunicar*, vol. 23, no. 45. ISSN 19883293. DOI 10.3916/C45-2015-07. (Saracchini, Catalina y Bordoni 2015)

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2015 (Ejemplar dedicado a: Realidad virtual y educación), págs. 92-98 [en línea], no. 287, pp. 92-98. [Consulta: 31 diciembre 2022]. ISSN 1136-7733. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=5390544&info=resumen&idioma=SPA. (Catalina y López García 2015)

- CATALINA, C.A. y MARTÍNEZ-ZARZUELA, M., 2017. Realidad Virtual para rehabilitación de patologías cardíacas. PARANINFO DIGITAL [en línea], [Consulta: 3 enero 2023]. ISSN 1988-3439. Disponible en: http://www.index-f.com/para/n26/012.php. (Catalina y Martínez-Zarzuela 2017)
- LÓPEZ GARCÍA, C., CATALINA, C.A. y ZEDNIK, H., 2017. Realidade Virtual e Aumentada: Estratégias de Metodologias Ativas nas Aulas sobre Meio Ambiente. Informática na educação: teoria & prática [en línea], vol. 20, no. 1. [Consulta: 31 diciembre 2022]. ISSN 1516-084X. DOI 10.22456/1982-1654.70613. Disponible en: https://www.seer.ufrgs.br/index.php/InfEducTeoriaPratica/article/view/70613. .(López García, Catalina y Zednik 2017)
- LÓPEZ GONZÁLEZ, M.V., GARCÍA-VALCÁRCEL MUÑOZ-REPISO, A., DEL POZO, M., BASILOTTA GÓMEZ-PABLOS, V. y CATALINA, C.A., 2018. Métricas para la evaluación y análisis de Serious Games. Aportaciones en base al Proyecto eConfidence. Edunovatic 2017. Conference proceedings [en línea]. S.l.: Adaya Press, pp. 1039-1045. [Consulta: 31 diciembre 2022]. ISBN 978-94-92805-02-7. Disponible en: https://dialnet.unirioja.es/servlet/articulo?codigo=7013515&info=resumen&idioma=SPA. (López González et al. 2018)
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- SARACCHINI, R.F.V. y CATALINA, C.A., 2014. An easy to use mobile augmented reality platform for assisted living using pico-projectors. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) [en línea], vol. 8671, pp. 552-561. [Consulta: 31 diciembre 2022]. ISSN 16113349. DOI 10.1007/978-3-319-

11331-9_66. Disponible en: https://link.springer.com/chapter/10.1007/978-3-319-11331-9_66. (Saracchini y Catalina 2014)

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Proyectos Europeos

- WORKINGAGE («Smart Working environments for all Ages | WorkingAge Project | Fact Sheet | H2020 | CORDIS | European Commission» 2019)(Rick et al. 2019): Proyecto H2020 que utiliza métodos innovadores de Interacción Hombre Maquina (realidad aumentada, reconocimiento de gestos/voz, EEG y eye-tracking) para medir el estado emocional/cognitivo/salud del usuario o usuaria. Al mismo tiempo, los sensores IoT podrán detectar las condiciones ambientales. El propósito es promover hábitos saludables de los usuarios o usuarias en sus entornos de trabajo y actividades de la vida diaria con el fin de mejorar sus condiciones de trabajo y de vida. Liderazgo y dirección del proyecto con el equipo del ITCL.
- SIMUSAFE («SIMULATOR OF BEHAVIOURAL ASPECTS FOR SAFER TRANSPORT | SimuSafe Project | Fact Sheet | H2020 | CORDIS | European Commission» 2017)(Consortium 2017): Proyecto H2020 para crear 4 tipos de simuladores que interactúen en el mismo entorno virtual (coche, moto, bicicleta y peatón) para evaluar de forma segura la percepción del riesgo y la toma de decisiones de los usuarios o usuarias de la carretera. Los simuladores miden el sesgo de la conducción en vehículos reales (con pruebas en entornos naturalistas y de control) y simulados. Se trata de un proyecto de 8 millones de euros con 14 socios. Liderazgo y dirección del proyecto con el equipo del ITCL.
- ECONFIDENCE («Confidence in behaviour changes through serious games | e-Confidence Project | Fact Sheet | H2020 | CORDIS | European Commission» 2016)(«eConfidence» 2016): Proyecto H2020 para crear una metodología para crear Serious Games que promuevan un cambio de comportamiento. Se creó una metodología que se aplicó en los dos juegos. Principalmente el Serious game "Escuela de empatía" https://www.youtube.com/watch?v=DZY98YT2cH8 con Unity 3D. Proyecto valorado por la Comisión Europea como excelente, invitado a presentar el proyecto en una exposición de “Tecnologías para el Bien Social” en el Parlamento Europeo. Liderazgo y dirección del proyecto con el equipo del ITCL.

- NACODEAL(«DOMEO - AAL Programme» 2011): El objetivo era ofrecer nuevas soluciones a los problemas a los que se enfrentan las personas mayores cuando se enfrentan a las nuevas tecnologías y durante sus tareas diarias, manteniendo su autonomía en la sociedad actual. Estas soluciones están integradas por la Tecnología de Realidad Aumentada mediante un dispositivo portátil que les asiste, proporcionándoles instrucciones sobre cómo proceder en distintas actividades de la vida diaria. Liderazgo y dirección del proyecto con el equipo del ITCL.

Principales Proyectos Nacionales o Regionales

- PRODUCTIO(«Productio - Mejora de la industria conectada a través de tecnologías habilitadoras» [sin fecha]): Realidad virtual y aumentada para la industria, con manuales interactivos en 3D y acceso a la información.
- INSPECTOR («Inspector proyecto para el mantenimiento en la industria conectada | ITCL» [sin fecha]): Simulador de instalaciones para formación y evaluación de seguridad con realidad virtual.
- InRoad («InRoad 4.0 Carreteras inteligentes 0 fallecidos» [sin fecha]): Simulador de drones para formación en revisión de infraestructuras.
- Secusim («SECUSIM, sistema de entrenamiento indirecto para fuego» [sin fecha]): Simulador militar multipuesto para fuego indirecto, mortero (Instructor, Comandante, Observador y Equipo de mortero).
- PIGADVISOR («PigAdvisor - Asesor virtual para granjas - ITCL» [sin fecha]): Desarrollo de un clasificador de enfermedades porcinas con imágenes de tejidos.
- TISSUSIM («TISSUSIM. Simulacion de comportamiento de materiales - ITCL» [sin fecha]). Reconstrucción 3D de tejidos a nivel de hilo para simulación.
- SV3D («SV3D - Sistemas de seguridad y videovigilancia en 3D basado en videogrametría. - ITCL» [sin fecha]): Sistemas de seguridad y videovigilancia en 3D basado en videogrametría. Visualizador de modelo 3D de nube de puntos para sitios web.
- TextoSign («TextoSign Móvil - ITCL» [sin fecha]): Avatar 3D para traducir texto a Lengua de Signos Española.
- Estarteco («Estarteco juego de realidad aumentada para medio ambiente | ITCL» [sin fecha]): Serious Game para mostrar los valores de los ecosistemas (14 marcadores realidad aumentada simultáneos).
- SIMPRO («SIMPRO - Simulación de Métodos de Producción - ITCL» [sin fecha]): Editor para simulación de maquinaria industrial.

- Simulador de carretillas («Simulador de carretillas elevadoras para formación | ITCL» [sin fecha]): Desarrollo de un simulador de Realidad Virtual de carretillas para el entrenamiento de operadores de carretillas.
- Factoría Virtual («Factoría virtual - ITCL» [sin fecha]): Desarrollo de un entorno inmersivo para experimentación de procesos de manufactura y montaje mediante realidad virtual

CONTRIBUCIONES CIENTÍFICAS DE LA TESIS

Hindawi
Journal of Advanced Transportation
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https://doi.org/10.1155/2020/6039762

Research Article

Music Distraction among Young Drivers: Analysis by Gender and Experience

Carlos A. Catalina[1,2] **Susana García-Herrero**[1] **Elvira Cabrerizo**[1] **Sixto Herrera**[3] **Santiago García-Pineda**[1] **Fatemeh Mohamadi**[4] **and M. A. Mariscal**[1]

[1]*Escuela Politécnica Superior, Universidad de Burgos, Burgos, Spain*
[2]*Instituto Tecnológico de Castilla y León, Burgos, Spain*
[3]*Department of Applied Mathematics and Computer Science, Universidad de Cantabria, Santander, Spain*
[4]*School of Architecture and Cities, University of Westminster, London, UK*

Correspondence should be addressed to Susana García-Herrero; susanagh@ubu.es

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The aim of this study was to quantify the probability of committing a speed infraction by young drivers and to investigate to what extent listening music could affect young drivers' emotions as well as their driving performances at the wheel. To achieve this aim, employing Bayesian networks, the study analysed different music styles, in which they resulted in sample drivers' speed infractions. Gender and drivers' experiences at the wheel were the other factors, which were taken into account when interpreting the study results. Variables taken into account in this study included type of music whilst driving, gender of drivers, and drivers' driving experiences. These variables further incorporated into the study of other telemetric variables including acceleration, number of revolutions per minute (RPM) of the engine, brake, traffic, and other types of infractions other than speed, which were considered as dependent variables. A driving simulator was used, and different driving simulation studies were carried out with young people aged between 20 and 28 years. Each participant carried out three simulations by listening to different type of music in each journey. The study defined a conceptual model in which the data were analysed and evaluated mathematically through Bayesian networks. A sensitivity analysis was performed to evaluate the influence of music on driving speed. Based on the different variables, the study further analysed the probability of speed infractions committed by drivers and their adequate speed. The range of frequency probabilities varied between 96.32% (which corresponds to experienced male drivers who do not listen to music) and 79.38% (which corresponds to less-experienced female drivers who listen to music), which resulted in their happiness or aggression.

1. Introduction

The number of fatalities related to traffic accidents continues to grow globally and already have reached the figure of 1.35 million deaths annually [1]. Consequently, different measures of actions have been taken to reduce the number of traffic accidents. In Spain, at the national level, the "Objective Zero" plan, developed by the Government of Spain, was formulated through the so-called "Strategic Road Safety Plan 2011–2020" in order to target zero victims in traffic accidents in Spain [2]. According to the Directorate General of Traffic of Spain [3], in 2016, the human factor was the cause of 70% of traffic accidents in Spain.

Several researchers have reported the behavior of drivers as the most influential factor in road traffic accidents [4, 5]. Such studies have argued the behavior of drivers as one of the most influential factors in fatal accidents since it contributes to speed violation and, as a result, an increment of the risk of suffering an accident and the severity of the injury [6–8].

Moreover, Blanco [9] identified two types of risk from the drivers' point of view: perceived risk and assumed risk.

According to Blanco, there is currently an underestimation of perceived risk and overvaluation of the risk assumed, for example, using drugs, reversing, or exceeding the speed limit can closely contribute to high risk of accidents caused by drivers. Whilst such behavior of drivers often causes accidents, the drivers tend to not consider or assume those behaviours as risky, for example, Choudhary and Velaga stated that "drivers are exposed to a greater risk while operating a music player because this is not perceived as a risky behavior [10]." Additionally, as found by Oviedo-Trespalacios [11], around 83% of the young people will allow the use of music player in an application designed to avoid the use of smartphones while driving. As a result, drivers do not consider listening to music as a risk factor.

The impact of listening to music while driving is an important field that has been studied by several researchers. However, different results have been reported, for example, Brodsky documented harmful effects of music on drivers in three categories: the excitement, aggressiveness, and distraction of the drivers themselves whilst driving [12]. In contrast, Ünal et al. [13] concluded that listening to music while driving can be considered as a good strategy to counteract boredom and to satisfy demands at the wheel. Others studies reported the effect of music as a counter measure against drivers' fatigue [14, 15]. Dalton et al. analysed the sound types and volumes that mostly affect the driving style [16]. Other studies have narrowed down their focus on how the change of abrupt music to quiet music is more effective than gradual change to music in terms of calming drivers in stressful situations [13]. The study of Qi et. al. [17] determined that changes in ambient music have significant effects on drivers' behaviours. Zhu et. al. [18] concluded that music with a specific rhythm mitigates the emotion of anger and improves driving quality.

The meta-analysis performed by Millet et al. [19] includes several variables to measure driving performance, with a categorization on "operational definitions," as recommended by Caird et al. [20, 21]. The categories comprised of vehicular longitudinal control (e.g., speed and speed variance), vehicular lateral control, driver reaction time, traffic signal violation, and collisions. The metasurvey resulted in interesting findings in two categories including "group who listened to music while driving showed significantly more collisions and poorer longitudinal control when compared to subjects in the control group."

Wen et al. [22] analysed the impact of music on young individuals, while taking into account the user's personality, their driving speed, and the frequency of their lane crossing. They found that rock music increases the standard deviation of speed and frequency of lane crossing more than light music or no music. However, Navarro [23] did not find a direct relation between driving with music and the car-following distance. Finally, Zimasa et al. [24] found that negative moods as a result of listening to music lead to aggressive driving.

In recent years, the use of driving simulators for the training purposes has become trendy aiming for improving knowledge associated with driving. Moreover, as driving simulators are risk-free and time and cost-effective [25, 26], they can be used to simulate the real situation and investigate the impact of drug consumption [26], drowsiness [27], mobile phone [28], adjusting the radio, and searching music on portable devices such as an MP3 [29–32] on driving style. Observing the behavior of the driver, designing/controlling the vehicle and testing drive systems for driving are amongst the most important investigations performed through employing driving simulators.

In addition, driving simulators are being used for observing how drivers behave in the face of conflicting situations or dilemmas [33, 34]. They also allow the study of high-risk situations, such as pedestrian crossings [35] or curves [36] and even for cycling [37]. In this way, employing simulators help researchers to look for effective strategies in order to spot-on the risk factors, measure them, and finally come up with solutions to lower the risk probabilities down.

To this end, as highlighted above, the aim of the present study is to carry out a driving simulation experiment in order to quantify the extent to which listening (or not listening) to music affects the probability of committing a speed violation. Different emotions induced by different kinds of music and their impacts on drivers' behaviours are also considered in the current study. Furthermore to this, the sex of drivers and the level of their driving experience have been taken into account.

2. Data and Methodology

2.1. Database

2.1.1. Simulator. To conduct the current study, the DriveSIM driving simulator alongside with all other necessary hardware including the pedals, the parking brake, the steering wheel, the panel controls, the seat, and the other necessary supports of the vehicle were used. The installation had three television screens to get a peripheral vision during the driving simulation. The simulator included all kinds of situations as well as ultrarealistic contexts that allowed users to practice as if they were in command of a real vehicle. Experiencing very different situations such as driving with adverse weather, aggressive behavior of other drivers, and/or driving in various types of roads were also included in a simulator study. The vehicle chosen to carry out the simulations embodied the dynamic characteristics of a vehicle with 4×4 traction including 151 HP, diesel, an average consumption of 5.7 L, a weight of 1550 kg, and a manual gear control. The chosen routes were vias high performance with high traffic of other users.

The selected simulator recorded the telemetry of the vehicle every 15 frames into the internal database, and the computer used run the programme between 30 and 45 FPS (frames per second). FPS is a commonly used measurement tool in the computer graphic field. It measures the number of times that the PC is able to calculate everything needed in terms of input of the user, calculated dynamics, and AI traffic and is able to render the 3D environment in the different cameras operating in the simulator. It can save two/three records per second simulated.

The information provided by the simulator included the following parameters: the position of the vehicle, speed, angular and linear acceleration, rotation, pressure, vertical force and side, wheel temperature, suspension, brake temperature, address, the position of the pedals, gears, parking brake, lights, turn signals, revolutions, the maximum speed allowed, and so on. The simulator also saved a record with the infractions committed by the driver during the simulation. The simulator had a total of 93 possible infractions, which were grouped into the following categories: traffic lights, vertical traffic signs, road markings, and other infractions of speed infractions. The following sections demonstrate discussions of each category separately.

2.1.2. Study Population. A total number of 19 young Spanish drivers aged between 20 and 28 years old participated in this study. Prior to the testing, participants were asked to fill out a form in which they provided researchers with the information in terms of their age, sex, driving experience (for example: how often they drive on a per week basis). In this way, the study population was divided into demographic groups depending on their gender and their driving experience.

2.1.3. Music. The current study is based on the classification of moods induced by music. Moods are grouped into four basic emotional situations based on the study carried out by the University Pompeu Fabra [38]. These emotional situations are aggression, sadness, relaxation, and happiness. A general narrative of a natural driving while using the simulator was provided. Specific trip purposes such as urgent or nonurgent were excluded from this study as they could result in skewed answers to the main research question of the study.

Table 1 shows different moods and their relation with different musical genres.

Table 1: Musical genres and moods that produce.

Genre	Aggression	Sadness	Relaxation	Happiness
Rock	+	−	−	+
Alternative	+	−	−	+
Rap	+	−	−	−
Electronic	+	−	−	−
Blues	−	+	+	−
Folk	−	+	+	−
Jazz	−	+	+	−
Classical	−	+	+	−
Soundtrack	−	+	+	−
Vocal	−	+	+	−
Country	−	+	+	+
Reggae	−	−	−	+
Pop	−	−	−	+
RBSoul	−	−	−	+
Latino	−	−	−	+

Referring to the first column in Table 1, different musical genres are listed. The headings for the following columns are based on different states of mood including aggression, sadness, relaxation, and happiness. Moods are valued in the table above with a "+" and "−" symbols. Symbol "+" represents when the state of mind to which it refers is more present than in the rest of genres. Symbol "−" represents when the status of mood is less present than in the rest of genres.

In present study, the four states of moods were regrouped into two groups including aggression/happiness and sadness/relaxation. A total number of 20 songs including new and old songs were listed for each of the two groups.

The songs were selected from the main platforms of the moment including AllMusic, iTunes, and Spotify, which allow to identify and select musical genres. Considering that different music style can result in different emotional moods; before their selection, they were listened in order to ensure that they belong to the emotion sought in each case. They are selected and classified according to the corresponding group of emotions, as indicated in Table 2.

It has long been argued that music is something very personal. In his study "Book of Music and Emotion," Juslin [39] analysed different perspectives such as philosophy, musicology, and psychology in relation to the impact that music can have on emotion. In this book, factors of development and personality as well as the social factors are covered.

In this study, each participant had their personalised list of songs from Table 1. Prior to carrying out the simulations, all participants had filled out a survey, in which they evaluated the songs in terms of their association with happiness/aggressions and their association with sadness/relaxation. In this way, a custom list of songs for each participant, with the 3 songs of happy/aggressive that were most valued in terms of their contribution to activation, and the 3 songs of sadness/relaxation were valued in terms of their contribution to relaxation.

2.1.4. Realisation of the Simulations. In the first place and prior to taking records of the results generated by the simulation, the participants were subjected to a first contact with the simulator. Each simulation test allowed participants to adapt themselves to the characteristics and the sensitivity of the stimulator, becoming familiar with the driving simulators varied between participants, demonstrating a difference between 10 and 20 minutes. Once the drivers felt comfortable, they proceeded to perform two driving experiments.

In the first place, a simulation was carried out without music. This served as a reference for later analysis to monitor the differences between driving with or without music. The duration of this simulation was 10 minutes, and it was carried out for all participants on the same route.

