# TESIS DOCTORAL

## Doctorado Internacional

**ESTUDIO DEL PROCESO DE TOMA DE DECISIONES Y LA INFLUENCIA DEL FEEDBACK EN SITUACIONES DE RIESGO EN CONDUCCIÓN**

*STUDY OF THE DECISION MAKING PROCESSS AND FEEDBACK INFLUENCE IN RISKY DRIVING SITUATIONS*

Doctorando:

Miguel Ángel Torres Cobo

Directores:

Antonio Maldonado López y Alberto Megías Robles

**Universidad de Granada**

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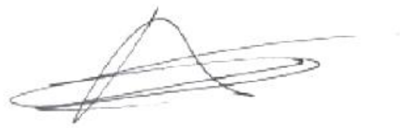

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## ÍNDICE

**SUMMARY**

Every year, around 1.25 millions of people in the world die because of traffic accidents. Almost 50% of the deaths among individuals between 15 and 44 years old are caused by traffic accidents (World Health Organization, 2015). This issue needs further research on the causes and the possible solutions. There are multiple factors related to road accidents, but according to most investigation in this matter the human clearly leads the table as the main cause (Wierwille et al., 2002).

Driving is a complex activity which entails cognitive resources like control the vehicle, manage possible risks and decision making on the planned route (Lehtonen, Lappi, Koirikivi, & Summala, 2014; Megías et al., 2017).

Although studies have demonstrated the relationship between risk perception and risk behavior (Dionne, Fluet, & Desjardins, 2007), there have also been contradictory findings disputing this relation. In many instances risk-taking is undertaken with the knowledge that the actions may lead to highly risky situations (e.g. overtaking dangerously or speeding up to cross a yellow traffic light). Sometimes unconscious actions like distractions or lack of abilities (novel drivers) are responsible of accidents but in most of times are conscious risk decisions which trigger damages. Risky driving behaviors such as speeding, close car following, and engaging in non-driving related secondary tasks are commonly observed. Thus, there are differences between evaluate the risk and decision making in risky situations.

Providing feedback to drivers of their risky behaviors may decrease the likelihood of hazardous situations, thereby reducing crashes or crash severity. However, inappropriate feedback could lead to distraction and/or added workload to the driver, resulting in undesirable effects on road safety (Feng y Donmez, 2013).

The conceptual framework of this thesis focused on the study of cognitive processing in decision-making in risky driving situations. The thesis consists of three broad foci:

a) The first experimental block (chapter 2) focuses on the study of the effect of non-contingent feedback in risky behavior using a driving context. From the literature, we analyze the characteristics of different types of risky behaviors compared to

driving. Risky behaviors are decisions making which include a serial of steps like representation of the situation, evaluation of alternatives and feedback (Rangel, Camerer & Montague, 2008). Our findings show how a contingent feedback led to faster and safer responses than a control group without any feedback; whereas a non-contingent one gives rise to slower responses and, more importantly, an enhanced risk-taking behavior that could be the cause of undesirable effects on road safety. The feedback effect was even more evident in the appearance of an opposite response bias as a function of contingency and enhanced by learning. These results accord with the theoretical accounts based upon the feedback influence on the threshold level of decision making.