The second round of the simulation was carried out with music. In this simulation, each participant listened to the custom music tracks. The driving route (vias de high performance) in the second round was similar to the driving route in the first round (driving without music). The tour began with listening to songs that resulted in sadness/relaxing emotions and then continued with the songs that provoked aggression/happiness in drivers.

Table 2: Final song selection.

Aggression/Happiness	Sadness/Relaxation
Single Ladies (Put a Ring on It)—Beyoncé	Only Time—Enya
(I Cannot Get No) Satisfaction—The Rolling Stones	Riptide—Vance Joy
Uptown Funk—Mark Ronson y Bruno Mars	Bow and Arrow genre—Reuben and the Dark
Happy—Pharrell Williams	No Shade in the Shadow of the Cross—Sufjan Stevens
One More Time—Daft Punk	Should Have Known Better—Sufjan Stevens
We Will Rock You—Queen	The Last Goodbye—Billy Boyd
La Gozadera—Gente de Zona	Hurt—Johnny Cash
Girls Just Want To Have Fun—Cyndi Lauper	Underwood See You Again—Wiz Khalifa/Cover Flute, Violin, Piano
I love Rock n roll—Joan Jett The Blackhearts	River Flows in You—Yiruma
Shake It Off—Taylor Swift	If I Die Young—The Band Perry
So What Alcohol—Pink	Melodía Desencadenada—Ghost
Bang Bang—Jessie J, Ariana Grande, Nicki Minaj	Elysium—Gladiator
Sax—Fleur East	Hallelujah—Pentatonix
All Star—Smash Mouth	True Love Waits—Radiohead
Party Rock—LMFAO	I Will Always Love You—Whitney Houston
Pump It—The Black Eyed Peas	Clown—Emeli Sandé
El Vals del Obrero. Resistencia—Ska-P	Let It Be—The Beatles
El lado de los Rebeldes—LA RAÍZ	Hallelujah—Lindsey Stirling
Highway to Hell—AC/DC	Kings of the Past—Lion King
Moves Like Jagger—Maroon 5-ft. Christina Aguilera	My Heart Will Go On—Whitney Houston

Overall, each participant spent a minimum of 30 minutes with the driving simulator (10 minutes for training, 10 minutes on driving without music, and 10 minutes on driving with music).

2.1.5. Data to Analyse. The simulator employed in this study recorded all telemetry data in a database. Of all the data collected for this study, the following variables were selected for further analysis: speed, revolutions, infractions, acceleration, brake, and the maximum speed allowed. All these variables are explained in detail in Section 3 (Figure 1. Conceptual model).

All these records were synchronised with the personalised list of music for each participant. This was performed to obtain the telemetry data, correlated with the type of songs, which were listened to at every moment. After the realisation of the 57 simulations (19 participants and 3 scenarios: without music, with music type which relaxed, and music which activated), the results demonstrated a total number of 107,395 records (an average of 5,650 records for each participant).

2.2. Bayesian Network. As pointed out earlier in the Introduction section, the aim of this study was to appraise the probability of committing a speed infraction based on the drivers' behavior. To achieve this aim, discrete Bayesian networks (BNs) were employed since they are highly regarded as machine learning technique, in which they efficiently learn the joint probability distribution (JPD) of multivariate problem involving discrete variables $X = \{X_1, \ldots, X_n\}$ [40], where X_i is the each variable considered in the model. The created model enabled us to estimate the probability of each variable (inference) based on the knowledge of the state of some of the variables (evidence). In particular, we were able to gain knowledge on how the probability of committing a speed infraction changes depending on the driver's behavior (sensitivity analysis). This was in keeping with previously performed research, in which they have used Bayesian networks in their studies of traffic accidents to raise that various relationships exist between several factors [7, 41–44].

Bayesian networks (BNs) are models combining probability and graph theory to efficiently learn the joint probability distribution (JPD) of the considered aleatory variables (X_i):

$$p(X_1, \ldots, X_n). \tag{1}$$

In particular, BNs are based on directed acyclic graphs (DAG) representing the probabilistic dependence, direct or conditional, among the variables and, using the Bayes rule, enabling the factorization of the JPD (joint probability function)

$$p(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} p(\pi_i), \tag{2}$$

where x_i corresponds to a realisation of the aleatory variable X_i, and π_i is the set of parents of node X_i in the graph, namely the set of nodes linked with X_i by an arrow pointing to this node. As a consequence, first, the DAG was obtained (structural learning) by applying the score-based greedy learning algorithm proposed by Buntine [45], and then, the parameters associated to the factorization are estimated by maximum likelihood as these are the ones that better explain the observed data.

Currently, there are a lot of packages, libraries, and programs to learn Bayesian networks implemented in different programing languages (e.g., R: http://www.bnlearn.com/, Python: https://pomegranate.readthedocs.io/en/latest/BayesianNetwork.html, or Matlab: https://github.com/bayesnet/bnt). Based on previous experiences [44, 46–51],

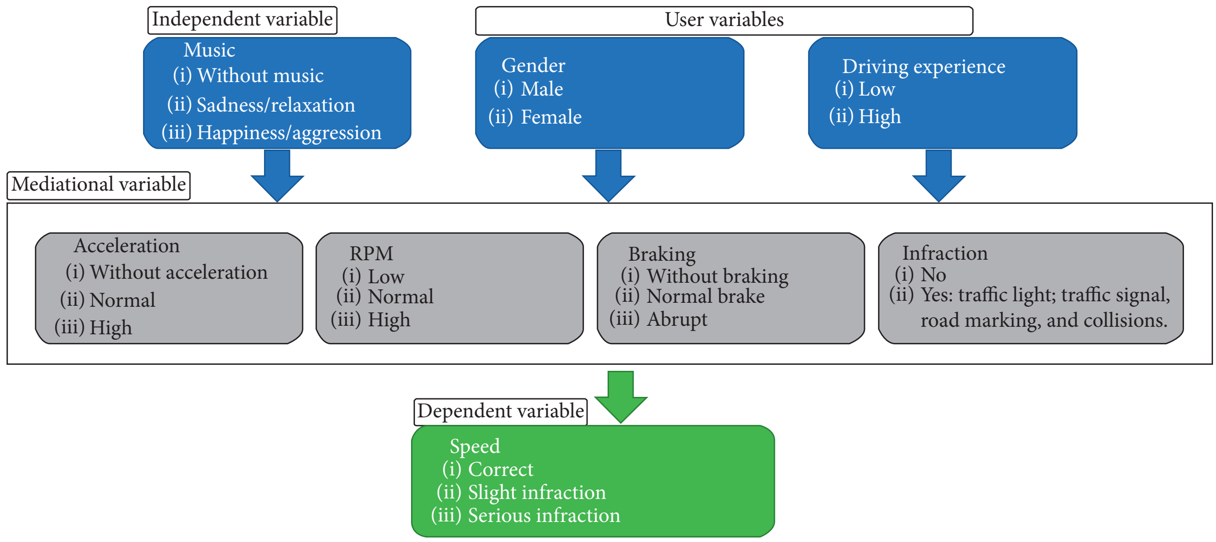

Figure 1: Conceptual model.

the Matlab Toolbox Bayes Net [52] (https://github.com/bayesnet/bnt) was the package finally considered.

Once the model has been obtained, the probability of any event can be estimated. In particular, for the target variable, the Bayesian network assigns a probability for each state, and then, it can be interpreted as a Bayesian classifier. In order to know the skill of our model, a 10-fold cross-validation was developed creating a random partition of the database in ten subsamples, so using the 90% to train and the remaining 10% to evaluate and repeating this process, it has been evaluated in order to know the skill of our model and avoid overfitting. To this aim, perform this procedure ten times, one for each subsample. As a result, 11 test samples were obtained, one per fold and the latest one considering the prediction of the complete sample obtained by joining the 10 folds.

The evaluation of each model was performed using the area under the ROC (receiver operating characteristic) curve (AUC) [53], which is a standard score for probabilistic and binary classifiers that varies from 0.5 (random guess) to 1 (perfect performance) and was considered as a measure of the overall accuracy of the model [54].

Finally, once the model has been evaluated and its predictability tested, the 100% of the database has been considered to train the model used for the sensitivity analysis.

3. Conceptual Model

The conceptual model (Figure 1) used in this study contains the following groups of variables:

The music variable has been divided into three states. The first one refers to driving without background music, the second refers to when driving while listening to either a sad or a relaxing music, and finally, the third state refers to driving while listening to a background music that is classified as a music that can result in cheerfulness or aggression.

Demographic and driving experience variables as user variables have also been considered in this study. For the driving experience variable, two states are defined. One in which it refers to drivers with little experience at the wheel, and the other in which it refers to those who have an extensive experience at the wheel. The data for the driving experience was obtained from the forms filled out by the participants prior to analysis. Both the years their driving license was issued, and the frequency of driving car was taken into account. The questions related this issue were "How often do you drive a car?" and "when driving license was issued?" If the driver had the driving license for more than 1 year and a half and, at the same time, he/she drives more than once a week, then the variable "experience steering a wheel" is classified as experienced; otherwise, the driver is classified as little experience."

The telemetry variables that have been taken into consideration to develop the mathematical model are as follows: acceleration, revolutions, infractions, brake, and finally, the speed that is the variable object of study.

As regards the "acceleration" variable, three states have been considered. The first state indicates that there is no acceleration; all the cases in which the vehicle carries a constant speed is stopped or carries a negative acceleration (braking) is included in this section. The second state indicates that the acceleration is normal. The third state indicates that the acceleration is high.

The variable "revolutions" also have three different states. The first state refers to the time and situation when revolutions are lower than 2250 rpm. The second state refers to the situation and time if revolutions are between 2250 and 3000 rpm. Finally, the third state refers to situation and time if the level of revolutions is higher than 3000 rpm.

The variable "infractions" is divided into two states. The first state indicates that an infringement is being committed, and the second state indicates that not any infringement is being committed. The infringements do not take into account the speed infraction since a specific variable has been defined for studying it.

The grouping of the infractions are as follows: traffic lights (skipping a red light), traffic signs (failure to comply with traffic signs), road markings (failure to comply with the different road markings), safety distances (failure to maintain the safety distance), lights (incorrect use of lights), collisions (collisions with other vehicles or objects on the road), abuses (pedestrian or animal abuse), and other infractions.

The "brake" variable contains three states. The first state is the one obtained when the driver is not pushing the brake. In addition, we distinguish the other two states: if the braking is normal or if it is done abruptly.

With regards to "speed" considered as the target variable, this variable has been divided into three states according to the speeds states established by the DGT as suitable for driving (Table 3). Driving speed below legal speed limit, driving speed more than legal limit but less than the radar limit (driving speed is between the speed limit and the speed of activation of the cinemometer), and driving speed higher than the radar limit.

Table 4 below shows the registered cases and their percentage for each state of the variables that are part of the model.

In this case, the number of records shown in (Table 4) is important since they display the status of the vehicle in each "instant." In this table, the vehicle data of each simulation are collected. The data are stored keeping in mind the FLOPS.

This model has been validated since all AUCs exceed 0.7, meaning that they are data reliable (Table 5).

Table 3: DGT speed.

Speed limitation (km/h)	30	40	50	60	70	80	90	100	110	120
Cinemometer activation speed	38	48	58	68	78	88	98	109	120	131

4. Results

4.1. Sensitivity Analysis. Different sensitivity analysis performed in this study is shown below. Figure 2 represents the results generated from the Bayesian network. As the graph illustrates, speed as the core variable located in the centre of the graph has direct links with all the variables considered in the model and introduces conditional dependencies between its parents (gender, driver experience, and braking) and children variables (infraction, acceleration, RPM, and music) given by the V-structures of the Bayesian network (e.g., speed --> infraction <-- driving experience). In this sense, given any children variables involved, a statistical dependency grows between infraction and its parents. As a result, several stets of flow generated by the model reflect the sequence pointed out in the conceptual model. The model, however, includes relations which could be less obvious in obtaining a more useful model.

4.1.1. Influence of Music on the Probability of Speed Infraction. Table 6 shows the probability of driving based on different driving speed states. From the results, the probability of driving below legal speed limit while not listening to music is 95.34%. Looking at the first column, it is evident that most of the time that drivers were behind the wheel and respected the speed limits. However, the corresponding probability varies depending on the type of music. That is listening to sad and happy music reduces the probability of driving at an adequate speed to 89.9% and 86.59%, respectively.

Such a solid evidence indicates that when drivers do not listen to any music, the probability of committing a slight infringement (above the legal speed but below the threshold of the radars) is 4.18%. However, when drivers listen to any kind of music, the probability of their committing infraction increases to 7.35%. Similarly, if the drivers do not listen to any type of music, the probability of committing a serious infraction (detected by the radars), therefore, stands at 0.48%. Yet, if the drivers listen to a sad and happy music, the probability of exceeding the speed accounts for 2.74% and 6.06%, respectively.

Referring to Table 4, it can be argued that the reference data (a priori) indicates that, without analysing the type of music, the percentage of time driving at an appropriate speed, committing a slight infraction, and or a serious infraction account for 90.68%, 6.24%, and 3.08% of cases, respectively. Therefore, the probability of committing a serious infraction is almost half in comparison to the probability of committing a slight infraction. When making a comparison between the data presented in Table 6 with the data obtained in Table 4 "a priori," it can be concluded that the probability of driving at an adequate speed is higher if drivers do not listen to music. The probability of committing a serious speed violation then is bigger if drivers listen to music that generates happiness/aggression.

4.1.2. Influence of Music and Gender on the Probability of Infringement of Speed. In the second round of analysis, the probability of driving at an adequate speed, at minor infraction speed, and at a serious infraction speed were examined in their relation to the type of music variables including no music, sadness/relaxation, and happiness/aggression while taking into account the gender variable (male/female). The results of such a cross-tabulation tests are shown in Table 7.

The performed cross-tabulation tests revealed that, in the absence of music, the probability of driving at an adequate speed in women (95.94%) is slightly higher than that in men (94.38%). Further analysis revealed the data for the probability of driving at an adequate speed, at minor infraction speed, and at a serious infraction speed in relation to different type of music listened by male and female drivers. What becomes apparent from the analysis is that when it comes to listening to whether a sad or relaxing music, men are those who have a greater chance of driving at an adequate speed, 92.19%. The figure for female drivers is 88.65%. Concerning the type of music that transmits whether happiness/aggression emotions, the same tendency repeats. Men drivers have a greater chance of driving at an adequate speed of 87.92% in comparison to female drivers 85.88%. Nevertheless, the probability of driving at an adequate speed

Table 4: Table of records.

Variable	State	No of records	Percentage (%)
Speed	Correct	97,879	90.68
	Minor infraction	6,736	6.24
	Serious infraction	3,320	3.08
Music	Without music	37,744	34.97
	Music sadness/relaxation	33,620	31.15
	Music happiness/anger	36,571	33.88
Acceleration	No acceleration	49,202	45.58
	Normal acceleration	29,366	27.21
	High acceleration	29,366	27.21
RPMs	<2250	64,522	59.76
	$2250 < x < 3000$	32,912	30.49
	>3000	10,501	9.75
Brake	No brake	98,453	91.22
	Normal brake	4,742	4.39
	Abrupt brake	4,740	4.39
Infractions	No infraction	103,999	96.33
	Infraction	3,936	3.67
Sex	Women	63,840	63.78
	Men	39,095	36.22
Driving experience	Low	49,306	45.68
	High	58,629	54.32

for both male and female drivers is lower than in the case of listening to a sad/relaxing music, even less at the time both gender drive without listening to any music.

In light of above, it can be concluded that women drive at a more appropriate speed than men when music does not play any role as a factor of distraction. However, in the presence of music (either a sad or a relaxing type of music), women have a greater chance of committing either a minor or a major speed violation. Column 4 (minor infraction speed) and column 5 (serious infraction speed) present this data. In any case, either men or women, both have greater chances of committing infraction in comparison to driving without music.

Discussing the data in details, it can be argued that in the case of female drivers, when they listen to a relaxing or sad music, the level of their committing to a minor infraction is higher than when they listen to happy/aggression type music. However, this is not a case when it comes to committing serious speed violations. This means that the probability of committing an infraction by female drivers is greater if the type of music heard transmits to cheerful/aggression emotions of drivers.

When it comes to male drivers, it can be appreciated that in all music states, there is a reduction in the probability of exceeding the speed. However, this reduction is not the same in all cases. When they listen to sad music or they do not listen to music, we have reductions in odds of more than 4.5 points in both cases, compared to a reduction of 3 points when it comes to happy music.

To this end, it could be concluded that both men and women whether listen to music or not, the likelihood of their committing a serious excess in speed are decreased for all cases. When listening to sad/relaxing music, it is women who have a higher probability of committing either minor or major speed infractions. However, when listening to a music that transmits to their happiness/anger emotions, men have higher probability of committing a minor speed infraction (7.61%) compared to women (7.20%). This reverses in terms of committing a serious speed infringement. The figure for female drivers is higher than for male drivers. 6.91% for female drivers and 4.47% for male drivers.

Table 5: Area under the ROC curve.

Estate 1	Estate 2	Estate 3
0.76383	0.72272	0.81235
0.76108	0.7122	0.8102
0.75167	0.72043	0.80972
0.73589	0.7036	0.81726
0.74621	0.70979	0.79946
0.74307	0.70411	0.80594
0.75507	0.71723	0.80274
0.73844	0.70965	0.78705
0.75963	0.7204	0.7874
0.75929	0.71533	0.82535
0.75131	0.71337	0.80597

When listening to happy music, women keep the percentage of speed violation almost constant in the environment of 7%. Men reduce the percentage of infringement serious compared to the mild but to a lesser extent than when they listen to sad music or do not listen to music.

4.1.3. Influence of Music and Driving Experience on the Probability of Speed Violation. The aim of third round of analysis is to examine whether the driving experience could play any role on the speed violation depending on no music or the music type that was listened. If so, to what extent

Table 6: Probability of speed violation in relation to the music.

Music	Adequate speed (%)	Minor speed infraction (%)	Serious speed infraction (%)
No music	95.34	4.18	0.48
Sadness/relaxation	89.90	7.36	2.74
Happiness/aggression	86.59	7.34	6.06

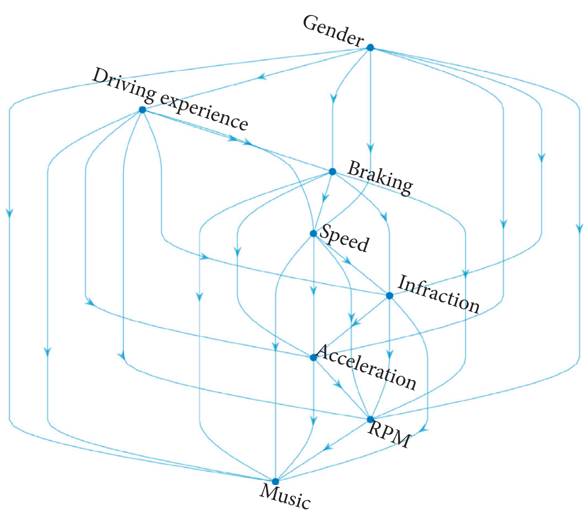

Figure 2: Bayesian network graph.

driving experience could result in any infringements on speed. The results are presented in Table 8.