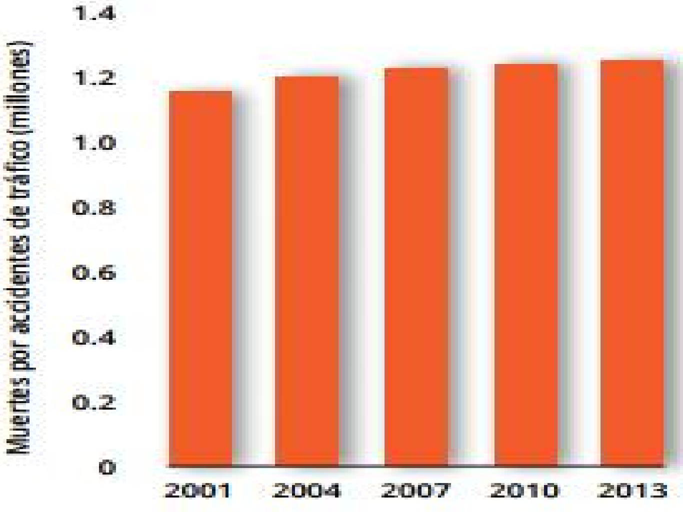
b) The second experimental block (chapter 3) differentiates between urgent and evaluative behaviors (Megías, Maldonado, Cándido & Catena, 2011b). The first one includes time pressure, depends on stimulus and has possible negative consequences. It is based on System 1 or automatic system, which uses previous experience and emotional characteristics of the situation. On the other hand, evaluative behavior consists of analyze different choices without negative consequences. These types of tasks need a controlled process based on logical rules, system 2 or rational-analytic system (Megías, López-Riañez, M., & Cándido, A. (2013). We investigate the effect of different types of feedback in these tasks. Moreover, it is studied the driving experience to evaluate learning mental models used to drive. It is demonstrated that the learning process is slow, reflexive and attention resources demanding. But, when the driver becomes an expert, develops procedure rules, cognitive heuristics, which decreases the attention resources demanding. We try to understand how feedback can influence these types of learning.

c) The third experimental block (chapter 4) tries to explain the effects of response feedback on risk behavior and the neural and cognitive mechanisms involved, as a function of the feedback contingency. We observed that contingent feedback, compared with non-contingent one, promoted changes in the response bias towards safer decisions. This behavioral modification implied a higher demand on cognitive control, reflected in larger amplitude of the N400 component. Moreover, the contingent feedback, being predictable and entailing more informative value, gave rise to smaller SPN and larger FRN scores compared to the non-contingent one. Finally, these findings provide a new and complex insight about the neuro-physiological basis of the influence of the feedback contingency on the processing of decisions-making under risk.

Taking together, this thesis studies the role of feedback in decision making process in risky behavior using a driving context. This information can be useful to design programs intended to improve road safety.

# CAPÍTULO 1: INTRODUCCIÓN

**Número de muertes por accidentes de tránsito en el mundo**



250
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De 25 a 34
De 35 a 44
De 45 a 54
De 55 a 64
De 65 a 74
De 75 a 84
Más de 84
2015
2016

En ocasiones, actuaciones no conscientes como distracciones o carencia de habilidades de conducción (conductores noveles) son responsables de accidentes. Pero, en la mayoría de ocasiones, son decisiones de riesgo llevadas a cabo de forma consciente las que provocan los daños (Dirección General de Tráfico, 2017). Por ejemplo, no ponerse el cinturón, velocidad excesiva o conducir bajo los efectos del alcohol. Concretamente, el 12% de españoles que conducen turismos han consumido alguna droga de comercio ilegal y/o alcohol, antes de conducir. Este es el dato general del estudio de prevalencia del consumo de sustancias psicoactivas elaborado por la DGT en 2015 (DGT, 2016). Durante el mismo año, el 45% de los conductores implicados en accidentes ocurridos en vía interurbana había cometido alguna infracción durante el proceso que desencadenó el accidente. Las infracciones de velocidad fueron el 26% del total de infracciones; no mantener el intervalo de seguridad, el 18% del total y las infracciones por no respetar la prioridad fueron el 14% del total (DGT, 2016).

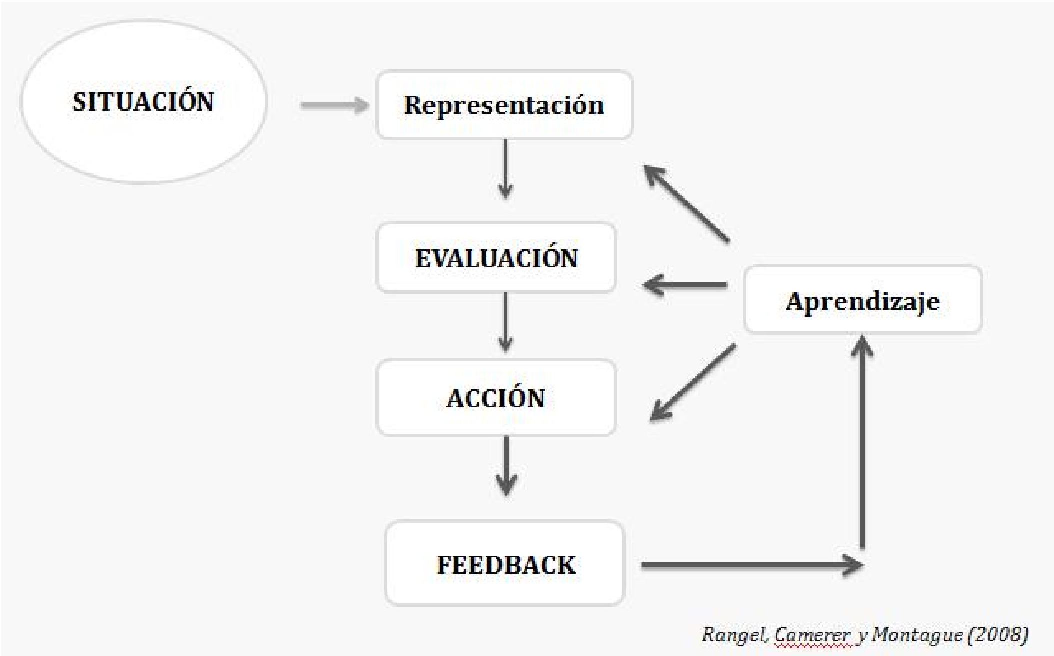
## 1.2. COMPORTAMIENTO DE RIESGO

Para definir el comportamiento de riesgo nos encontramos con dificultades en la propia definición del término. Según Trimpop (1994), el riesgo es cualquier comportamiento consciente o inconscientemente controlado, con una incertidumbre percibida sobre su resultado y/o sobre sus posibles costes y beneficios para el bienestar físico, económico o psicosocial de sí mismo o de los demás. Entre los diferentes autores parece existir un consenso en considerar como parte fundamental la ocurrencia de un evento adverso (Rayner & Cantor, 1987). Para Yates y Stone (1992), son tres los elementos fundamentales que componen el comportamiento de riesgo: existencia de posibles pérdidas, que estas pérdidas sean importantes para la persona, y que exista cierta incertidumbre en el resultado de la acción.

Una vez definido el comportamiento de riesgo, nos preguntamos por qué lo llevamos a cabo aun sabiendo los peligros que puede incluir. Por ejemplo, debido a la información disponible y a las campañas de sensibilización, los conductores de motocicleta conocen los riesgos que conlleva no ponerse el casco. En este caso, la percepción del riesgo ayuda a tomar la decisión más adecuada (ponerse el casco), pero lo que debemos preguntarnos es por qué aun sabiendo los riesgos que incluye, en ocasiones, elegimos la opción menos beneficiosa para nuestra seguridad (no ponerse el casco). Este ejemplo es extrapolable a numerosas situaciones de la vida diaria, como por ejemplo, frenar o no ante un semáforo en ámbar, mantener relaciones sexuales sin preservativo o realizar una inversión de dinero en una empresa.

Los modelos de toma de decisiones permiten explicar los comportamientos de este tipo. Existen diferentes modelos que han resultado ser útiles en diferentes ámbitos, como elecciones económicas simples (Basten et al., 2010; Rangel & Clithero, 2013), autocontrol (Hare et al., 2009; Kable & Glimcher, 2007; Peters & Büchel, 2011; van den Bos & McClure, 2013) y aprendizaje social (Boorman et al., 2013).

Como cualquier comportamiento, la conducta de riesgo implica una toma de decisión. Si indagamos en el proceso de toma de decisiones, las investigaciones recientes organizan la decisión en cinco etapas (Rangel, Camerer & Montague, 2008): a) primero, se construye una representación de la situación en la que se plantea el problema de decisión; b) segundo, se evalúan los comportamientos disponibles en términos de las recompensas y castigos que se puedan alcanzar; c) tercero, se selecciona una acción en función de la evaluación previa y de las propias necesidades; d) cuarto, una vez la acción ha sido realizada, se produce una reevaluación del proceso basándose en la deseabilidad de las consecuencias obtenidas; y e) quinto, la reevaluación de nuestra acción es empleada para actualizar el resto de procesos de decisión y así aprender a mejorar la calidad de las futuras decisiones realizadas y automatizarlas.