As Table 8 indicates, under the "No music" variable, the drivers with less driving experience have a higher probability of driving at an adequate speed of 96.26%. 1.5 points higher probability compared to expert drivers. However, when music is played, probabilities change. Listening to songs that convey sadness or relaxation, in less-experienced drivers, reduces their chance of driving at an adequate level. The probability reaches 86.89% compared to highly experienced drivers, in which their probability to drive at an adequate speed reaches 92.54%. Slightly similar results become evident when less expert drivers listen to songs that convey to their either joy or aggression emotions. Only 80.26% of less-experienced drivers drive at an adequate speed. This is while, 92.89% of highly experienced drivers drive at an adequate speed.

When the effect of music on drivers with little experience is analysed, it becomes apparent that driving without music entails performing a lower percentage of minor infractions as well as serious infractions: 2.92% and 0.84%, respectively. In the case of driving while listening to music that causes happiness or anger in the less-experienced drivers, the percentage of infractions in both minor and major cases is around 10% (9.95% and 9.80%). This means that, when driving with cheerful music on, the less-experienced drivers do not perceive the increase in speed and commit minor and/or serious infractions with almost the same probability that approaches 10% in both cases.

These findings suggest that less-experienced drivers are highly affected by the songs they listen to. This is while highly experienced drivers have greater control over their emotions when they simultaneously listen to any kind of music and drive. Further to this, it can be argued that, although in the case of driving without listening to music, less-experienced drivers are those who have a higher probability of driving at an appropriate speed; less-experienced drivers are also those who are mostly affected by music, and thus have less probability of driving at an adequate speed.

Referring to the expert drivers, not listening to music follows the same pattern as with less expert drivers. 94.71% of expert drivers drive at an adequate level of speed in comparison to the time they listen to any type of music. Similar to less-experienced drivers, driving without listening to music makes highly experienced drivers aware of their infractions and prevents them from driving at a speed above the threshold of the radars. Listening to either cheerful or sad music, however, changes the pattern for experienced drivers too. It goes from producing a reduction in the probability of serious infringement when listening to sad music from 1.32% to a minor infringement of 6.14%. Same pattern happens with happy music. The figure for serious speed infraction is 2.35% when compared to minor infraction speed which is 4.76%.

Taking the spectrum of the above analysis, it can be asserted that expert drivers suffer to a lesser extent of effects of listening to music while driving, and this is while less-experienced drivers are highly affected by listening to music. In all cases, driving without listening to music makes both categories of drivers to be aware of their actions and the surrounding driving environment and avoid exceeding the speed above the limit of the radars.

4.1.4. Influence of the Music of the Driving Experience and the Gender in the Probability of Speed Violation. Through conducting a multidimensional cross-tabulation procedure, the probability of driving at an adequate speed or at an inadequate speed depending on the music type, gender, and driving experience was examined. Table 9 represents the data for this analysis.

"No music" variable was the first variable to be considered for the first round of analysis. "No music" played while driving and how experienced both male and female drivers were at the wheel were examined and compared. Highly experienced women drivers tend to respect speed limit most of the time when they were not listening to music while driving. 95.76% was the figure that appeared during the analysis in contrast to the figure of 92.99% that appeared for highly experienced male drivers. Few differences, however, were presented in the findings for less-experienced female and male drivers when they were not listening to music. 96.32% of less-experienced male drivers were driving at an adequate speed level in comparison to female drivers,

Table 7: Probability of speed infraction depending on music type and gender.

Music	Gender	Adequate speed (%)	Minor speed infraction (%)	Serious speed infraction (%)
No music	Women	95.94	3.55	0.51
	Men	94.38	5.17	0.44
Sadness/relaxation	Women	88.65	7.92	3.42
	Men	92.19	6.33	1.48
Happiness/aggression	Women	85.88	7.20	6.91
	Men	87.92	7.61	4.47

Table 8: Probability of speed infraction depending on the music type and experience steering wheel.

Music	Experience	Adequate speed (%)	Minor speed infraction (%)	Serious speed infraction (%)
No music	Low	96.26	2.92	0.82
	High	94.71	5.04	0.25
Sadness/relaxation	Low	86.89	8.75	4.36
	High	92.54	6.14	1.32
Happiness/anger	Low	80.26	9.95	9.80
	High	92.89	4.76	2.35

Table 9: Probability of speed violation based on music, gender, and experience at the wheel.

Music	Gender	Experience	Adequate speed (%)	Minor speed infraction (%)	Serious speed infraction (%)
No music	Women	Low	96.22	3.07	0.71
		High	95.76	3.87	0.37
	Men	Low	96.32	2.70	0.99
		High	92.99	6.97	0.05
Sadness/relaxation	Women	Low	84.17	10.43	5.40
		High	93.02	5.48	1.50
	Men	Low	92.77	5.13	2.09
		High	91.77	7.19	1.04
Happiness/anger	Women	Low	79.38	10.00	10.62
		High	93.45	3.95	2.60
	Men	Low	82.34	9.82	7.84
		High	92.05	5.97	1.97

in which 96.22% of them were driving at an adequate speed level.

As predicted, the data for listening any type of music (either sad/relaxing or cheerful/irritating) amongst both experienced and less-experienced male and female drivers changed. Less-experienced male drivers appeared to have a higher probability of driving at an adequate level of speed in comparison to less-experienced female drivers. In contrast, the highly experienced female drivers appeared to drive at an adequate speed level in comparison to highly experienced male drivers.

Comparison of less-experienced or highly experienced male drivers indicate that with sad music, less-experienced men drivers have a higher probability of driving at an adequate speed level (one-point percentage above the expert men). With the happy type of music, this situation gives a total turn. The expert men keep their probability of constant driving at an adequate speed of 92.05%, while this probability reduces drastically, reaching 82.34% for less-experienced drivers.

It can be concluded that both highly experienced male and female drivers are less likely to be affected by music or with no music while driving. This is because the probability of exceeding the speed limit remains constant in both. However, the effect of listening to music is accentuated when the male drivers are less experienced. The probabilities of driving at an adequate speed in women are in the range of 96–79% and in men 96–82%. When the speed is analysed in greater depth, it is observed that the most situations to commit a serious infraction on speed happen by listening to music that convey happy/angry emotions. In both men and women, probability is much higher if the driver is less experienced than is an expert driver. Therefore, the less-experienced men drivers are those who are to a greater extent affected by the music, especially when it transmits to their joy/aggressive emotions.

Serious speed infraction for less-experienced drivers is discussed in more details. In the case of less-experienced female drivers who listen to the type of music that convey happiness/aggression emotions to them, the probability is more than 10%. This is almost duplicated when compared with the music type that conveys sadness/relaxing emotions to them (5%). When this situation is compared with the “ideal” situation of driving without music (0.71%), the probability of committing a serious infraction on the speed has been multiplied by 15%. Nevertheless, the probability to commit serious speed infraction in the second worst situation (listening to the music that convey sad/relaxing emotions) in less-experienced men, the figure, reaches 2%, almost quadrupling the probability by placing it near 8%. When this situation is compared with the "ideal" of driving without music (0.99%), the probability of committing a serious infringement on speed has been multiplied almost by 7 times. This suggests that men in contrast to women present a greater increase in their probability of committing any speed infractions in the case of listening sad/relaxing music compared with cheerful/irritating music. However, overall, women are those who present a greater increase in the likelihood of committing a serious speed infraction, from the case of more satisfying to the irritating music that causes joy/aggression in them.

The data presented in Tables 4 and 9 bare comparison for their results in which they make it evident that less-experienced drivers (both men and women) are more influenced by the music type that generates happiness/anger emotions in them. Thus, the probabilities of their committing either a serious and/or minor infractions are far greater to "a priori" data (around 5 percentage points).

5. Conclusions

Throughout this work, we have sought to find an answer to the question of to what extent listening to music can influence the mood and the performance of drivers while driving. To find an answer to this question, several simulation tests were carried out with the total number of 19 young drivers aged between 20 and 28 years old, taking into account both their gender and their driving experience. Through conducting simulation-based research and employing Bayesian networks as the analysis platform to analyse the data, we were able to come up with several conclusions as follows:

The first round of analysis made it apparent to us that, regardless of the type of music that is listened while driving, the probability of committing a slight infraction on speed is 3% higher than driving without music. However, when it comes to a serious infringement of the speed, the fact of listening to sad music while driving results in an increased level of 2% compared to driving without music and listening to happy music that results in an increased percentage of 5.5%. It can, therefore, be concluded that driving with music increases the tendency to increase in speed level. Especially, if happy music is played, drivers commit more serious infractions (their speed reaches above the radar limit).

Nevertheless, the aim of the present study was to go beyond the surface and deepen more in research through conducting a further analysis, in which we examined the relationship between listening to music and its effects on driving mood and performance on both male and female drivers. This was performed as we believed not all drivers are the same. Some observations can be made from the analysis. First, either listening to relaxing music or not listening to music reduces the probability of committing a serious excess in speed for both genders. However, women have a lower chance of driving to an adequate speed when they listen to music.

Concerning the type of music, it can be concluded that both driving while listening sad music or driving without listening to music, makes drivers aware of their infractions and prevents them from driving over the threshold of the radars.

As already highlighted, when defining a driver, an important aspect to be considered is how experienced a driver (she/he) is at the wheel. We argue that although in the case of driving without music, less-experienced drivers have a higher probability of driving at an adequate speed, and less-experienced drivers are also those who are mostly affected by music when it makes an appearance in the driving.

On the other hand, when less-experienced drivers are behind the wheel and listen to a happy music, they are unable to notice the increase in their speed, and thus commit either serious or minor infractions with almost same probability. In the case of expert drivers, listening to a sad music and not listening to any music follows the same pattern as with less-experienced drivers. In terms of listening to cheerful music, the pattern, however, changes. It goes from being stable to producing a reduction of the likelihood of serious infringement against a minor infraction. Therefore, it can be argued that expert drivers suffer to a lesser extent of the effect of music. This is in contrast to less-experienced drivers who can be highly affected by listening to music. In all cases, driving without listening to any music makes drivers aware of the road and the surrounding environment; as a result, they avoid exceeding the speed above the limit of the radars.

Concerning the relaxing music, its effect is more evident on less-experienced drivers. The reduction in the probability of exceeding the speed is from serious infraction versus the likelihood of a minor infraction, which is greater than driving without music. However, when it comes to happy music, the results change. The less-experienced drivers do not realize and commit any infractions for speeding, either mild or severe, with the same probability.

Concerning the cross-tabulation analysis of the role of driving experience and gender together, it can be concluded that in both cases for male and female experts, the driving performance is less affected by music or without listening to music since the probability of exceeding speed is constant in both serious and minor speed infractions. However, it should be noted that when drivers are less experienced, the effect of music on their driving performance is more noticeable. Analysing speed in greater depth, it is observed that the greater probabilities of committing a serious violation of speed occur when happy/angry music is listened.

In both men and women cases, the probability of being affected by music is much greater if the driver is less experienced compared to an expert driver. Conclusion would be that less-experienced drivers are those who are to a greater extent affected by music.

Analysing less-experienced drivers in terms of committing a serious speed violation, it becomes apparent that men in contrast to women present a greater increase in probability in the case of listening sad/relaxing music compared to happy/aggressive type music. However, women are those who show the greatest increase in probability of committing a serious speed infraction from driving without background music or the most favourable types of music, even to the most aggressive type of music that causes either joy/aggressive emotions in them.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Analysis of Drivers' Eye Movements on Roundabouts: A Driving Simulator Study

Amin Azimian [1], Carlos Alberto Catalina Ortega [2], Juan Maria Espinosa [2], Miguel Ángel Mariscal [2] and Susana García-Herrero [2,*]

[1] School of Architecture, The University of Texas at Austin, Austin, TX 78712, USA; amin.azimian@austin.utexas.edu

[2] Departamento de Ingeniería de Organización, Universidad de Burgos, 09006 Burgos, Spain; cco0001@alu.ubu.es (C.A.C.O.); jespinos@ubu.es (J.M.E.); mariscal@ubu.es (M.Á.M.)

* Correspondence: susanagh@ubu.es

Abstract: Roundabouts are considered as one of the most efficient forms of intersection that substantially reduce the types of crashes that result in injury or loss of life. Nevertheless, they do not eliminate collision risks, especially when human error plays such a large role in traffic crashes. In this study, we used a driving simulator and an eye tracker to investigate drivers' eye movements under cell phone-induced distraction. A total of 45 drivers participated in two experiments conducted under distracted and non-distracted conditions. The results indicated that, under distracting conditions, the drivers' fixation duration decreased significantly on roundabouts, and pupil size increased significantly.

Keywords: roundabout; eye movement; driving simulator; eye tracker

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1. Introduction

Roundabouts are a proven safety countermeasure and are safer than conventional signal-controlled and stop sign intersections. Nevertheless, they do not eliminate the risk of traffic crashes. Navigating through roundabouts can be an intricate task because of driver–car interactions, circulatory geometry, and environment perception. According to the Professional Association of Training Companies in Logistics, Transportation, and Road Safety, the majority of drivers make one or more mistakes when passing through roundabouts. That is, 65% do not occupy an appropriate lane as they exit roundabouts, 15% drive straight into roundabouts by crossing lanes, and 60% do not use proper turn signals [1]. Similar results were presented in the annual crash reports provided by Spain's National Traffic Department (DGT), which stated that traffic accidents at roundabouts increased by 34% from 2012 to 2016 and that fatal accidents in these road junctions doubled during the same period [2]. Most traffic crashes that occur at roundabouts are entering/exiting circulating crashes, rear-end crashes, collisions with pedestrians and cyclists, and collisions with parts of roundabouts (e.g., central island, curb) [3,4]. Arndt and Troutbeck [3] reported that roughly 80% of traffic crashes at roundabouts take place on entry lanes, mostly because of a driver's failure to give the right of way to oncoming traffic or vulnerable road users [5].

Distraction is one of the critical threats to the health and the safety of drivers, accounting for 22% of rear-end crashes [6] and 3% of single-vehicle crashes at roundabouts [7]. These statistics are supported by the findings of [8] from a roadside observation intended to capture the prevalence of drivers' secondary behaviors. The authors found that 21.1% of drivers are engaged in distracting activities at roundabouts and that the most common sources of distraction are holding and/or talking on a phone (8.4%) and having a conversation with passengers (3.4%). Distraction is also prevalent among pedestrians crossing the road [9,10]. According to the survey conducted by [9], talking on a mobile phone while crossing the street increases the risk of conflict with a vehicle.

As distraction is generally underreported in national databases and police reports, previous research attempted to determine its potential sources and prevalence using surveys [11–13] and experimental testing [14–18]. Although survey questionnaires can be used to identify potentially distracting activities that lead to traffic crashes, major concerns arise as to the reliability of self-reported data. In contrast, experimental testing approaches such as naturalistic driving studies, field observations, and driving simulations provide researchers with realistic information regarding distracting activities and driver performance.

Past research efforts uncovered that the use of cell phones while driving impairs a driver's performance [19–21]. However, most of these works focused on occurrences on straight road segments [22,23], intersections [24–27], and railway crossings [28,29]. Few investigated cell phone-induced distraction effects on drivers' performance parameters at roundabouts [30,31]. Nonetheless, these roundabout-oriented works did not assess drivers' eye movements on roundabouts under distracted and non-distracted conditions. Table 1 shows some driving simulation studies that revolved around cell phone-induced distraction.

Table 1. Summary of previous works.

Paper	Road Type	Driving Performance Parameters	Eye's Behavior Parameters
Strayer et al. [20]	Multilane highway	Driving speed; following distance; brake onset time	N/A
Yan et al. [21]	Urban road	Brake reaction time; driving speed fluctuation; car-following distance undulation; car-following time	N/A
Choudhary and Velaga [19]	Rural highway	Speed; variation in longitudinal acceleration; steering reversal rate; standard deviation of lane positioning	N/A
Pawar and Patil [27]	Stop-controlled intersections in four-lane undivided major road	Response time; deceleration rate; average speed while approaching intersection and at the intersection	N/A
Jin et al. [32]	Urban highway	Mean/std of throttle opening value; mean/std of steering wheel angle; std of vertical acceleration; mean/std of longitudinal velocity; mean/std of lateral acceleration	Mean/std of saccadic velocity; mean/std of blink frequency; mean/std of peak saccadic velocity; mean/std of blink duration
Papantoniou, P. [23]	Rural and urban routes	Speed; lateral position; direction; average brake; average gear; motor revolution; space headway; time to headway; time to line crossing; reaction time	N/A
Li et al. [25]	Signalized and unsignalized intersections	N/A	Glance frequency; glance duration
Li et al. [26]	Intersections	Approaching speed; reaction distance; maximum deceleration/acceleration; waiting time; gap acceptance	N/A
Liu and Ou [22]	Highway	Response time; the response accuracy; mean and variance of speed (m/s); standard deviation of lateral acceleration (m/s2); standard deviation in longitudinal acceleration (m/s2); lateral lane position	N/A
Haque et al. [30]	Single-lane roundabouts	Reaction distance; initial speed; time to reduce initial speed to the minimum value; gap selection; post-encroachment time; time taken to cross the roundabout; time to recover speed	N/A

Eye Movement and Distracted Driving

Given the increase in distracted driving-related crashes around the world, various researchers [33–35] attempted to investigate the visual characteristics relevant to distracted driving, as eye movement data can uncover important information in the assessment of secondary tasks. For example, Bao and Boyle [33] evaluated drivers' visual scanning behaviors using in-vehicle cameras to monitor drivers' head movements as they make right- and left-hand turns and straight-through driving maneuvers at intersections. Romoser and Fisher [34] used an eye tracker to determine participants' points of gaze during turns at intersections in two different conditions: (1) when drivers are stationary at an intersection and are waiting for a break in traffic to execute a turn and (2) when drivers begin a turn and are aiming to move in the direction from which other vehicles are most likely to come into conflict with their vehicles. Similarly, Romoser, Pollatsek, Fisher, and Williams [35] used an eye tracker to assess the glance patterns of drivers who approach and enter intersections.

In consideration of the above-mentioned issues, the present study was aimed at investigating differences in scanning behaviors under distracting and non-distracting conditions on roundabouts. We chose to focus on these junctions rather than intersections, as some crashes still occur on the former. Moreover, as some dominantly occurring crash types on roundabouts such as rear-end crashes, entering-circulating crashes, and single-vehicle collisions occur at different parts of roundabouts [4], we examined five locations on roundabouts to assess drivers' behaviors.

2. Methodology

2.1. Driving Simulator

In carrying out our investigation, we used a driving simulator specially designed for training purposes. It enables the simulation of realistic driving scenarios under different traffic and weather conditions in a safe environment. A driving simulation system can calculate speed, acceleration, and other motorist or vehicle characteristics on the basis of the performance of a driver. The system can also configure vehicles through changes to traction, gears, and other components. The apparatus used in this work was equipped with three 43 inch monitors designed to visualize a simulated road environment. Computer graphics were used to produce a front image, a side mirror image, and a rear-view mirror image of road traffic conditions. Figure 1 presents the driving simulator used in our study.