SITUACIÓN
Representación
EVALUACIÓN
Aprendizaje
ACCIÓN
FEEDBACK
Rangel, Camerer y Montague (2008)

conceptualizar uno de los sistemas de procesamiento como predominantemente emocional y basado en conexiones asociativos aprendidas a través de la experiencia: "sistema experiencial-afectivo"; mientras que el otro sistema realizaría un análisis más racional de la situación de acuerdo a un conjunto de reglas lógicas o estadísticas: "sistema racional-analítico". El sistema experiencial-afectivo generaría respuestas rápidas y eficaces con un coste reducido en el momento de realizarlas. Este sistema estaría guiado principalmente por el concepto de "marcador somático" o "affect heuristic" (Damasio, 1994; Slovic et al., 2007).

En la misma línea, diferentes terminologías han sido utilizadas para describir estos dos sistemas, pero generalmente, coinciden en señalar el Sistema 1 como predominantemente automático, asociativo y poco exigente en cuanto a recursos cognitivos. En cambio, el Sistema 2 se caracteriza por ser controlado, deliberativo, lento, consciente y basado en reglas lógicas (Evans, 2008; Kahneman and Frederick, 2005; Sloman, 1996).

Recientes estudios dentro del campo de la conducción han mostrado una clara distinción entre dos tipos de procesamiento del riesgo asociados a cada uno de los sistemas propuestos por los modelos de doble vía. Estas investigaciones diferencian entre comportamiento urgente (por ejemplo, decidir frenar o no ante una situación de riesgo) y comportamiento evaluativo (por ejemplo, evaluar si una situación conlleva riesgo o no) (Megías, Maldonado, Cándido & Catena, 2011b). Estas investigaciones diferencian entre comportamiento urgente y comportamiento evaluativo. El primero se lleva a cabo bajo presión temporal, desencadenado por estímulos y puede conllevar consecuencias negativas. Estaría basado en el Sistema 1 o automático, el cual implica un procesamiento basado en la experiencia previa y de naturaleza vivencial y emocional de la situación. Por el contrario, el comportamiento evaluativo consiste en evaluar la situación, la decisión ejecutada no es decisiva y no conlleva consecuencias negativas. Este tipo de tareas requieren activar un modo de procesamiento más controlado en el que la evaluación de la situación es más incisiva y los resultados están basados en reglas lógicas (Megías et al., 2014). Esta descripción coincide con las características del sistema racional-analítico o Sistema 2.

Para mayor evidencia de las diferencias entre los dos tipos de comportamientos, urgente y evaluativo, estudios previos han mostrado también diferencias a nivel neural. Datos de fMRI han esclarecido un incremento en la activación de áreas implicadas en programación motora, procesamiento emocional e integración visuomotora en comportamiento urgente comparado con el comportamiento evaluativo. Además, se observa una mayor activación frontal en tareas urgentes, lo cual sugiere la participación del control cognitivo en respuestas consideradas seguras y no arriesgadas (Megías et al., 2015). Estos resultados refuerzan un procesamiento más automático del riesgo en tareas urgentes, basado en gran parte en heurísticos y un enfoque experiencial. Las tareas urgentes, que como ya hemos comentado, se caracterizan por la presión temporal y la posibilidad de consecuencias negativas, crean un contexto adecuado para que el proceso de toma de decisiones sea guiado mediante el Sistema 1 o experiencial-afectivo.

Para poder profundizar en el estudio de la toma de decisiones y los modelos de doble vía aplicados al campo del comportamiento de riesgo en conducción, centraremos nuestro método de trabajo en la distinción entre tareas urgentes y tareas evaluativas.

## 1.4. FEEDBACK

Si seguimos la perspectiva teórica sobre la toma de decisiones compuesta por cinco etapas (Rangel, Camerer & Montague, 2008), nuestras decisiones futuras dependerán de las consecuencias obtenidas previamente en situaciones similares, por tanto, el feedback cobra vital importancia. El uso de feedback ha demostrado su eficacia al mejorar la ejecución de tareas o facilitar cambios en la vida diaria (Kluger & De Nisi, 1996; Smither, London & Reilly, 2005). El momento y el tipo de feedback es esencial a la hora de modificar conductas. Por ejemplo, los castigos inmediatos son más eficaces en comparación con castigos realizados con retraso (Abramowitz and O'Leary, 1990; Banks and Vogel-Sprott, 1965; Cheyne and Walters, 1969; Penney and Lupton, 1961).

Con el objetivo de una mejor compresión del efecto del feedback, previos estudios han mostrado cómo su uso modifica el umbral que cada sujeto utiliza para percibir y escoger una acción en un proceso de toma de decisiones. Una recompensa modifica el umbral para una situación, generando una respuesta más rápida y apropiada (Simen, Contreras, Buck, Hu, Holmes & Cohen, 2009).

En el ámbito de la seguridad vial, estudios previos han demostrado su eficacia Donmez, Boyle & Lee (2007). En este sentido, Feng y Donmez (2013) analiza diversos parámetros que influyen en la eficacia del feedback, como son el momento de aplicación, la modalidad o la información que contiene dicho feedback a través de un modelo constituidos por tres tipos de “loops”. El primer “loop” es referido al feedback provisto durante la conducción: por ejemplo, feedbacks salientes como alertas auditivas para captar la atención del conductor (Scott & Gray, 2008). El segundo “loop” se refiere al proceso introspectivo que el conductor realiza después de un trayecto. Un conductor puede aumentar su distancia de seguridad en trayectos futuros si ha estado cerca de sufrir un accidente por no respetar dicha distancia. Este tipo de “loop” decae con el paso del tiempo (Chapman & Underwood, 2000). Por último, el tercer “loop” se refiere al feedback presentado después de la conducción, es decir, si el feedback es provisto basado en la actuación del conductor sobre un periodo extenso de tiempo, el feedback positivo puede ser efectivo para motivar al conductor a invertir esfuerzo en cambios de comportamiento (Kluger & DeNisi, 1996). Este último posee una mayor fuerza en el cambio del modelo mental del conductor y, por ende, su comportamiento. La fuerza de este “loop” puede ser afectada por el tipo de reforzamiento (Kluger & DeNisi, 1996), el contenido del feedback y es mediado por la aceptación del conductor (Donmez et al., 2008a).

Si nos adentramos en dilucidar qué tipo de feedback es más efectivo, diversos estudios demuestran que un feedback contingente negativo como reducción de puntos o multas tiene mayor influencia que uno positivo como dar puntos por conducción segura (Maldonado et al, 2015). De igual forma, se ha demostrado que una experiencia previa con feedback no-contingente produce dificultades en siguientes aprendizajes (Maier and Seligman, 1976; Maldonado et al, 1991). Este efecto ha sido interpretado como un cambio en el procesamiento y en la atención dada a los estímulos siguientes al feedback no-contingente (Bennet et al, 1995). Además, se ha comprobado que se utilizan zonas cerebrales diferentes dependiendo del tipo de feedback (Catena et al, 2012). A nivel cortical, la red responsable de la generación de expectativa/incertidumbre estaría incluida en el cíngulo anterior y cortezas prefrontales dorsolaterales, áreas parietales posteriores y la ínsula. Parte de esta red es probablemente responsable de la generación de expectativa, es decir, la representación anticipada de las características hedónicas y perceptuales del próximo evento. Sin embargo, existe otra parte, la más anterior, que entra en acción cuando no ha sido posible predecir el resultado en el pasado, o dicho de otra manera, cuando el resultado es percibido como incierto (Catena et al, 2012).

Como vemos, han sido numerosos los estudios que analizaban el efecto de la contingencia del feeedback en tareas decisionales y de aprendizaje, pero han sido escasas las investigaciones sobre el tema en el ámbito de la conducción y seguridad vial. A lo largo de los artículos incluidos, intentaremos averiguar el papel que cumple el feedback no-contingente en dicha área.