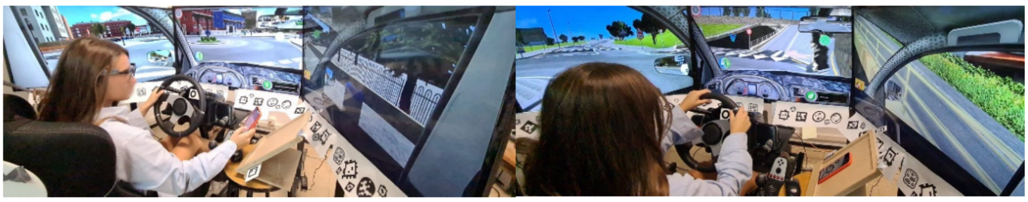

Figure 1. Driving Simulator.

2.2. Eye Tracker

To assess drivers' eye movements, we used Tobii Pro Glasses 2 (Figure 2), which features a one-point calibration procedure, auto parallax compensation, and slippage compensation, thus allowing for persistent calibration throughout testing. The eye tracker was equipped with two cameras and had a sampling rate of 100 Hz. For the analysis of drivers' behaviors on roundabouts, we defined various areas of interest (AOIs), namely front mirror, windshield, driver-side mirror and window, and passenger-side mirror and window. The data recorded by the eye tracker were analyzed using the Tobii Pro Lab software, through which participants' fixation duration and eye pupil size for each AOI were determined. These two metrics are important because they reveal a driver's visual distraction. As reported by Jiang et al. [36], distraction among pedestrians is associated with increased pupil diameter and reduced fixation duration.

Figure 2. Tobii Pro Glasses 2.

2.3. Participants

Prospective participants were screened for eligibility, and if eligibility criteria were satisfied, they were provided a consent form approved by the Institutional Review Board of the University of Burgos. A total of 45 individuals, specifically 13 females and 32 males, participated in this study. They were healthy, 19 to 56-year-old adults living in Burgos, Spain, who had no eye diseases and mental illness but had intact physical functioning and limb movement. They were selected based on years of driving experience and frequency of vehicle use in real life.

2.4. Procedure

All the participants were given detailed information about the study in advance, and data were collected from those who provided informed consent. Each participant filled out a survey questionnaire with questions related to demographic factors and particularities of individual driving. They later received an introductory tour of the simulator and were allowed a practice drive for familiarization with the apparatus and simulated road environment. The virtual road environment featured a multi-lane rural and urban roads that encompassed six roundabouts with stable traffic flow and where drivers had a high degree of freedom to select speed and operating conditions; nevertheless, such conditions were somewhat influenced by other vehicles on the road. Additionally, all the participants were tasked to drive in clear weather conditions and during the day. After the training, they were instructed to operate in two counterbalanced experimental drives. Before each experiment, a trained research assistant fitted the eye tracker onto each test participant's head. During the calibration, the test participant was asked to look at a calibration card (target) held in front of him/her for a few seconds. The assistant then initiated recording using the Tobii Glasses Controller software running on a computer. After the session, the assistant stopped the recording and removed the head unit from the test participant. All interactions with the eye tracker (listing the participants to be tested, initiating calibration, starting/stopping recordings, etc.) were done through the Tobii Glasses Controller software. In the non-distracting experiment, the participants were asked to drive through a simulated route with six roundabouts while refraining from using a cell phone. Depending on each individual driving style and behavior, every subject had to drive for approximately 10 to 15 min without any distraction, keeping attention focused on the road. The other experiment was performed fully under cell phone-induced distraction. That is, the trained research assistant placed a single phone call as well as sent multiple WhatsApp messages to participants during the experiment. During the call, the research assistant maintained a natural conversational flow that required participants to respond to various open-ended questions. Typical questions included inquiries related to future plans, the academic course, and preferred leisure activities. In addition, the participants were asked to open Instagram and go through the feed. These applications were selected because they are downloaded frequently from the app store/play store and are popular among young people, which is this study's target group. The participants were instructed to drive as they typically would on a real road, adhering to the speed limit as well as other traffic laws outlined by DGT.

2.5. Data Analysis

First, the Tobii Pro Lab software was used to output videos and corresponding CSV files. Second, we extracted information related to pupil diameter and fixation duration via the AOIs and for each location inside and outside roundabouts. As shown in Figure 3, all the measurements were made in five roundabout locations, namely, (1) 50 m behind the entry line, (2) pre-entrance, (3) at the entry line, (4) at the entrance, and (5) on the exit line. The total fixation duration for each AOI inside roundabouts was measured. For between-group comparisons (distracting vs. non-distracting conditions), multiple paired *t*-tests were conducted for matched samples to determine whether the measured parameters under distracting and non-distracting conditions significantly differed. Paired *t*-tests were chosen, as the observations were not independent of one another (e.g., each subject participated in both experiments.). For each participant, we essentially looked into differences in the values of fixation duration and eye pupil diameter and tested whether the mean of these differences was equal to zero. We also used a one-sided alternative that involved calculating the task load (TL) score in cases wherein such load was higher under distracted driving than under non-distracted driving:

$$H_0\text{: mean } (TL_{\text{distracting}} - TL_{\text{Non-distracting}}) = 0 \quad (1)$$

$$H_a\text{: mean } (TL_{\text{distracting}} - TL_{\text{Non-distracting}}) > 0 \quad (2)$$

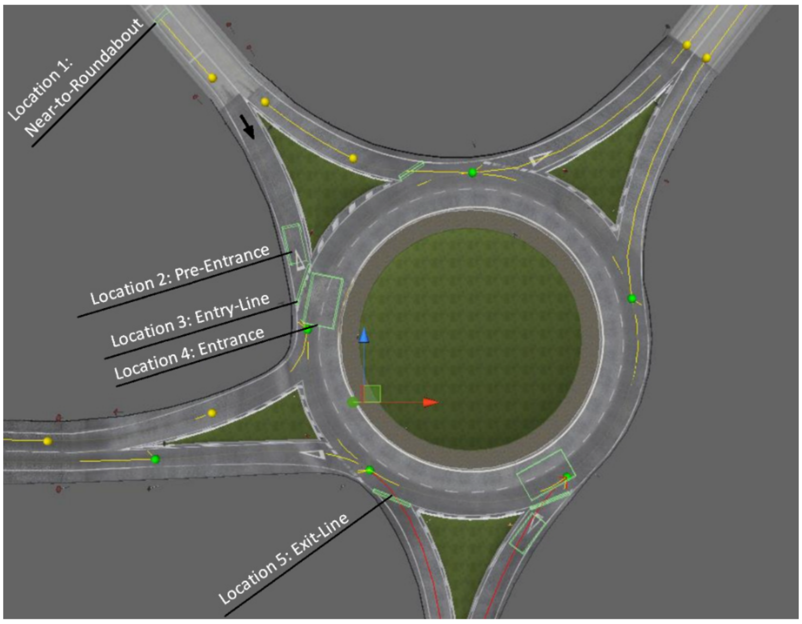

Figure 3. Locations of interest inside and outside a roundabout.

With regard to the eye pupil size, we proposed a one-sided alternative wherein the median pupil dimeter (PD) under distracting conditions was higher than that under non-distracting conditions:

$$H_0\text{: mean } (PD_{\text{distracting}} - PD_{\text{Non-distracting}}) = 0 \quad (3)$$

$$H_a\text{: mean } (PD_{\text{distracting}} - PD_{\text{Non-distracting}}) > 0 \quad (4)$$

A similar one-sided alternative was put forward for fixation duration, that is, a case wherein fixation duration (FD) under non-distracting conditions was higher than that under distracting conditions:

$$H_0\text{: mean } (FD_{\text{Non-distracting}} - FD_{\text{distracting}}) = 0 \quad (5)$$

$$H_a\text{: mean } (FD_{\text{Non-distracting}} - FD_{\text{distracting}}) > 0 \quad (6)$$

Lastly, in order to realize whether there exist gender differences in fixation durations under distracting condition, the non-parametric Mann–Whitney U test was used because of its robust properties in calculating unequal sample size between conditions [37].

$$H_0\text{: Median } (FD_{\text{Male}}) = \text{Median } (FD_{\text{Female}}) \quad (7)$$

$$H_a\text{: Median } (FD_{\text{Male}}) \neq \text{Median } (FD_{\text{Female}}) \quad (8)$$

To reject the null hypothesis, we considered a level of significance of 0.1 (one-sided) and used STATA (version 16) for this purpose.

3. Results

Between-Group Comparison of Eye Parameters in Roundabouts

A total of 13 participants were excluded from the analysis because their eye movements were not detected by the eye tracker. In location 1, there was a significant between-group difference in fixation durations when the drivers were looking at all the AOIs: front mirror ($p = 0.0005$), windshield ($p = 0.020$), driver-side mirror ($p = 0.005$), driver-side window ($p = 0.030$), passenger-side mirror ($p = 0.034$), and passenger-side window (0.003). In location 2, a significant between-group difference in fixation durations was found when the participants were looking at front mirror ($p = 0.030$), windshield ($p = 0.040$), driver-side mirror ($p = 0.009$), driver-side window ($p = 0.014$), and passenger-side window ($p = 0.049$). However, no such difference was found with respect to gazes on the passenger-side mirror. With reference to location 3, the between-group difference in fixation durations was significant only when the participants looked at front mirror ($p = 0.080$), windshield ($p = 0.050$), driver-side mirror ($p = 0.085$), and driver-side window ($p = 0.077$). As regards location 4, a significant between-group difference in fixation duration occurred only when the drivers looked at the driver-side mirror ($p = 0.087$). Finally, in the matter of location 5, the fixation durations differed significantly between the groups when the driver looked at mirror ($p = 0.037$), windshield ($p = 0.006$), and driver-side mirror ($p = 0.088$). Table 2 summarizes the results.

Table 2. Paired *t*-test for the comparison of fixation durations under distracting and non-distracting situations.

Location	*p*-Values					
	Front Mirror	**Windshield**	**Driver-Side Mirror**	**Driver-Side Window**	**Passenger-Side Mirror**	**Passenger-Side Window**
No. 1	0.0005	0.020	0.005	0.030	0.034	0.003
No. 2	0.030	0.040	0.009	0.014	0.253	0.049
No. 3	0.080	0.050	0.085	0.077	0.0694	0.026
No. 4	0.469	0.425	0.087	0.623	0.856	0.593
No. 5	0.037	0.006	0.088	0.226	0.937	0.735
Inside Roundabouts	0.0003	0.005	0.001	0.010	0.202	0.012

For each AOI inside roundabouts, a significant between-group difference in total fixation durations arose when the participants looked at front mirror ($p = 0.0003$), windshield ($p = 0.005$), driver-side mirror ($p = 0.001$), driver-side window ($p = 0.010$), and passenger-side window (0.012). As for pupil size (Figure 4), the results of the paired *t*-test showed that the median left ($p = 0.02$) and right ($p = 0.04$) pupil diameters increased significantly. In contrast, for each AOI inside roundabouts, there was no significant difference between male and female participants in fixation duration under distracting condition.

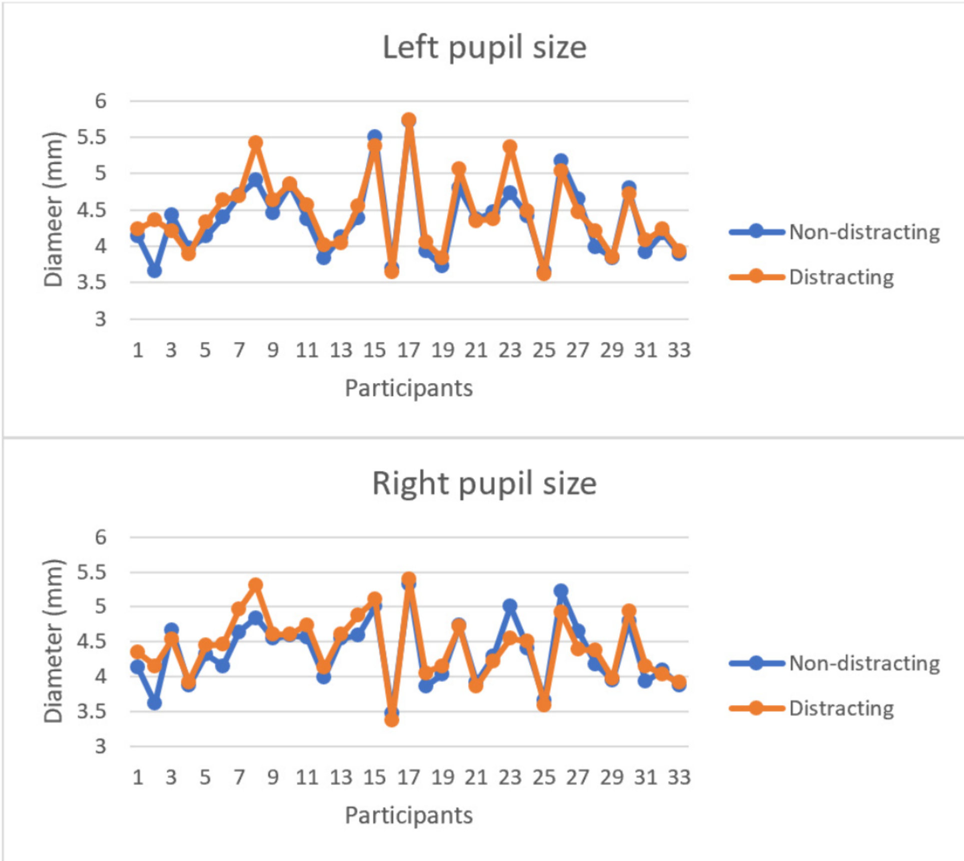

Figure 4. Comparisons of pupil size under distracting and non-distracting conditions.

4. Discussion

This study investigated the effects of cell phone-induced distraction on drivers' eye movements inside and outside roundabouts. For this purpose, two driving simulator scenarios featuring distracting and non-distracting conditions were featured in experiments.

The analysis of the drivers' eye movements suggested that the participants drove less cautiously when they were approaching roundabouts (location 1), considering the reduced fixation durations in all AOIs as a result of cell phone-induced distraction. Similar trends for all the AOIs except the passenger-side mirror were observed in location 2, where the drivers were near entry lines. This similarity can be explained by the attempts of most of the drivers to exit the left lane and keep right when approaching an entry line and before entering a roundabout. Moreover, the majority of the drivers involved in the experimented reduced fixation duration on an entry lane approaching a roundabout (location 3), especially for the driver-side window. This finding is critical, as it indicates that the drivers paid reduced attention to oncoming traffic in roundabouts, which can result in entering-circulating crashes. In contrast, in location 4, no significant change in fixation duration was observed with respect to the driver-side window, meaning that the drivers started paying attention to oncoming traffic only when their vehicles were fully inside the roundabout. This behavior can elevate the risk of side-swipe crashes. As for location 5, a significant drop in fixation duration in connection to front mirror, windshield, and driver-side window was found, thereby likely increasing the risk of rear-end and exiting-circulating crashes when drivers exit a roundabout. Finally, comparing distracting and non-distracting scenarios highlighted that the total fixation duration inside roundabouts decreased by 36% on average, thus posing a significant crash risk. The participants who drove in roundabouts under distracting conditions exhibited wider eye pupil diameters than those shown by those who drove in roundabouts under non-distracting conditions, which is consistent with the findings of [36].

To tackle distracted driving challenges on roadways, especially on roundabouts, various effective countermeasures are recommended. Awareness campaigns are proven strategies to educate about distracted driving. According to reference [38], a one week distracted driving awareness campaign at a large university, which consisted of mass emails and group discussions with students, substantially improved distracted driving behaviors among students. In addition, legislative countermeasures such as cell phone use bans were associated with reductions in observed handheld phone use among young drivers [39]. As for technology countermeasures, the most current technology is phone-based blocking applications, which often use the phone's GPS to track whether the user is in a moving vehicle. There are many other technology-based approaches that monitor driver's performance [40], eye behavior [41], and phone usage [42] and provide real-time alerts to drivers aimed at reducing distracted driving.

5. Conclusions

The results on driver performance and eye movements indicated that between-group differences in fixation durations and eye pupil diameters were significant. That is, the participants drove less cautiously near and inside roundabouts when they were exposed to cell phone-induced distraction. Our exploration into the drivers' behavior during travel on a roundabout under distracting and non-distracting scenarios showed that the drivers were compelled to exert more effort to keep their eyes on the road as they used their cell phones.

The findings can be used by decision makers as reference in developing distraction-specific technologies so that cell phones cannot be used by drivers on roadways, especially when they pass through roundabouts. The results can also serve as a guide in the establishment of test methods designed specifically to compare eye glance metrics for each AOI with accepted criteria for evaluating whether a task excessively interferes with driver attention and becomes unsuitable for a driver to perform while driving.

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Informed Consent Statement: Design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Article

Effects of Mobile Phone Use on Driving Performance: An Experimental Study of Workload and Traffic Violations

Carlos A. Catalina Ortega [1], Miguel A. Mariscal [1], Wafa Boulagouas [1], Sixto Herrera [2], Juan M. Espinosa [1] and Susana García-Herrero [1,*]

[1] Escuela Politécnica Superior, Universidad de Burgos, 09001 Burgos, Spain; cco0001@alu.ubu.es (C.A.C.O.); mariscal@ubu.es (M.A.M.); wafa.boulagouas@umc.edu.dz (W.B.); jespinos@ubu.es (J.M.E.)
[2] Departamento de Matemática Aplicada y Ciencias de la Computación, ETS de Ingenieros de Caminos, Canales y Puertos, Universidad de Cantabria, 39005 Santander, Spain; herreras@unican.es
* Correspondence: susanagh@ubu.es

Abstract: The use of communication technologies, e.g., mobile phones, has increased dramatically in recent years, and their use among drivers has become a great risk to traffic safety. The present study assessed the workload and road ordinary violations, utilizing driving data collected from 39 young participants who underwent a dual-task while driving a simulator, i.e., respond to a call, text on WhatsApp, and check Instagram. Findings confirmed that there are significant differences in the driving performance of young drivers in terms of vehicle control (i.e., lateral distance and hard shoulder line violations) between distracted and non-distracted drivers. Furthermore, the overall workload score of young drivers increases with the use of their mobile phones while driving. The obtained results contribute to a better understanding of the driving performance of distracted young drivers and thus they could be useful for further improvements to traffic safety strategies.

Keywords: mobile; phone; distractions; traffic; violations; workload; young; drivers

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1. Introduction

Traffic accidents account for 1.35 million deaths a year on 2018 and keep being a significant cause of injuries and fatalities [1]. This has led countries all around the world to give the highest priority to improve road safety and devote considerable efforts to manage the injury profiles for traffic accidents and develop a safer road traffic system, such as vehicle safety, road infrastructures improvement, enhancement of drivers' care, traffic rules and regulations, awareness campaigns, etc.

As a matter of fact, statistics on traffic accidents and related injuries have shown that 80–90% of traffic incidents are caused by drivers' operational mistakes, errors and misbehaviors, inattention, fatigue, and distraction [2–6].

Although there are numerous potential in-vehicle sources of distraction, extensive research has reported that the use of mobile phones is among the major factors that lead to traffic accidents [7–10]. In this regard, researchers reported that, in 2015, there were 4.7 billion people using mobile phones and that this number was expected to reach 5.6 billion by 2020 [11]. Furthermore, the development of the telecommunications industry and this increasing number of subscribers would make the use of mobile phones among drivers very common.