## 1.5. EXPERIENCIA PREVIA

Para lograr una conducción óptima se requiere el aprendizaje de decisiones seguras en diferentes situaciones de riesgo, que dependen de la adquisición de habilidades cognitivas como por ejemplo, búsqueda visual, reconocimiento del peligro o control del vehículo (Lehtonen, Lappi, Koirikivi, & Summala, 2014; Sagberg, & Bjørnskau, 2006). Estas habilidades son adquiridas mediante el aprendizaje y la experiencia en carretera y deberían introducir cambios permanentes estructurales y funcionales al desarrollar nuevos procesamientos automáticos (Sagi et al., 2012).

Una forma de evaluar el proceso de aprendizaje y los posibles modelos mentales utilizados es establecer una comparación entre personas con experiencia en el proceso decisional y novatos, en este caso, personas que no han conducido nunca y conductores con cierta experiencia.

A través de la literatura conocemos que el riesgo de accidente de los conductores noveles disminuye rápidamente durante los primeros meses después de conseguir el carnet de conducir, indicando que algunas habilidades de conducción importantes son aprendidas durante este periodo (Sagberg, & Bjørnskau, 2006). En cambio, es requerido más tiempo para desarrollar las habilidades perceptuales y cognitivas necesarias para interactuar de manera segura con el escenario de conducción.

Investigaciones previas han mostrado que los conductores noveles subestiman el riesgo de accidente en situaciones que conllevan distintos peligros. Al mismo tiempo, sobrevaloran su propia habilidad de conducción. Dichos conductores están más dispuestos a tomar decisiones arriesgadas en comparación con conductores con experiencia. Estos factores contribuyen a que los conductores jóvenes aparezcan en mayor proporción en las estadísticas de accidentes (Deery, 1999).

Además, los conductores con poca experiencia poseen deficiencias en la percepción de los peligros en comparación con conductores expertos. La experiencia en conducción mejora la percepción de los peligros y guía el patrón de exploración visual hacia las zonas que implican riesgos potenciales (Borowsky, Shinar and Oron-Gilad, 2010).

Mediante este trabajo pretendemos contribuir a conocer cómo la experiencia construye y modifica los modelos mentales implicados en la toma de decisiones en situaciones que implican riesgo. Para ello, trabajaremos con tareas evaluativas y de decisión, con el objetivo de analizar las implicaciones del Sistema 1 o automático y el Sistema 2 o reflexivo en el proceso decisional en función de la experiencia previa.

Además, presentamos la posible existencia de dos tipos de procesamientos automáticos en la ejecución de estos comportamientos. Por un lado, tareas rápidas de aprender que implican toma de decisiones de riesgo, como por ejemplo, frenar cuando estamos a punto de atropellar a un peatón. En este caso, implican un uso de heurísticos afectivos con las características descritas en el Sistema 1 o automático y basado en emociones (Slovic et al, 2007). Por otro lado, también hablamos de procesamiento automático cuando este forma parte de un tipo de comportamiento experto. En este caso, a la hora de decidir en escenarios complejos, como son los de conducción, asumimos la existencia tanto de heurísticos afectivos como de modelos mentales aprendidos a través de una amplia experiencia y del feedback (Frank, Cohen, & Sanfey, 2009).

Teniendo en cuenta el paradigma de la conducción, está demostrado que el proceso de aprendizaje implica un procesamiento lento, reflexivo y demandante de recursos atencionales. Pero, cuando el conductor se convierte en experto, desarrolla reglas procedimentales, heurísticos cognitivos, que permiten disminuir la demanda de recursos atencionales y por tanto, realizar otras tareas mientras conduce, como por ejemplo, seguir la ruta indicada en una pantalla.

A lo largo de este trabajo, pretendemos analizar el efecto del feedback y de la experiencia sobre los distintos comportamientos, automáticos y evaluativos.