Taken together, there is a recent trend and growing interest in technology-based distractions (particularly the use of mobile phones) and a substantial body of research has investigated the risk factors related to their use on the drivers' performance and road safety. A survey conducted in Australia found that driver distraction contributed to 13.6% of serious traffic crashes [12]. Analogously, in 2019, the Department of Transportation's National Highway Traffic Safety Administration estimated that distracted driving has claimed around 3142 lives in the US [13]. Moreover, an observational study in the US reported that out of 3265 observed drivers, 32.7% had distracted driving and talking on the phone, and that texting/dialing a phone were among the most frequently observed distractions (i.e., 31.4% and 16.6%, respectively) [14]. As regards predictors for such secondary tasks, an investigation of the observable distractions while driving in the UK found that age emerges as a significant predictor for most of the observed secondary tasks, including mobile phone use [15]. Moreover, this study pointed out that young drivers are more likely to be distracted. Indeed, young people keep using and interacting with their mobile phones too frequently. A naturalistic study found that young people aged between 17–22 years old touch their mobile phones while driving 1.71 times per minute, on average [16]. Similarly, a study involving 254 young participants aged between 17–23 years old found that they touch their mobile phones 1.6 times per minute, and more than half are performed while the vehicle is in motion and half of the screen-touches are to use WhatsApp [17]. Another study involving 114 young people (aged between 17–25 years old) specified that young people have greater use of social media platforms while driving [18]. The descriptive results of this study showed that fully 80.7% of them were chatting and texting, 73.7% were talking on their mobile phones, 53.5% were using Facebook, 41.2% were interacting on Snapchat, and 30.7% were checking their emails.

In Spain, a recent study reported a total of 410,974 traffic accidents occurred in the last four years (2016, 2017, 2018, and 2019). According to this study, these traffic accidents involved 666,504 drivers, of which 8.33% were involved in serious accidents and 12.82% of them were young drivers (under 25 years old) [19]. Moreover, this study found that 4048 of the distracted drivers were using their mobile phones. Similarly, a week-long surveillance campaign carried out in Spain by the DGT (the DGT is the Spanish General Traffic Department) found that 2873 drivers were using their mobile phones while driving [20].

Likewise, out of 10 young people, eight admitted to having distracted driving, and 67% specified that they checked their mobile phones frequently while driving [21]. Another study done in Spain by Linea Directa Foundation in collaboration with the Institute of Traffic and Road Safety (Intras) in 2019, estimated an average mobile phone usage to be 6 h and 48 min and particularly at traffic lights, traffic jams, and when they think "the road is safe" [22]. As regards the use of mobile phones in Spain, it was reported that WhatsApp and Instagram were among the top three applications downloaded and on which the subscribers were more active [23].

It is well established in the literature that distracted driving takes drivers' eyes off the road, switches their consciousness from driving to other tasks, and results in false perceptions. Indeed, traffic accidents take place when the drivers' performance is below the required levels for the traffic environment [24]. In this regard, a recent study confirmed that safer driving requires an assessment of driver mental states [25]. Furthermore, the authors have explained that the capacity of humans' mental resources that could be used to process information received (i.e., mental workload) is limited and the use of mobile phones claims further cognitive resources. Therefore, the margin of the driver's attentional capacity decreases as long as the amount of information being processed increases. In-depth studies investigated such mental mechanisms have put in light the deployment of numerous approaches and different measures to assess the cognitive load. These approaches could be grouped into four main groups [26]: (i) physiological such as electroencephalogram (EEG), electrocardiography (ECG), galvanic skin response (GSR), and respiration, (ii) eye tracking, (iii) performance-based vehicle speed, and (iv) subjective, e.g., NASA TLX (National Aeronautics and Space Administration Task Load Index) which is the most commonly used assessment tool in the literature

The present study is designed to provide an integrated framework to assess the influence of technology-based distractions (particularly, the use of mobile phones behind the wheel) on driving performance. For this purpose, first, a simulation experiment was conducted using a driving simulator to collect data on driver infractions under the influence of mobile phone distractions. Driving simulators are widely used in human factors, driver behaviors, driver perception, and driver distraction studies as they offer a safe, efficient, and controllable environment. Thus the driving simulator is proved to be a valid substitute for different aspects of real driving experience [27–29]. This study was then extended to assess the workload associated with the use of mobile phones while driving. For this purpose, the NASA TLX, which is a well-known subjective multidimensional method, was used to rate six aspects of perceived workload, i.e., mental demand, physical demand, temporal demand, performance, effort, and frustration. In addition to these scales, an overall value of perceived workload was measured as well [30]. Finally, several studies used machine learning techniques in road safety studies to address distracted driving issues [31,32]. In this paper, a tree-based machine learning method was deployed for classification and regression problems.

The rest of the paper is organized as follows: Section 2 describes the design and methodology of the study. Section 3 provides the results, discusses the main findings, summarizes the most relevant weaknesses, and suggests directions for future research. Section 4 concludes the study.

2. Background and Related Work

Road safety literature is rich in research and studies that investigated the influence of technology-based distractions on driving performance. A summary of the main findings from 13 selected past studies is given in Table 1.

The selected past studies are reviewed with regard to the objective of the research, the type of the study, and the methodology adopted.

Table 1 shows that mainly three types of research studies are interested in distracted driving due to the use of mobile phones:

(i) survey studies that assess patterns and prevalence of distracted driving and analyze the characteristics of the distracted drivers (e.g., gender and age);
(ii) naturalistic studies that observe behaviors of the drivers and record secondary tasks (in particular, the use of mobile phones) over a period of time; and
(iii) experimental studies that employ driving simulators to design specific driving scenarios, close to a real driving environment, to collect data on the influence of the distractions on the driving performance.

Although survey studies in their different forms (questionnaire, phone interviews, or online), and naturalistic studies are two main approaches that utilize large samples made up of hundreds of subjects to analyze the distracted driving phenomenon, these methods suffer several limitations. First, the data used to conduct such studies involved subjective responses from respondents and interviewees which are, generally, biased and lead to inconsistent outputs. Second, in observational studies, data are collected at one particular location.

Experiment studies, including the present study, are advantageous over other types as they provide a safe and controllable environment for scholars to collect data on distracted driving under specific conditions which are dangerous in the real world or difficult to be reproduced.

Moreover, in comparison of experiment studies of Table 1, and in contrast to survey studies, experiment studies consider typically small samples involving 20–80 participants, and they mainly collect data either on: (i) speed infractions, (ii) lateral control, (iii) lane-changing, and (iv) traffic accidents. Advantageously, the present study is designed to collect several driving performance measures, such as traffic accidents, traffic rules, lateral distance, speeding, and other violations. (Violations studied in this paper will be detailed in Results and Discussions section).

Table 1. Summary of similar past studies.

Paper	Research Type	Dataset Characteristics		Data Collected		Instruments		Distractions		Random Forest
		Sample Size	Age Group	Workload	Behavioral Data	Workload Assessment Tool	Data Collection Tool	Mobile Phone Distractions	Other Distractions	
[33]	E	20 20	25–45 > 65	X	Crash rate Acceleration Lane position	NASA TLX	Simulator	-	Challenging road events	-
[34]	N	11 9	13–34 39–51	X	Task-related interior glances	NASA TLX	-	Texting	-	-
[35]	E	20	20 (SD 3.1)	X	Collision; Aggressive driving Traffic rules violations Lane keeping	NASA TLX	Simulator	-	Affective states	-
[36]	E	16 16 20	19.2 (SD 2.3) 19.1 (SD 1.3) 19.9 (SD 1.1)	X	Lateral position	NASA TLX	Simulator	-	Road conditions	-
[37]	E	50	18–59	-	Lane excursions	-	Simulator	Texting	-	-
[38]	E	34	18–30	X	Speed Variance of lane position	NASA TLX	Simulator	Calling	Road conditions	
[39]	S	200	39.5 (SD 10.2)	X	Driving accidents Human errors	NASA TLX and CFQ cognitive failure questionnaire	-	-	-	-
[40]	E	25 24	22.12 (SD 2.45) 37.62 (SD 7.22)	X	Longitudinal and lateral controls	-	Simulator	Texting and calling	-	-

Table 1. *Cont.*

Paper	Research Type	Dataset Characteristics		Data Collected		Instruments		Distractions		Random Forest
		Sample Size	Age Group	Workload	Behavioral Data	Workload Assessment Tool	Data Collection Tool	Mobile Phone Distractions	Other Distractions	
[41]	E	34	Male: 32.5 (SD 5.38) Female: 30.46 (SD 4.2)	X	Car-following	EEG	Simulator	Calling	-	-
[42]	S	475 232	≤30 >30	X	Situation awareness Driving performance	SWAT	-	-	High altitude environment	-
[43]	N	20	57.8 (SD 2.7)	X	Speed variability Reaction time Number of traffic violations	NASA TLX & EEG	-	-	Three complexity levels of the situation	-
[44]	E	18 18 18 18	18–25 31–40 55–65 70–80	-	Braking responses	EEG	Simulator	-	Acoustic and visual distraction stimuli	-
[45]	E	41	18–61	-	Gap acceptance at intersections Intersection crossing completion time	-	Simulator	Texting	-	-

E: Experimental, N: Naturalistic (observational), S: Survey.

Furthermore, primary methods used to analyze the data collected are the statistical models, for instance, Logistic regressions and Logit models. However, the large number of factors and parameters collected from police reports as regards the traffic accidents challenges the statistical methods to handle all of these variables. Thus, statistical modeling is generally effective in the case of a smaller dataset with fewer attributes, otherwise they end up over-fitting. To address these shortcomings of the statistical models, machine learning techniques have emerged for classification and regression problems. They are more adequate for learning from large datasets with a high number of attributes and observations, for example, Bayesian Networks and Artificial Neural Networks [46], Decision Trees [47], Random Forests [48], etc.

Therefore, in this paper, a tree-based machine learning method (Random Forest) is deployed for classification and regression problems. This method has been previously used to identify when a driver is distracted based on driving behavior data [49], and to establish the relevance of the variables affecting the driving behavior [50], and is found to be a robust and competitive method in both tasks, especially when a limited sample size is available. Despite the differences between the objectives and approaches of the cited studies, the results are consistent with those obtained in this paper, although we extend the analysis to a more general overview of the driving behavior leading to an increment of the traffic infractions.

As part of the underlying causes of distracted driving and resulted impairments, much previous research given in Table 1 used either subjective measures to evaluate the mental workload, such as the NASA TLX and RSME (the Rating Scale Mental Effort), or physiological measures, such as variability in heart rate or changes in brain activity using, for instance, the EEG. Likewise, this study specifically assesses the cognitive workload and efforts of processing auditory and visual information related to the secondary task (i.e., the use of the mobile phone, particularly for calling and texting) using NASA TLX. This design is very convenient to expand the context of previous studies and contribute to the body of literature on technology-based distracted driving.

3. Materials and Methods

3.1. Participants

In the beginning, a total of 44 subjects participated in the experiment. Nevertheless, five of them were discarded: two participants were eliminated due to age (48 and 56 years old), two others due to missing information on NASA-TLX, and one additional participant was not considered in the study as the recordings of the simulator were corrupted. Finally, only 39 participants successfully completed the experiment. This sample size is consistent with published literature (as discussed in the previous section), and large enough to conduct the study.

The study sample was made up of 12 females and 27 males, aged between 19 and 32 years old ($\mu = 21.5$ and SD = 2.6), and had a valid Spanish driving license. The average number of years since the participants got their driving licenses was 2.84 (SD = 2.38) ((a) of Figure 1). On average, most of the participants drove around 5000 Km per year or less ((b) of Figure 1) and 82% of them drove at least weekly ((c) of Figure 1). Finally, the participants were asked about how much they like to drive and responses showed that most of them liked or liked very much to do so ((d) of Figure 1).

Young people were selected as they use their mobile phones more regardless of road and traffic conditions, are more likely to underestimate the difficulty of driving, and are less likely to understand the risks associated with multitasking [38,51–53].

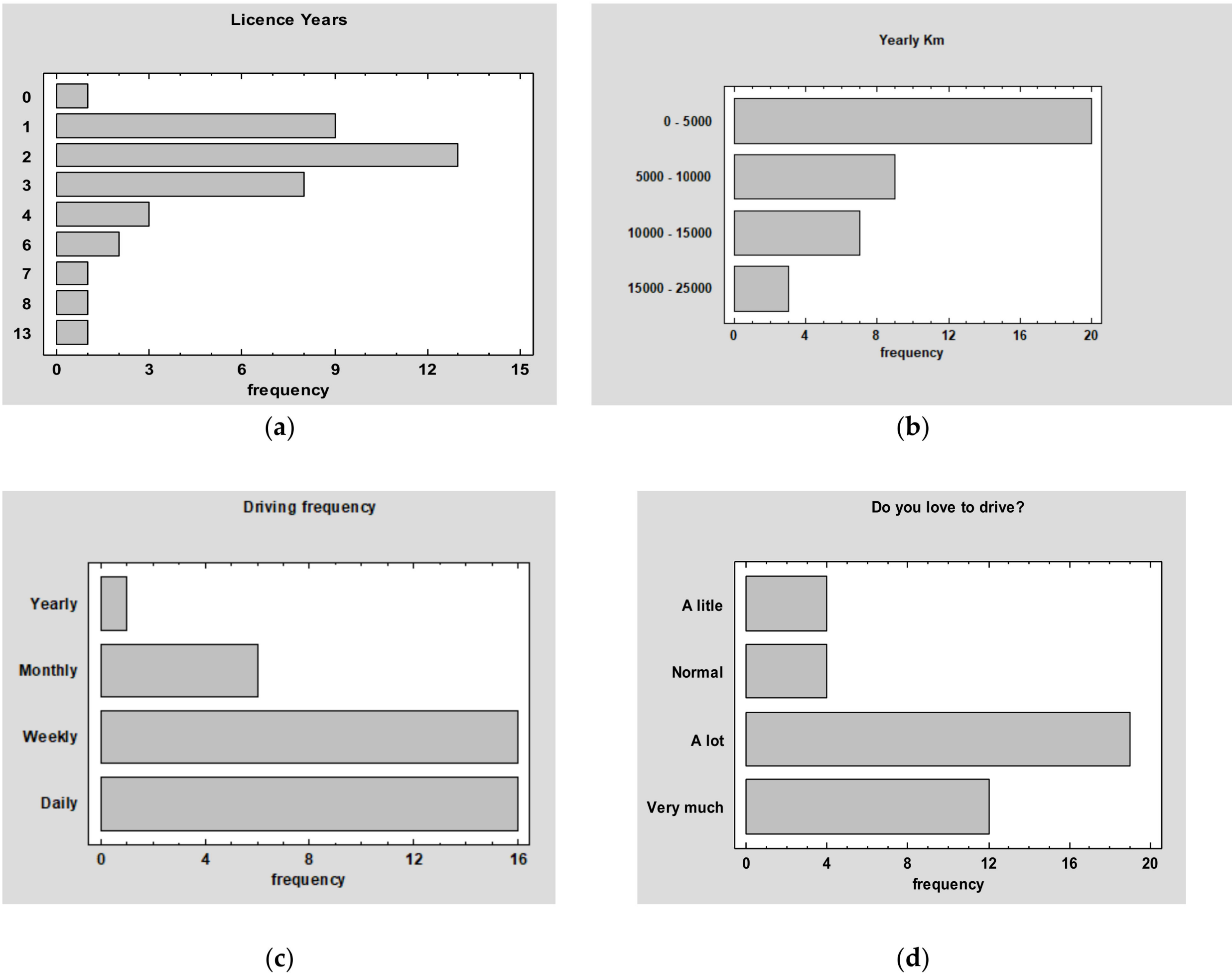

Figure 1. Descriptive of the study sample: (**a**) Frequency of the license years; (**b**) Km driven per year; (**c**) Driving frequency between daily, weekly, monthly and yearly; (**d**) How much the participants love to drive.

3.2. Apparatus

For the experiment, an adapted DriveSim simulator located at the University of Burgos, Spain was used. It is a high-quality driving training-based simulator that contains three big screens to yield a high immersive environment, a steering wheel (Logitech G27), pedals, gear lever, and real car controls and signals (ignition key, turn lights, etc.) for more realism (Figure 2).

The simulator screens are 39″ with a 1920 × 1080 resolution each. The simulator can record driving data between 40 and 60 Hz depending on the elements in the environment and the interior of the car, i.e., dashboard and mirrors, as key elements.

The simulator includes artificial intelligent traffic and pedestrian agents to better mimic a real driving experience. A mobile phone was placed to the right of the steering wheel which is commonplace for mobile phones nowadays.

3.3. Experimental Design

A specific trajectory was created to perform the experiment. It covered rural roads and urban areas and included several roundabouts, stops, traffic lights, and pedestrian crossings (Figure 3). The entire trajectory could be run within about 15 min depending on the traffic and status of the traffic lights. The simulation was configured to have a sunny day with medium traffic and pedestrian density. Both traffic and pedestrians were randomly generated, and the trajectory was complex enough to avoid the learning effect during the laps.

Figure 2. Simulator with three screens used in the study.

Figure 3. The trajectory of the experiment.

During the experimental phase, two laps were run. The first lap was run with normal conditions in the simulator and no distractions were applied. Into the second lap, the distractions were introduced in the form of several secondary tasks using the mobile phone. The objective was to estimate the effect of mobile phone-related distractions and measure the resulting workload due to multitasking. Accordingly, the participants had to respond to a call, reply to several WhatsApp messages, and use Instagram. These tasks had to be done with a specific mobile phone provided for the experiment placed on the simulator cockpit in a specific position to the right of the steering wheel. The mobile phone had particular contacts on the agenda who should be contacted during the experimental phase.

3.4. Experimental Procedure

At their arrival, the participants were introduced to the experimental procedure and asked to sign the bioethical consent. After that, they did a test into the simulator in a free driving scenario for 5–10 min. The aim was to check any potential motion or simulator sickness that could generate a big dropout during the experimental phase. In case the participants felt the motion sickness associated with driving simulators, they were rejected [54–56]. Furthermore, the test contributed to making the participants more familiar with the simulator and feel more comfortable during the experiment [57]. Whenever the first test was successfully completed, the participant fulfilled the socio-demographic survey and proceeded with the experiment. Additionally, the participants were informed that they could quit the simulation, at any moment, if they felt any motion sickness or discomfort.

During the experimental phase, two laps were run. In the first lap, the participants got the instructions to drive like they are used to doing in real life with normal conditions on the simulator and no distractions. Following a successful first drive, the participants immediately completed the NASA-TLX.

The NASA-TLX is a well-known tool used to self-evaluate the subjective workload of the volunteer in a task. It rates the overall workload of the task and six other subscales [30]:

- Mental Demand: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
- Physical Demand: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
- Temporal Demand: How much time pressure did you feel because of the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
- Overall Performance: How successful were you in performing the task? How satisfied were you with your performance?
- Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?
- Frustration Level: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Each subscale ranges from “very low” to “very high” respectively, except for the Overall Performance that uses two bipolar descriptors, “success” or “failure”. It also implies the need to fulfill a workload comparison of 15 questions to evaluate the contribution of each dimension to the workload of a specific task.

In the second drive, the participants had to drive and perform several secondary tasks. Nevertheless, they were instructed not to perform the distractions when stopped in red light or similar situations. Particularly, secondary tasks were to respond to a call, replay several WhatsApp messages and later use Instagram.

In case, the participant was not able to perform all the secondary tasks, the data regarding their driving performance were discarded. Immediately, after completing the second drive, the participants completed the NASA-TLX again.

3.5. Data Collection

The simulator recorded the telemetry data for each experiment in an SQLite database allowing the collection of a large amount of valuable data related to the simulation. Particularly, telemetry data were associated with the user/simulation and violations. They covered 28 types of records, most of which were focused on the conditions of the vehicle at any given time: speed, control status, accelerations, etc., but also included other valuable data, for instance, the speed limit of the road on which the user was running along. Moreover, the simulator detected inappropriate driving and determined the penalties. In fact, there were up to 87 different conditions in which the simulator registered a penalty, such as exceed the speed limits, flashlights, incorrect use of lights, cross over continuous lines, or go to the side of the road, etc.

As regards data collected from NASA-TLX after the two simulated drives, participants completed physical forms which were later copied into a csv-file (CSV-Comma Separated Value) to be processed easily later.

3.6. Study Variables and Data Analysis

Violations were organized in a similar way to a previous study [58] which is consistent with recent research on mobile phone distractions and driving performance [59]. Among 87 types of violations recorded by the simulator, 32 were eliminated as they did not fit the simulation conditions; for instance, switch on the light when driving at night or into the tunnel, park in inadequate places, etc. Out of 55 types of violation left, the participants committed 36 of them, which were grouped into five groups: (i) Lateral Distance: cross over continuous lines, do not respect the distance from the curb, etc.; (ii) Traffic Rules: do not stop at the red traffic light, at a pedestrian crossing or stop sign, incorrect use of turn signals; (iii) Speed: speed violations, i.e., do not respect the speed limits; (iv) Accident: collisions or serious traffic accident; and, finally, (v) Others: drive with the handbrake on, use the clutch incorrectly, etc.

3.7. Data Analysis Methods

In order to analyze the main factors contributing to the drivers' violations, two approaches were considered. On the one hand, the contribution of each feature to the variability if the target variable was estimated by means of an Analysis of Variance (ANOVA). On the other hand, a Random Forest, a tree-based ensemble method, was considered to obtain the importance of each feature to model the target variable [60,61]. Finally, for illustrative purposes, classification and regression trees were used to model the occurrence (Number of violations > 0) and number of violations committed by the participants. In this sense, both regression and classification problems were considered in this work.

3.7.1. Decision Trees

Tree-based methods [62–65] define a tree as a structure by recursively splitting the features' space. Each division is obtained by calculating the best predictor split determined by a chosen purity criterion over the target variable. In particular, the Gini Index and the Sum of the Squared residuals (RSS) were considered for classification (Equation (1)) and regression models, respectively. Note that, as a result, a disjoint partition of the features' space based on the purity criterion is obtained. In the resulting tree, each node corresponds to a test on an attribute (i.e., mobile phone use), each branch corresponds to an attribute value (i.e., mobile use = Yes or No), and each leaf (terminal node) represents a final class/value (i.e., violation = Yes) which is assigned to the subsample fulfilling the different conditions defining the path to reach the leaf node from the top of the tree.

$$\text{GINI} = 1 - \sum_{i=1}^{n} p_i^2 \quad (1)$$

These methods have several well-known advantages and drawbacks. First, the trees have a graphical representation that is easy to be assimilated and interpreted. Compared to other methods, decision trees can be constructed relatively fast and they do not require a very big sample to obtain competitive results [64]. Second, some attributes could not be selected to grow the tree as they are secondary in terms of the increment of the global purity of the partition obtained. For this reason, they can be used as a feature selection in a pre-process for other learning algorithms. Third, they work with both quantitative and qualitative (i.e., discrete) predictors. Finally, for a sufficiently complex (i.e., large or deep) tree, all instances could be correctly classified although this commonly leads to over-fitted models.

3.7.2. Random Forest

Random forest [66,67] is a tree-based bagging (Bootstrap Aggregating) method that constructs N independent trees considering, on the one hand, a random selection of the predictors, and a new sample obtained utilizing a bootstrap over the original one, on the other hand. As a result, N predictions are obtained (one for each tree of the forest) which are combined to obtain the final one.

For the classification and regression, the majority vote class and the mean are commonly used. Note that despite the overfitting of each particular tree, the average of multiple independent trees prevents the overfitting of the random forest. However, the graphical representation of the random forest is not possible and, consequently, its interpretation is more difficult than in the case of the trees. To partially overcome this problem, the importance of each variable, in terms of the error reduction obtained when this feature is chosen in a node, can be obtained as an estimation of the contribution of each feature to the target one.

For this work, the Random Forest has been built considering N = 150 trees, based on cross-validation up to 300 trees, and randomly chosen at most half of the variable features. Based on the results obtained with the tree model, the maximum number of leaf nodes was established in 10, maintaining in some ways the coherence between both approaches.

4. Results and Discussions

4.1. ANOVA

ANOVA analysis, summarized in Table 2, provides several findings related to the number of violations considering the mobile phone-related distractions.

Table 2. ANOVA test for the number of violations.

Violations	Sum Sq	Mean Sq	F Value	Pr (>F)
Lateral Distance	73.220	73.221	14.169	0.000 ***
—Crossing over a hard shoulder line	12.732	12.733	6.138	0.015 *
—Crossing over a solid line	13.190	13.190	13.486	0.000 ***
Traffic Rules	3.800	3.800	0.011	0.915
Speed	128.700	128.707	1.526	0.220
—Speed limit 20 Km/h	6.222	6.222	6.773	0.011 *
Accident	2.101	2.101	1.170	0.283
—Accident out of the road	0.609	0.609	4.321	0.041 *
Others	2.300	2.297	0.115	0.736

* *p*-value < 0.05 *** *p*-value < 0.001.

Results of Table 2 show that data of most of the violations are statistically significant. Indeed, Lateral Distance violations have the highest significance level (*p*-value < 0.001) which is consistent with the literature related to mobile phone distractions and lateral distance violation.

Indeed, outputs of the analysis of a literature review [59] suggested that there are significant differences in the driving performance, in terms of lane position and headway, between distracted and non-distracted drivers. Furthermore, many past studies [68–72] confirmed that several factors that arise from mobile conversations while driving could increase the risk of crashes, for instance, lateral movement, steer speed, steer deviation, and perception-reaction time. While using the mobile phone, the driver stops focusing on the driving task and keeps only one hand on the steering wheel leading to a deterioration in lateral control of the vehicle and potential for a serious traffic accident [73,74].

The simulator used in the experiment does not compute directly the lateral distance. Thus, it is impossible to compute the differences in the lateral distance. Nevertheless, several other violations related to the position of the driver in the road (i.e., cross over hard shoulder line, cross over a continuous line, and do not respect the minimum distance from the curb) were used to estimate the lateral distance.

Two other significant results are found after a deeper analysis of each specific violation. First, the accidents categorized into the simulator as "You have had a serious accident: you have run off the road" is a violation that could be included in the Accident category as well as Lateral Distance. Thus it reinforces previous findings. The second significant violation is related to the speed limit of 20 Km/h.

4.2. NASA-TLX Results

ANOVA analysis, summarized in Table 3, provides findings related to the different factors in the workload NASA-TLX considering the mobile phone-related distractions.

Table 3. ANOVA Test summary of NASA-TLX sources of workload.

NASA TLX	Sum Sq	Mean Sq	F Value	Pr (>F)
Mental Demand	155,478	155,478	13,365	0.000 ***
Physical Demand	84,298	84,298	12,794	0.001 ***
Temporal Demand	22,908	22,908	18,464	0.178
Effort	134,221	134,221	14,336	0.000 ***
Performance	33,466	33,466	46,122	0.035 *
Frustration level	39,524	39,524	23,094	0.133
Overall Workload Score	6596	6596	38,997	1.851×10^{-8} ***

* p-value < 0.05; and *** p-value < 0.001.

Results of Table 3 show that, according to the F values, five dimensions of the NASA-TLX were found to have statistically significant performance differences associated with the use of the mobile phone while driving, namely, Mental Demand, Physical Demand, Effort, Performance, and Overall Workload Score (p-value < 0.001).

The results of the analysis of the NASA-TLX of the workload and the influence of the mobile phone distractions on the violations during the two drives are given in Tables 4 and 5. Results of Table 4 show that the mobile phone-related distractions influence most of the violations and more significantly in the case of Lateral Distance violations and speeding (p-value 0.002 and 0.015, respectively). Similarly, results of the NASA-TLX workload in Table 5 show that scores of the overall workload and some subscales are statistically significant. The dimensions Temporal Demand and Frustration of the NASA-TLX did not discard the null hypothesis. In fact, in the case of Temporal Demand, the non-significance could be explained by the fact that in both drives the trajectory run is the same and, consequently, the time necessary to perform the task is quite similar.

Moreover, high significances (p-value < 0.001) are found in the case of Mental Demand, Physical Demand, Effort, and the Overall Workload. The participants reported a high workload when using a mobile phone while driving. Furthermore, the dimension Performance of the NASA-TLX is found statistically significant (p-value < 0.05), and the participants reported lower scores which could be explained by the fact that the task is much more complex so they, themselves, feel that they drive worse than while driving without using the mobile phone (without distractions).

4.3. Random Forest

As the results showed, mobile phone distractions had paramount importance on Lateral Distance Violations. In terms of importance, this variable has the second contribution in the case of the classification problem with nearly 100% together with the Physical Demand. This is also reflected by the results of the ANOVA test (Table 3) in which the contribution of this variable is statistically significant at 99%.

As regards the regression tree of the Lateral Distance violations, Figure 4 shows the fraction of the sample falling on each end node. Note that the mobile distractions appear in the first nodes reflecting the capability of this variable to isolate homogeneous samples in terms of purity and significant differences in terms of the number of penalizations among both subsamples with and without mobile phone distractions. Moreover, this variable shows paramount importance (~99%) as given by the random forest extending this regression tree.

Table 4. Comparison of driving performance of the drivers during the two drives.

	No Distractions			Distractions			Differences				
Variable	**μ**	**SD**	**C.I. (95%)**	**μ**	**SD**	**C.I. (95%)**	**μ**	**SD**	**C.I. (95%)**	**T-Student**	***p*-Value**
Lateral Distance	2.54	2.10	(1.86; 3.22)	4.28	2.70	(3.40; 5.16)	−1.74	0.55	(−2.84; −0.65)	−3.18	0.00
LD: crossing over a hard shoulder line	1.13	1.15	(0.76; 1.50)	1.97	1.69	(1.43; 2.52)	−0.85	0.33	(−1.50; −0.19)	−2.58	0.01
LD: crossing over a solid line	0.69	0.69	(0.47; 0.92)	1.49	1.21	(1.10; 1.88)	−0.80	0.22	(−1.24; −0.35)	−3.56	0.00
Speed limit 20 Km/h	1.46	0.94	(1.16; 1.77)	2	0.97	(1.68; 2.32)	−0.54	0.22	(−0.97; −0.11)	−2.48	0.02
Accident out of the road	0.03	0.1	(−0.03; 0.08)	0.21	0.52	(0.04; 0.37)	−0.18	0.09	(−0.35; −0.01)	−2.05	0.04

μ: Mean, SD: Standard Deviation, and C.I: Confidence Interval.

Table 5. Comparison of the results of NASA-TLX dimensions during the two drives.

	No Distractions			Distractions			Differences				
Variable	**μ**	**SD**	**C.I. (95%)**	**μ**	**SD**	**C.I. (95%)**	**μ**	**SD**	**C.I. (95%)**	**T-Student**	***p*-Value**
Mental Demand	238.20	97.12	(206.72; 269.69)	326.03	115.71	(288.52; 363.54)	−87.82	24.19	(−135.99; −39.64)	−3.63	0.001
Physical Demand	35.64	45.91	(20.76; 50.52)	102.18	106.50	(67.66; 136.7)	−66.54	18.57	(−103.52; −29.55)	−3.58	0.001
Effort	144.49	83.07	(117.56; 171.41)	222.31	109.21	(186.90; 257.71)	−77.82	21.97	(−121.58; −34.06)	−3.54	0.001
Performance	152.82	96.61	(121.51; 184.14)	326.03	115.71	(288.52; 363.54)	−87.82	24.19	(−135.99; −39.64)	−3.63	0.001
Overall Workload Score	0.56	97.12	(206.72; 269.69)	102.18	106.50	(67.66; 136.7)	−66.54	18.57	(−103.52; −29.55)	−3.58	0.001

μ: Mean, SD: Standard Deviation, and C.I: Confidence Interval.

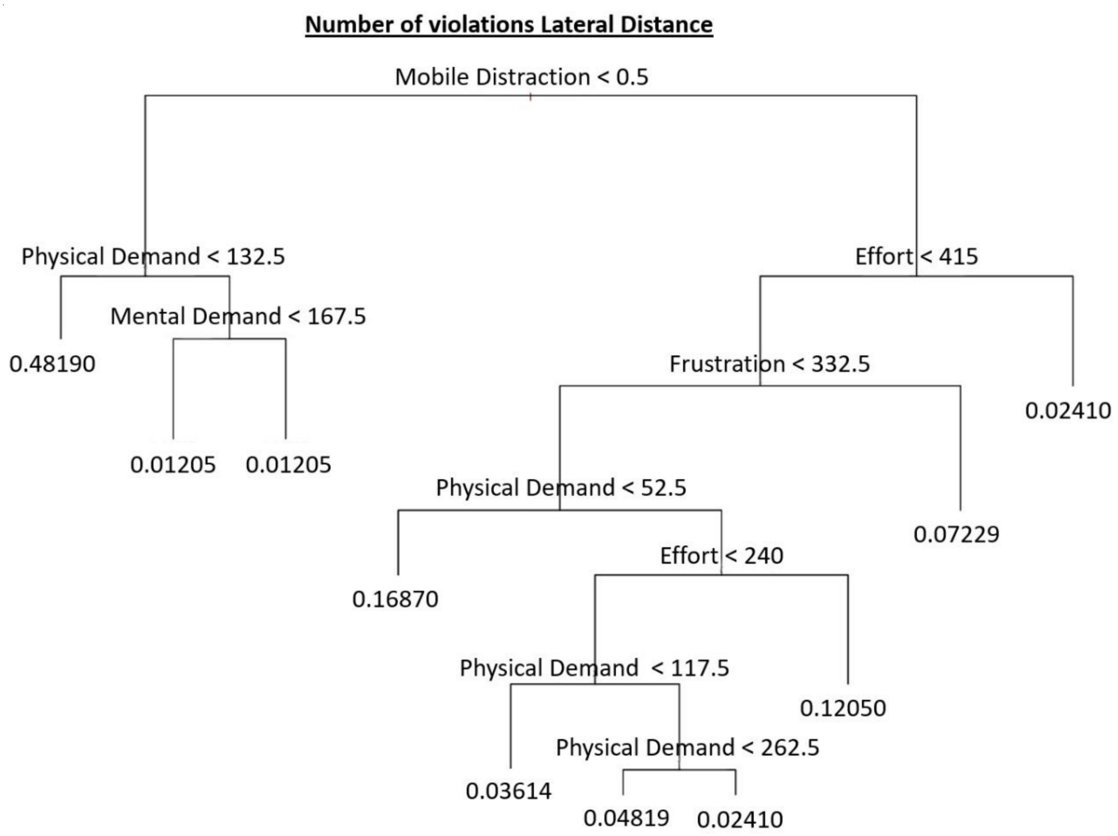

Figure 4. Regression tree related to the number of violations of Lateral Distance.

It is important to note that the rest of the features which contribute to the following nodes lead to deeper branches and correspond to particular cases (the value 0.01205 corresponds to one individual) and are therefore pruned to avoid overfitting issues.

Other interesting results are found as regards one of the specific violations related to Lateral Distance, i.e., the violation "You have crossed over the hard shoulder line". This means that at least one of the car wheels was over the hard shoulder line of the road.

The first node is the global score of the NASA-TLX that can split the tree with 71% of the cases with a score less than 75.5 (Figure 5). Additionally, it can be noticed that, in the whisker diagram (Figure 6), more than 75% of the values are fewer than 75.5 of the score when there are no mobile phone distractions.

As regards the hard shoulder line violations, the results of Figure 5 show that, unlike in the case of Lateral Distance, mobile phone distractions do not appear in the Random Forest. Nevertheless, distractions associated with the use of mobile phones are a key factor in the general forest with an importance score higher than 60% (Figure 7).

Generally, in the Random Forest method, variables compete. Moreover, Overall Workload Score and mobile phone distractions are so related. Consequently, the presence of one variable in the Random Forest is sufficient. In other terms, the presence of mobile distractions in the Random Forest would not provide more information or division of the sample nor explain a residual part. Hence, one variable appears in the Random Forest, the other variable is absent.

The analysis of the importance graphs of the different violations and their related groups shows that the Overall Workload score and mobile phone distractions are found among the two more important factors in the case of 22 specific violations and three groups of violations. Moreover, although these factors do not appear in the Random Forests, their importance is still quite relevant (Table 6).

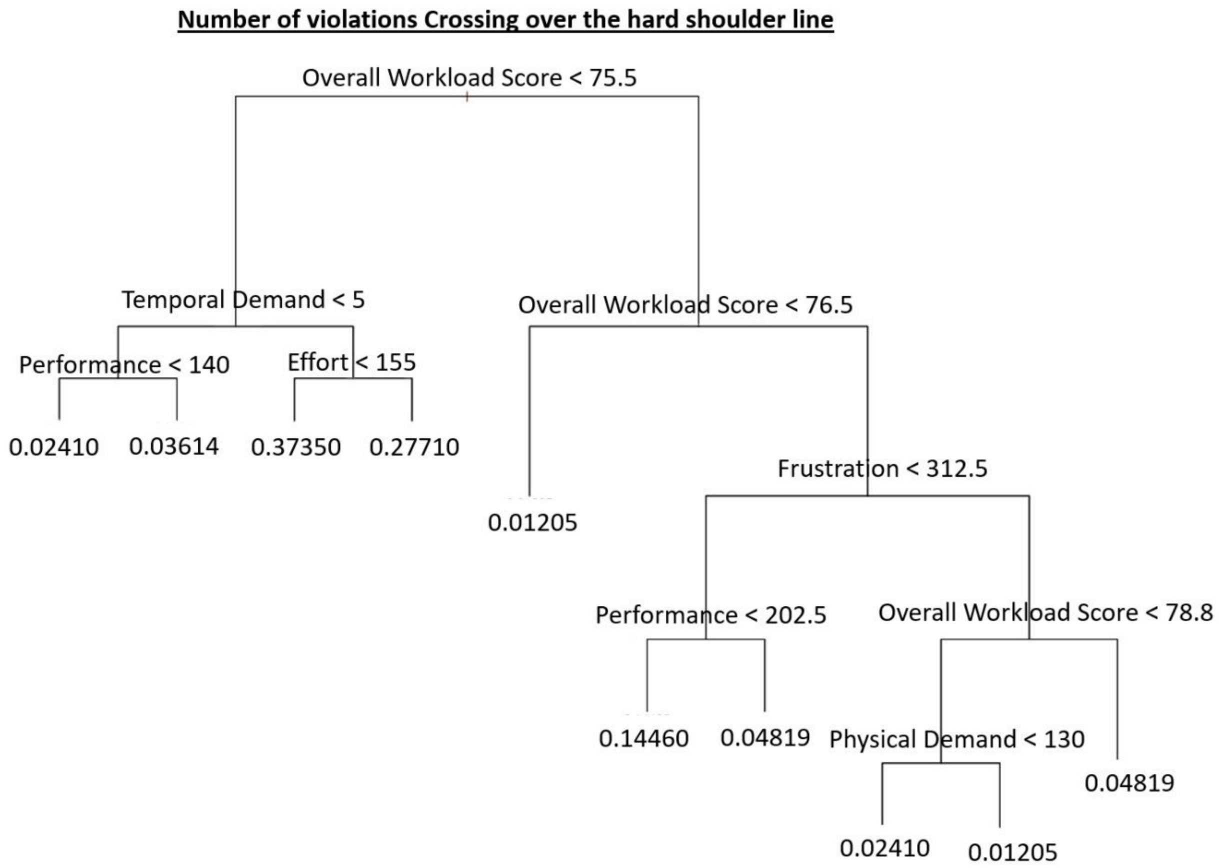

Figure 5. The Regression tree related to crossing over the hard shoulder line violations.