## 1.6. OBJETIVOS DE LA TESIS

El objetivo principal de este trabajo es estudiar el proceso de toma de decisiones en situaciones complejas que implican comportamiento de riesgo. Integrados en este objetivo principal, en los artículos incluidos en la tesis, pretendemos cumplir una serie de objetivos específicos:

En primer lugar, estudiar el efecto del feedback contingente sobre la toma de decisiones en situaciones de riesgo de conducción y compararlo con el feedback de tipo no-contingente. Desarrollaremos los diferentes tipos de comportamientos de riesgo y describiremos el proceso de toma de decisiones llevado a cabo. Este objetivo se aborda con el artículo que contiene el Capítulo 2.

El segundo objetivo es analizar el efecto del feedback sobre el comportamiento de riesgo, diferenciando entre tareas de evaluación y tareas de decisión. Además, se compararán grupos de conductores expertos y novatos para evaluar los factores atencionales y de aprendizaje implicados en el modelo utilizado para la toma de decisiones en situaciones de riesgo. El Capítulo 3 trata de dar respuesta a esta cuestión poniendo de relieve la importancia del sistema de procesamiento automático-experiencial.

Por último, el tercer objetivo es conocer los mecanismos neurales y cognitivos implicados en el comportamiento de riesgo cuando aplicamos diferentes tipos de feedback. Mediante el estudio electroencefalográfico, analizaremos los indicadores cerebrales relativos a la toma de decisiones de riesgo y la incertidumbre que conlleva.

Los componentes N400, SPN y FRN serán útiles para conocer la actividad cerebral durante una toma de decisión que implica riesgo, utilizando un contexto de conducción. Los mecanismos cerebrales implicados en el proceso de toma de decisiones en situaciones de riesgo son tratados en el Capítulo 4 y se integran con la información aportada en los capítulos anteriores.

# CAPÍTULO 2: LOS EFECTOS OPUESTOS DE LA CONTINGENCIA DEL FEEDBACK EN EL PROCESO DE TOMA DE DECISIONES DE RIESGO

Torres, M. A., Megías, A., Catena, A., Candido, A., & Maldonado, A. (2017). Opposite effects of feedback contingency on the process of risky decisions-making. *Transportation research part F: traffic psychology and behaviour*, *45*, 147-156.

**Abstract**

The main aim of this study was to look into the effect of feedback contingency on decision making in complex risky situations, using a driving context. Participants had to decide braking or not in a set of risky traffic situations. After the response, a negative non-contingent or contingent feedback was used. The results highlight the importance of feedback contingency upon safer decision making in risky contexts, as they showed how a contingent feedback led to faster and safer responses than a control group without any feedback; whereas a non-contingent one gives rise to slower responses and, more importantly, an enhanced risk-taking behavior that could be the cause of undesirable effects on road safety. The feedback effect was even more evident in the appearance of an opposite response bias as a function of contingency and enhanced by learning. These results accord with the theoretical accounts based upon the feedback influence on the threshold level of decision making. Moreover, the effects of feedback may be explained by new proposals focusing on the importance of attentional factors as well as of the mental models people build to react in complex risky scenarios, as a product of feedback and learning. Finally, this research may increase our understanding of the role of feedback in the process of learning safer behavior in complex risky situations.

## 2.1 Introduction

Risk is inherent in our daily lives. Many times we make decisions that can involve some risk like playing a lottery. But the importance of our decisions increases in more complex risky situations. This happens when we decide having sex without preservative, working without safety measures, making a money investment and more frequently, when we drive after taking alcohol or drugs or with an inappropriate speed.

In the study of risky behavior, the first problem is the definition of risk. There is a consensus to consider the uncertainty and probability as well as the importance of an adverse event as the fundamental elements of risk (Rayner & Cantor, 1987). Accordingly, Yates and Stones (1992) proposed that a risky decision implies the existence of probable losses, modulated by the uncertainty and importance of such losses regarding the possible gains.