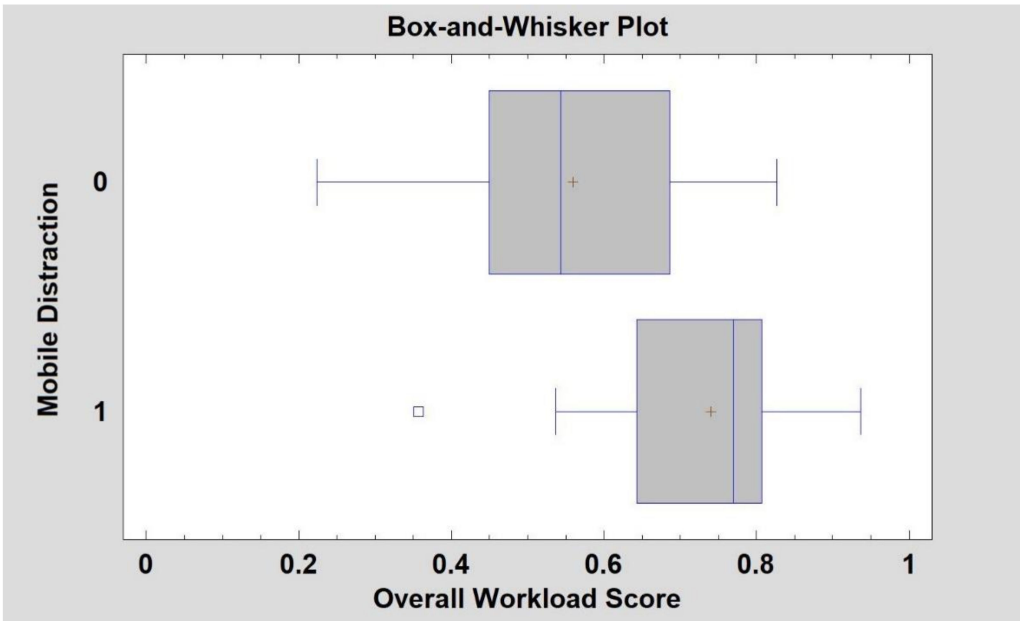

Figure 6. NASA-TLX scores with and without mobile phone distractions.

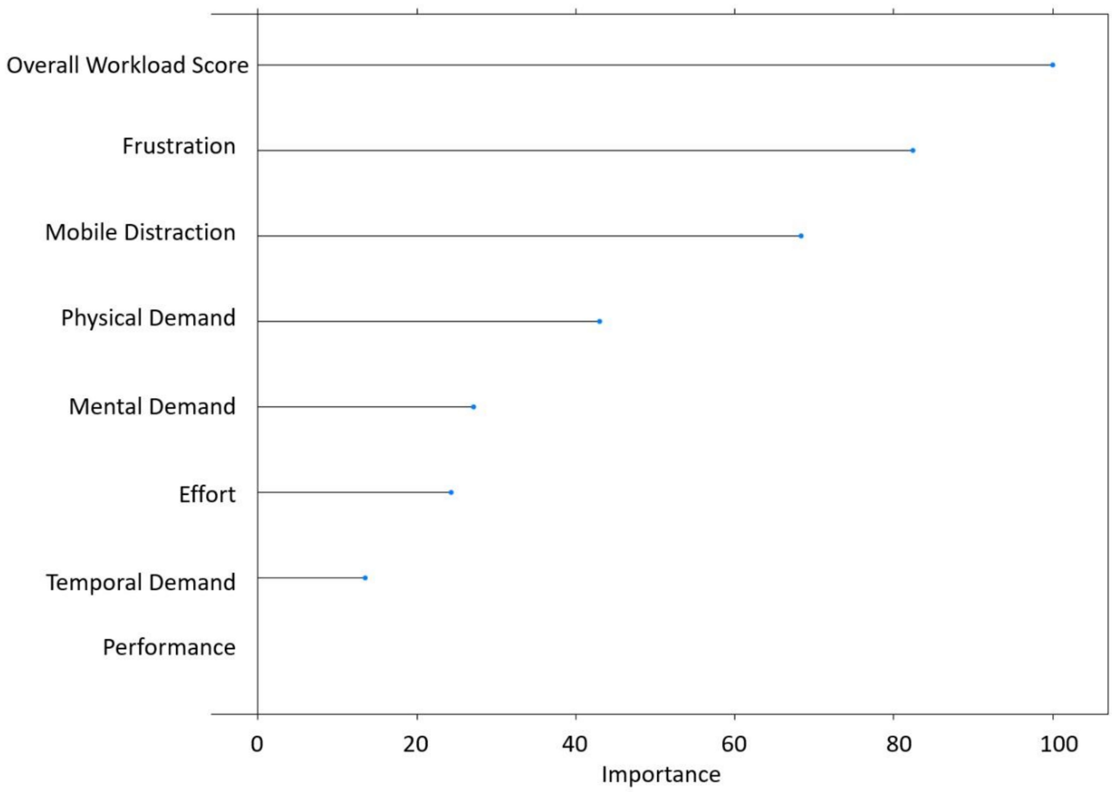

Figure 7. Importance graph related to crossing over the hard shoulder line violations.

Table 6. Summary of violations in which the importance of the Overall Workload Score and mobile phone distractions is among the three more relevant.

Violations	Overall Workload Importance	Mobile Phone Distractions Importance
Group of Lateral Distance Violations		2
Group of Speed Violations		2
Group of Other Violations	2	
Go through the amber light	1	
Do not stop at a red signal light		2
Failure to yield correctly	1	
Do not stop at a stop signal	1	
Drive in a forbidden direction	1	
Cross over a solid line	1	
Do not stop at a pedestrian crossing		2
Stopover an intersection with yellow crossing lines	1	2
Do not respect the minimum distance from the curb	1	
Exceed the speed limit of 20 km/h		2
Exceed the speed limit of 40 km/h	1	2
Exceed the speed limit of 70 km/h	2	
Exceed the speed limit of 90 km/h	2	1
Exceed the speed limit of 100 km/h	1	
Bump another vehicle	2	

Table 6. *Cont.*

Violations	Overall Workload Importance	Mobile Phone Distractions Importance
Bump an object		2
Hit another vehicle	1	
Serious accident: you have run off the road		2
Hit a cyclist	2	
Stall the vehicle	1	
Do not fasten the seat belt	1	
Incorrectly use the clutch		2

The findings of the present study come in line with previous research that reported unsafe driving behaviors of young drivers who constitute a high-risk group for traffic accidents, for instance, unsafe driving behaviors of unlicensed young drivers [75,76], risk perception and driving behaviors of young drivers [77,78], and use of mobile phones and infotainment technologies by young drivers while driving [79]. Furthermore, many researchers confirmed that by using their mobile phones, the drivers were more likely to engage in risky driving behaviors, and were less effective in controlling their lane position, managing their brake reaction time, speed, and headway deviation [80–82].

In fact, safely driving a motor vehicle requires a permanent monitoring of the road and quick and adequate responses to unexpected changes in the driving environment which depend mainly on the drivers' manual, visual, and cognitive abilities. However, the use of mobile phones for texting, surfing the web, responding to a call, and checking notifications from social media apps is confirmed to distract the drivers, reduce their attentions, and increase the risk of a crash. In this paper, and using the NASA-TLX, the driver workload was measured and the influence of mobile phone-related distractions was examined. The results obtained confirmed that multitasking (i.e., interacting with the mobile phone while driving) increases the driver's overall workload. This finding supports the conclusion of many traffic safety studies investigated the driver's workload in a wide range of driving conditions. For instance, an examination of the effects of road geometry and secondary task modality of the driver's workload reported that a visually demanding secondary task leads to a significant variance in the driver's workload [83]. Likewise, a study was conducted to estimate the impact of distractor tasks on the driving performance and driver's control over the vehicle and workload [84]. Results of this study suggested that the performance of a secondary distractor task increases the workload which influences the variability in steering wheel movements and lane-keeping. Moreover, previous studies used NASA-TLX to investigate the effect of different uses of mobile phones on the drivers' workload while driving and interestingly found that all the dimensions of the workload are significantly higher in the case of mobile phones use [85,86].

Mobile phone-related distractions are a potential risk to traffic safety and a growing problem that has the biggest impact on driving performance. Even though, the use of mobile phones without a hands-free device is already illegal in many countries, including Spain, eliminating their use seems to be difficult and legislation alone is ineffective in addressing distracted driving. This is because catching offenders is not an easy mission, as with speed. Moreover, the decrease in the use of mobile phones after law enactment does not last long and their use increases immediately following the first decrease.

Therefore, raising public awareness through adoption of behavioral strategies and instruction of positive road safety culture seems to be a promising solution. Indeed, as in the case of seatbelt use and drink-driving, creation of social norms will contribute to changing minds, modifying attitude and behaviors, increasing risk perception, and correcting acceptable risk definition. Particularly, many studies pointed out that young drivers fail to understand the effects of mobile phone use while driving and underestimate the associated risks [87]. Therefore, it is highly important to increase the number of campaigns targeting young drivers through targeted advertising using appropriate communication means and social media platforms, such as Facebook, Instagram, and YouTube.

Furthermore, a recent cross-sectional study conducted in Spain pointed out that older drivers affect their children's driving attitudes and behaviors. Therefore, another trend to improving traffic safety education consists in enhancing parents' road behaviors to influence positively the way their children, i.e., young drivers, perceive traffic safety and behave at the wheel [88].

Another equally important awareness program to minimize technology-based distractions, especially among young drivers, is the use of video game simulation methods. Researchers who applied these methods reported a reduction in mobile phone use among participants in the simulation experiment and confirmed that video game simulations were practical and cost-effective programs for training young drivers [89].

In terms of limitations, the nature of the present study, which used a driving simulator, considered only one driving scenario (i.e., a sunny day with medium traffic and pedestrian density), consequently, the results could not capture all possible violations in a real-driving environment.

Another possible limitation is the fact that the study sample was not representative and contained more males than females, as a result, the differences between the driving performance of distracted females and distracted male drivers (i.e., the influence of gender) were not investigated.

Further studies could move towards assessing the influence of technology-based distractions on driving performance in different conditions and consider analyzing the gender effects.

In this study we focused on young drivers. We also recommend studying the effect of mobile phone use among other age groups on driving behaviors.

5. Conclusions

The explosive development of communication means and infotainment technologies affects the driving performance of young drivers, particularly. Indeed, the use of mobile phones while driving has been identified among principal contributors to traffic accidents.

This study analyzed, experimentally, changes in the workload and vehicle control (such as lateral distance and hard shoulder line violations) of distracted and non-distracted young drivers. The findings of the present study confirmed the impairments associated with the use of mobile phones among young drivers leading to poor control of the vehicle. Thus, decision-makers need to consider raising awareness of young drivers of mobile phone use risk behind the wheel and encourage the implementation of active measures to mitigate this risk. Actually, some mobile phones are starting to have a driving mode on their operating systems that, when detecting that the user is driving, turns their phone operation into easy-use, or restricted, mode. Moreover, the incorporation of the eye-tracker system as a passive safety measure in vehicles would notify drivers whenever they engage in other activities which distract their attention from the roadway. Meanwhile, educational campaigns targeting young drivers on mobile phone use while driving must be reinforced to minimize risks.

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Estimating the Probability of Committing Traffic Infraction due to Mobile Use: Driving Simulator Study

Carlos A. Catalina Ortega

Instituto Tecnológico de Castilla y León, Burgos, Spain. E-mail: carlos.catalina@itcl.es
Escuela Politécnica Superior, Universidad de Burgos, Spain. E-mail: cco0001@alu.ubu.es

Susana García-Herrero

Escuela Politécnica Superior, Universidad de Burgos, Spain. E-mail:susanagh@ubu.es

Amin Azimian

*Escuela Politécnica Superior, Universidad de Burgos, Spain. E-mail:*aazimian@ubu.es

Adrián García

*Escuela Politécnica Superior, Universidad de Burgos, Spain. E-mail:*agm0164@alu.ubu.es

Miguel A. Mariscal

*Escuela Politécnica Superior, Universidad de Burgos, Spain. E-mail:*mariscal@ubu.es

Traffic accident is the ninth leading cause of death in all age groups worldwide. The are many factors contributing to the road traffic accidents. However, human factors account for approximately half of the traffic accidents. More specifically, driver distraction is one of the major concerns for transport safety and it may be caused by using hand-held or hands-free mobile phone which impairs driver's inattention for a period of time that and consequently may result an accident. Driving simulators are a useful tool, mainly aimed at educating and researching knowledge and skills in driving. The main advantage is that the simulation occurs in controlled environments to assess driving behavior without exposing the driver to a real risk. Therefore, the objective of the present study is to analyze the consequences of mobile phone use while driving.

As driving simulator is an effective tool to evaluate drivers' performance without exposing them to a real risk, the present study aims to conduct a driving simulator study to realize how the use of social media applications, individual characteristics would contribute to the likelihood of aggressive driving. Forty simulations were done and 43,259 data records were collected from people aged between 20-28 in this experiment. The Bayesian network method has been used to develop a global probabilistic model. The results indicate that the use of social media applications while driving will likely increase the likelihood of committing traffic infraction. In addition, the novice male drivers will highly likely to commit traffic infraction compared to other driver groups.

Keywords: traffic, safety, simulator, cell phone, app, distraction.

1. Introduction

More than 3,400 people died on the roads around the world every day with children, pedestrians, cyclists , young people aged between 15 to 29 and the elderly being the most vulnerable on the road (Pietrasik 2015) OMS:Seguridad_vial (2015). In developing countries, where motorization is increasing, there is talk of a public health crisis (Beaglehole, Irwin, and Prentice 2003). In addition to the loss of people, these accidents carry costs (e.g., resource mobilization, accident investigation, road maintenance, etc.). Direct and indirect costs related to these accidents were estimated at 1% of the Spanish gross domestic product in 2014 (Gómez 2014).

Distractions, traffic infractions and human errors are the leading cause of traffic accidents (García-Herrero et al. 2020, Febres et al. 2020, Aldred et al. 2020, García Herrero et al. 2019,

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Febres et al. 2019). Although traffic fatalities due to distraction had been dropped significantly after regulating the cell-phone ban in 2008 (Ragland 2012), but use of cell phone while driving is still common among young drivers (Lamble, Rajalin, and Summala 2002) (Creaser et al. 2015). Additionally, such prohibitions do not include the use of alternative devices, such as hands-free devices. Hence, these restrictive policies significantly increased the use of other methods. This creates direct evidence where the ban on cell phone use while driving has unwanted effect by inducing the replacement of hands-free devices. This can be differentiated based on sex (women tend not to use it while men opt in more alternative methods (Carpenter and Nguyen 2015)). This can also be differentiated by age groups, where the use of a hands-free cell phone mostly affects the performance (acceleration, lane deviation, reaction time and accuracy) of older drivers rather than younger drivers (Liu and Ou 2011).

Over the past decade, with the rise of mobile technology and the popularization of Smartphone, many studies have attempted to measure the impacts of cell phone use on driving using simulators. For example, Saifuzzaman et al. (2015) investigated the impact of mobile phone conversations on car-following behavior. They reported that variability was increased in driving speeds, vehicle spacings, and acceleration and decelerations. Paxion, Galy, and Berthelon (2015) investigated the impact of cell phone use on experienced and novice drivers under different driving conditions (simple, moderately complex and very complex). The results determined that the lack of experience and the complexity of the driving situation increase driver's reaction times. Moreover, Libby, Chaparro, and He (2013) compared texting and calling while driving. They reported that drivers sending or reading text messages have significantly slower reaction times, make more eye movements off the road , and are not able to detect so many targets on the periphery of the road compared to those making a phone call .

Recently, few studies drew attention to the impact of different mobile apps including social media or instant messaging Apps on drivers' performance and distraction. For example, McNabb and Gray (2016) compared the effects of four different smart phone tasks such as texting with the experimenter, reading Facebook posts, exchanging photos with the experimenter via Snapchat, and viewing updates on Instagram on car-following performance in a driving simulator. They reported that, brake reaction times in the text-based conditions were significantly higher than that in the image-based conditions.

The majority of previous research efforts placed the emphasis on texting and calling and their impact on driver's performance. However, less research efforts have been conducted to understand how the use of mobile apps would result in a traffic infraction. Hence, this objective of this paper was to estimate the probability of committing a traffic infraction as a result of using different mobile applications such as Facebook, Instagram and WhatsApp.

2. Methodology

2.1 *Driving Simulator*

The simulator with which this project was carried out is specially designed for training purposes in driving schools or training centers. It allows the realization of a realistic driving in a safe environment and simulates different scenarios with different traffic and weather conditions. The vehicles can also be configured by changing the traction, gears, etc. The apparatus is equipped with three 43-inch monitors to visualize the simulated road environment. The recording data for each simulation store in a database and can be accessed using SQlite DB browser Program.

Fig. 1. Driving simulator

2.2 *Mobile phone*

The mobile phone is used as a distraction tool in this study and it contains various applications which can divided into two categories: (i) Study applications such as Facebook, Whatsapp and Instagram which are used to asses driving behaviors, and (ii) App usage application that measures the time spent in using each mobile application. These applications were selected as they were downloaded frequently by people in app store/play store and have been popular among young people (Ford 2015) which are our target group in this study.

2.3 *Study population*

The study participants are aged between 20 and 28 and they were classified based on gender, years of driving experience and the frequency of using vehicle in real life. Young people are vulnerable at the wheel and commonly use smartphones while driving.

2.4 *Preparation*

Initially, each participant filled out a survey questionnaire with different questions related to demographic factors and particularities of individual driving. Later, they used driving simulator freely to become familiar with apparatus and road environment.

2.5 *Procedure*

After the training, in the first experiment, the participants were asked to drive through simulated urban route including signalized and stop-controlled intersection. Each subject had to drive for 10 minutes without any distraction, keeping the focus of attention merely on the road. Upon completion of non-distracted driving experiment, the participants were provided with a document with a series of guidelines on how to install and use the mobile applications on their Smartphone. Moreover, they were instructed not to use the mobile when the vehicle is stationary or in neutral condition, especially when a traffic light is red as this can alter the study data.

The second experiment was performed under the distracting conditions. That is, once the simulation started, a WhatsApp message was sent to the individual with the different guidelines to follow while driving. The different tasks were as follows:

- Three Instagram task including publishing images and videos.
- Three Facebook tasks including commenting and interacting with virtual friends.
- Two WhatsApp activities where a conversation was held with another individual outside the simulation environment.

The driving time for this experiment varies from 9 to 13 minutes as it depended on each individual's driving style and behavior. Moreover, depending on driving time, the number of records may vary from person to person. At the end of experiment the participants were asked to fill out an online survey (in Google Forms) in order to verify that they have paid attention to the telephone tasks of each application or if they have picked up the mobile while driving as required. The objective of this survey was to analyze the level of attention for each individual. Finally, out of 27 subjects who participated in this experiment, 7 subjects were dropped from the study as they didn't perform a minimum of six tasks outlined in the guideline.

2.2 *Analysis Method*

There have been four models analyzed in this study, in which "infraction" was considered as an objective variable and refers to the infractions committed by participants during driving, differentiating within the infractions among the most common ones due to distraction outcomes, such as deviations to adjacent lanes or to the sidewalk, as well as forgetting to turn on the turn signals.

Bayesian Networks (BN) has been used to establish the relationships and dependency among a set of variables. A Bayesian Network is a probabilistic model that relates a set of random variables through a directed graph, they are graphical networks without cycles in which random variables are represented and the likelihood relationships that exist between them (Lozano 2011). Each node of a Bayesian network is associated with a random variable, which can take values within a discrete or continuous range. These values are exclusive and exhaustive for each variable in the network (Galán 2002). These Bayesian models have different applications for diagnosis, classification and decision that provide important information as to how the variables are related, which can be interpreted as cause-effect relationships (Lozano 2011). Therefore, Bayesian networks constitute a method for the representation of uncertain knowledge, which allows reasoning based on the theory of probability (Galán 2002).

Therefore, Bayesian networks will allow to create global probabilistic models for a set of variables $X = \{X_1, X_2, \dots, X_n\}$ from a set of particular data of the same. According to (J.M Gutierrez 2004), Bayesian Networks explicitly represent knowledge about the problem, in probabilistic terms, through a joint probability function of the variables that form it, that is, Bayesian Networks are based on the Theorem of Bayes as shown in Eq.(1).

$$p(x) = p(x_1, x_2, x_3, \dots, x_n) \qquad (1)$$

This model is a probabilistic model of a joint probability function defined by an acyclic directed graph and a set of conditional probability functions, so that the dependency / independence structure shown by the Graph can be expressed in terms of the joint probability function through the product of several conditioned distributions, as follows:

$$p(x_1, x_2, x_3, \dots x_n) = \prod_{i=1}^{n} p\,(x_i|\pi_i) \qquad (2)$$

Where, x_i is the set of parents in the graph and π_i is the set of parents of the node.

2.2 *Validation Method*

Model's accuracy has been evaluated using sensitivity and specificity, which are independent of each other. According to (Fawcett 2004) the AUC is an identifier defined as the probability that a set of positive instances chosen randomly are superior to the negative ones. The higher the AUC (close to 1) indicates a greater predictive capacity of the model. For the present study, 100% of the database created for each model has been used to perform the Bayesian Network and also 100% of the data to calculate sensitivity analyzes. But, before performing sensitivity analyzes and validating each model, the AUC corresponding to each model has been calculated; for this, 10 partitions have been made on each database randomly; With 90% of the data the learning of the Bayesian network has been developed and with 10% the model has been evaluated (calculation of the AUC).

3. Study Variables

Different variables have been used for quantitative analysis in this study; (i) human factors (sex and driving experience), (ii) accumulated time (for using accumulated for Facebook, WhatsApp accumulated, Instagram), and (iii) traffic infractions (dependent variable) which are discussed in section 3.1 through section 3.3 respectively.

3. 1 *Human factors*

Sex is a critical factor in Road safety. This variable is determined through the survey questionnaire provided to participants before starting the experiment. As for the driving experience, we differentiated two states (novice and experienced drivers). This variable was defined based on the time driving license issues and how often the individual drives with car. A driver was classified as 'experienced" if the subject held the driver license more than 1.5 year and had drove more than 5 or more days per month or held driver's license less than a year but used his/her car on regular basis.

Table 1. Percentage of cases by driver's gender and experience.

Demographic Variables		
Name	States	% of cases
Sex	Female (1)	50%
	Male (2)	50%
Driving experience	Novice (1)	45%
	Experienced (2)	55%

3. 2 *Accumulated Time*

The accumulated time was used to measure how often the phone was active and how often the proposed mobile Apps were used by participants while driving. Table 2 represents the accumulated time by mobile App type which is divided into 4 different categories.

Table 2. Accumulated time by mobile App type

Mobile phone variables		
Name	States	% of cases
WhatsApp (accumulated time)	No WhatsApp use (1)	91.2
	Used less than 5 sec (2)	1.9
	Used between 5 and 15 sec (3)	2.1
	Used more than 15 sec (4)	5.5
Facebook (accumulated time)	No Facebook use (1)	95.7
	Used less than 5 sec (2)	0.8
	Used between 5 and 15 sec (3)	1.3
	Used more than 15 sec (4)	2.1
Instagram (accumulated time)	No Instagram use (1)	93.2
	Used less than 5 sec (2)	0.8
	Used between 5 and 15 sec (3)	1.4
	Used more than 15 sec (4)	4.5
Phone use (accumulated time)	No Phone use (1)	77.2
	Used less than 15 sec (2)	3.9
	Used between 15 and 30 sec (3)	5.9
	Used more than 30 sec (4)	13

3. 3 *Traffic Infractions*

In this study traffic infraction was considered as a target/dependent variable and it refers to numerous individual offenses listed as follows:

(i) Lane departure: Crossing shoulder and continuous line and failing to maintain the minimum distance to the curb.
(ii) Incorrect manoeuvres: Overtaking vehicles or cyclists.
(iii) Yielding violations (failure to give way to pedestrians, cyclists and vehicles).
(iv) Signalling violations: No right or left turn indicator when appropriate.
(v) Collision: Hitting a vehicle or object slightly or seriously, causing an accident such as overturning the vehicle or getting out of the traffic lane and the

endangering pedestrians, cyclists and / or animals.

(vi) Traffic signs violations: Skipping a STOP sign or pass a red or amber light.

It should be noted that the most common infractions committed when a person is distracted at the wheel are detour infractions and signalling infractions. All of them are integrated into the same group of infractions which is called IF infraction.

4. Results

After completing all experiments, data related to 7 Individuals were dropped from the database as they didn't meet the requirements. Therefore, a total of 43,259 data points were recorded and imported into a Matlab program where the probability relationships between the variables were defined. Later, the results together with the records were imported into a second Matlab program where we provided the degree of prediction presented by the model. The results of this study have been verified by calculating the AUC with cross validation. The result of the AUCs for this case is within the acceptable range of 0.75 and 0.82.

As shown in Table 3, around 1% of participants made traffic infractions while no use their mobile phone. However, when it comes to the use of the Smartphone less than 15 seconds, the probability of committing any infraction rises up to 7%. It should be noted that when the use of the Smartphone is between 15 and 30 seconds, the corresponding probability increases up to 10% which is 11 times greater than the probability of not using the mobile and 1.5 time greater than the probability of using mobile phone more than 30 seconds.

Table 3. Infraction probability by mobile phone use

Mobile phone	
ESTADOS	Infractions (%)
No use	1.12%
Used less than 15 sec	7.34%
Used between 15 and 30 sec	11.67%
Used more than 30 sec	7.52%

This could be justified by the fact that automatic level of consciousness of some participants would take care of driving task when they are engaged in a secondary task for a long time.

Additionally, different acts such as commenting, making conversation and sending images/videos using the key mobile applications such as WhatsApp, Facebook and Instagram have been assessed as they are mostly used by young people (Ford 2015). As shown in Table , the non-use of any application is associated with infraction probability of 2.5%. However, using the Facebook app for commenting and chatting, and WhatsApp for making a phone conversation would increase the infractions probability significantly, especially when they are used more than 15 seconds. In contrast, publishing images and videos in Instagram within 5 to 15 seconds is associated with higher infraction probability.

Table 4. Probability of committing an infraction according to application and the time of use of these.

%Infraction	Facebook (commenting and chatting with friends)	WhatsApp (making a conversation)	Instagram (Publishing images & videos)
No specific App use	2.56%	2.43%	2.52%
Used less than 5 sec	8.97%	8.27%	3.91%
Used between 5 and 15 sec	6.79%	7.46%	10.65%
Used more than 15 sec	13.60%	8.35%	9.19%

As shown in Table 5, the probability of committing traffic infractions in novice male and female drivers are 5.83% and 3.69% respectively which are higher than those in experienced male and female drivers. This may imply that an experienced driver is less likely to commit a traffic infraction than a novice driver.

Table 5. Probability of committing an infraction according to the sex and the experience of the driver.

Sex	Experience	Infraction%
Female	Novice	3.69%
	Experienced	2.53%
Male	Novice	5.83%
	Experienced	0.55%

However, this do not happen in all the cases, close attention to Table 6 which depicts the relationship between driver's gender, experience and phone usage duration with infraction probability indicate that experienced female drivers using mobile phone between 15 to 30 seconds are more likely to commit a traffic infraction than novice female drivers with the same phone usage duration.

Table 6. Probability of committing an infraction according to the sex, the experience of the driver and the mobile use.

Experience	Mobile phone	Infraction %	Infraction %
		Woman	Men
Novice	No use	1,57%	1,96%
	Used less than 15 sec	11,12%	10,41%
	Used between 15 and 30 sec	10,96%	17,18%
	Used more than 30 sec	8,24%	6,04%
Experienced	No use	1,12%	0,28%
	Used less than 15 sec	5,26%	0,80%
	Used between 15 and 30 sec	12,83%	4,48%
	Used more than 30 sec	8,02%	1,66%

5. Conclusions

This experiment showed that use of different mobile apps has a significant impact on driver's performance. For example, some participants paid little attention to driving and spontaneous tripping also occurred during driving. From the data analysis, it was found that of any application while driving increases the probability of traffic infraction. However, their impacts vary by usage time. As with drivers' sex and experience, it was found that young men drive aggressively when it comes to overtaking which is consistent with the findings of Vlahogianni and Golias (2012). Moreover, novice young drivers are likely to commit infraction than experienced ones.

This study focused on the main capabilities of each application and their impact on driver's behavior. The research findings can be used by decision makers and authorities to adapt effective prevention strategies and policies in order to restrict the use of cellphone while driving. One potential solution is to obligate the cellphone manufacturers and mobile network operators to equip the cell phones with a built-in application which restrict the use of social media and instant messaging applications when the vehicle is moving.

In terms of future work, it is recommended to perform a similar study to assess how the main features and capabilities of different social media apps (e.g., commenting, making a video call, and publishing images/video) would change driving speed, acceleration and distance to edge of traveled way.

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CONCLUSIONES

6 Conclusiones

El objetivo principal de la Tesis es establecer las pautas para proponer medidas de seguridad vial que ayuden a cumplir con los Objetivos de Desarrollo Sostenible 3.6 y 11.2 de la Organización Mundial de la Salud. Para lograr este objetivo, se estudiaron los efectos de distintas distracciones durante la conducción tanto en entornos urbanos como interurbanos. Se analizaron estos efectos mediante distintas herramientas. Los distintos experimentos realizados han permitido obtener resultados significativos basados en datos para apoyar propuestas y medidas, que puedan disminuir el número de muertes y lesiones por accidentes de tráfico.

6.1 Conclusiones generales de las contribuciones científicas

Si bien la Tesis utiliza como medio conductor las distracciones (música y uso de smartphone) los resultados y consecuencias del estudio se amplían mucho más. Como veremos a continuación, se aborda el impacto en las infracciones, la carga mental y se observan evidencias de por qué la experiencia ayuda a cometer menos infracciones.

- Los efectos de las distracciones por música y uso del smartphone en la conducción son muy claros. Se produce una mayor probabilidad de cometer infracciones por velocidad, se cometen más errores relacionados con mantener la línea de la conducción y el carril. Igualmente se cometen más infracciones en rotondas, un elemento vial que ayuda a la fluidez del tráfico pero que produce muchos accidentes. Además, las distracciones son un factor de alta importancia, justificado en los estudios realizados en 22 tipos de infracciones específicas y en 3 categorías agrupadas de infracciones. También se ha demostrado que incluso tiempos cortos de interacción con el smartphone, menores a 5 segundos, aumentan la probabilidad de cometer infracciones. Aun así, se sigue utilizando en muchos casos el smartphone mientras se conduce.

- Es importante remarcar que los auto test de esfuerzo NASA-TLX realizados muestran que los conductores y las conductoras son muy conscientes de que manipular el smartphone mientras conducen provoca una sobrecarga a varios niveles. Dicha sobrecarga se añade a una actividad como la conducción, que requiere de concentración y es peligrosa, aumentando la probabilidad de infracciones o accidentes. Se ha podido ver igualmente la relación directa entre Carga Mental y Distracción en los datos mediante los estudios de random forest realizados.

- La fijación de la mirada es un factor clave en las distracciones relacionadas con el uso del smartphone durante la conducción. Este acto implica fijar nuestra mirada para poder utilizarlo, siendo la vista el sentido principal que favorece una conducción segura. Como se ha podido ver en los artículos, esto implica que el usuario o usuaria deja de mirar a la carretera, incluso en situaciones peligrosas como es la conducción en rotondas. La principal consecuencia supone una disminución del tiempo que el conductor o conductora emplea en mira por la ventana y retrovisor izquierdos.

- La experiencia que tenga el conductor o la conductora al volante es, como se ha demostrado, un factor determinante. Esta permite no solo cometer menos infracciones, sino que facilita aprender e interiorizar las acciones de una conducción segura.

La conclusión general que extraemos de esta tesis doctoral es que el smartphone supone el principal y más peligroso distractor al volante en conductores y conductoras jóvenes y con poca experiencia. Teniendo en cuenta el contexto socio-cultural en el que nos encontramos, el smartphone es una tecnología imprescindible para la comunicación en las generaciones más jóvenes, estando presente durante la conducción a pesar de la carga mental que producen. Este tipo de usuarios y usuarias al volante, debido a su menor experiencia, no tienen aprendidos los mecanismos protectores de este tipo de infracciones, que sí se encuentran presentes en conductores y conductoras con más años al volante, ya que automatizan el gesto de dirigir su mirada para detectar los posibles peligros de la vía. Esta mezcla de juventud y falta de experiencia hace mucho más probable que los conductores y las conductoras noveles cometan infracciones que puedan ocasionar accidentes de tráfico.

6.2 Propuestas de seguridad vial según los resultados de la Tesis

A la vista de los resultados obtenidos se proponen las siguientes medidas de seguridad vial, teniendo en cuenta el momento actual tanto a nivel social como tecnológico. Algunas de las medidas propuestas no serían factibles hace años y, sin embargo, actualmente debido a la evolución tecnológica pueden ser muy viables:

- Incluir avisos, tanto en los navegadores de los coches como sobre todo en los navegadores más populares actualmente (Google maps, Waze…) que den mensajes según las circunstancias de la vía y, aún más relevante, según el perfil de conductor o conductora.

- Si el conductor o la conductora se acerca a una rotonda, “Recuerda mirar por el lado izquierdo al entrar en la rotonda y derecho si pasas de un carril interior a uno exterior”.
- Si se ha estado utilizando el móvil durante demasiados segundos: “Vigila tu conducción y tu posición en la vía, manipular tu smartphone puede implicar salidas del carril que lleven a accidentes graves”.
- Según la música que el propio dispositivo puede estar reproduciendo, o que pueda reconocer que se lleva en la radio “Llevas mucho rato con música alegre y agresiva, ¿quieres reproducir música más relajada o dejar de escucharla para poder centrarte en la conducción?”. Igualmente proporcionar dicho aviso si hay un tráfico denso o situaciones peligrosas frente al conductor o conductora.

Si el conductor o la conductora tiene poca o mucha experiencia estos consejos se pueden modificar en frecuencia o incluso eliminar por completo. El propio software puede medir las horas de experiencia que tiene el usuario o la usuaria al volante, puesto que, si comparamos dos conductores con los mismos años de experiencia al volante, pero con frecuencia de uso diferente (por ejemplo, uno de ellos que conduzca 1 hora al día mientras el otro tan solo coge el coche el fin de semana), queda claro que su experiencia a nivel de conducción es muy diferente.

- Incluir por defecto sistemas de eye tracking en los vehículos, estos equipos, aunque puedan resultar costosos, actualmente pueden ser una gran medida de seguridad, más aún si se contrastan los datos con los navegadores integrados que tienen todos los móviles. Los sistemas podrían detectar si el usuario o usuaria está prestando atención a los elementos importantes de la vía o si están distraídos o distraídas utilizando el Smartphone u otras herramientas que puedan crear distracciones. Esta medida por su impacto y coste debería ser impulsada a nivel político.
- Seguir trabajando en la concienciación y reforzar la formación a conductores y conductoras noveles marcando mensajes clave como “Centrar la mirada en la carretera”, “No uso del smartphone”, apoyado por estudios científicos. Se sugiere incluir añadir preguntas en los test del examen de conducción tales como “¿Qué indican los estudios que sucede en una rotonda si se conduce utilizando el smartphone?.”

6.3 Área de futuros estudios

Es muy necesario seguir estudiando cómo los factores humanos, y los cambios en la sociedad y tecnología, afectan a la seguridad vial y modifican nuestro modo de relacionarnos con la conducción.

Estudios posteriores en conducción naturalista serían de gran importancia para eliminar tanto el bias producido por el uso de simuladores, como por la obligatoriedad de utilizar el smartphone siempre durante los experimentos. De ese modo, también se podría ver cómo distintas generaciones interactúan realmente con el smartphone en la conducción real. También sería importante realizar un estudio más completo de comportamiento ya que, si bien estos estudios son altamente complejos de organizar, y generan una gran cantidad de datos descartable, los resultados serían de gran valor.

Para finalizar este apartado, es importante recordar que los acuerdos con empresas de conducción autónoma son imprescindibles, sobre todo niveles 2, 3 y 4, para compartir datos anonimizados de conducción. La tecnología ya está preparada, ya que los actuales vehículos de conducción autónoma cuentan con todos los sensores para recopilar datos tanto de la conducción, del tipo de la vía, hora del día, condiciones lumínicas, tipo de música o ruido en el vehículo y del perfil demográfico del conductor o conductora. Este nuevo protocolo de recopilación y estudio de datos ayudaría en gran medida a la comunidad científica con respecto al avance en los estudios de la seguridad vial, ayudando a disminuir los riesgos de infracción, lesión y muerte, principal preocupación de esta tesis doctoral.

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