From a psychological perspective however, the identification of the processes involved in risky behavior becomes more relevant. Assuming that such behaviors imply a decision making, the existence of at least four fundamental processes have been proposed: a) the perception of the risk factors involved in the situation; b) the evaluation of the different behavioral possibilities and probable consequences; c) the final choice of the response; and finally, d) the consequences obtained (feedback) should modulate the future behavior in similar situations to maximize profits and minimize losses (Rangel, Camerer, & Montague, 2008, among others).The main aim of this research was to look into the influence of feedback contingency (the last phase) upon the whole process of decision making in complex risky situations like driving, in order to get safer and more suitable behaviors.

To understand risk behavior, the first thing to keep in mind is that people do not always behave following a rational process and, however, in the most of these situations, they still perform quite well. People often used cognitive and affective heuristics following previous experience and/or influenced by their emotional states (Megías, Maldonado, Cándido, & Catena, 2011; Slovic, Finucane, Peters, & MacGregor, 2007) and personality traits (Figner and Weber, 2011).In this way, recent theories defend the existence of a dual-processing system in risk perception and risky behavior taking (Evans, 2008; Loewenstein et al, 2001; Sanfey and Chang, 2008). These dual-process models agree that risk perception and many risk decisions may be explained by an “affective heuristic", which rely more on the automatic processing system, being mostly unconscious or demanding less attentional resources, fast, sensitive to emotions, and based on situation–action connections that have been associated with success in the past, neglecting, in part, the possible negative consequences and the effect of feedback upon them. On the other hand, the controlled processing system is assumed to be more conscious and deliberative, based on logical or statistical rules, and slower than automatic processing system (Epstein, 1994). These theories could explain why in many situations people take risks guided, in part, by a more automatic processing system, even though these decisions seem to be irrational and could have negative consequences (Slovic et al, 2007).

“Automatic processes” are also assumed to be part of any “expert behavior”. From this perspective, in order to explain the decisions in complex risky situations, such as it happens while driving, we should assume the existence of “heuristics” or “mental models” built upon the effects of previous experience and expertise, as well as feedback and learning in risky context scenarios (Frank, Cohen, & Sanfey, 2009), as we will try to show in this research. Taking into account the driving paradigm, it has been frequently demonstrated that learning implies a more controlled processing and therefore, more reflexive, logical, slower and serial performance, demanding more attentional resources that prevents the novice driver to perform any other tasks while driving. On the other hand, when the driver gets to be an expert, he/she develops “heuristics” based upon procedimental rules, reducing the demand of attentional resources, which allows performing other tasks while driving.

However, what happens when a risky situation appears while we are driving? For example, because we arrive to a dangerous intersection with a possible stop or traffic light, a pedestrian is crossing the driveway or other vehicle makes a dangerous or unexpected action. Obviously, in this case, the individual should stop paying attention to anything else that could be doing (talking to someone, thinking about other things, listening to music, etc.) to focus on the risk context, in order to achieve the safest possible behavior in that specific situation. From this perspective, we should assume two different effects. First, the appearance of a risk situation implies the interruption of the relatively automatic processing of driving and increase the demand of attentional resources toward the risk and the new scenario. Second, it is obvious that the decision should be faster and safer with a higher preparation and experience in this activity, a better driver in this case. Moreover, the decision making process in this situation could be influenced by other variables, such as age, sex, personality traits, driving experience, taking drugs that severely limits our ability of perception and decision and so on, as it has been shown in previous research (Begg & Langley, 2001, Donmez et al., 2006;Gulliver &Begg, 2007; Megías, Cándido, Catena, Molinero, & Maldonado, 2014).

Accordingly, it is important to acknowledge that decision making in risky everyday situations like driving is a complex concept that needs an improved experimental and theoretical revision. At difference with simpler risky elections, the behavior in most of these situations involves many different features. An accurate driving implies learning safer decision making in many different risky scenarios, which depend on the acquisition of set of cognitive skills such as visual search, hazard recognition, attentional and vehicle handling control, safety motives, among others skills (Lehtonen, Lappi, Koirikivi, & Summala, 2014; Sagberg, & Bjørnskau, 2006). These cognitive skills are acquired by learning and experience, as they require practice and on-road experience and should induce permanent structural and functional changes developing new automatic processes (Sagi et al., 2012).

From this perspective, when the possibility of losses is so important, as in many of the risk situations of our daily lives, the individual should learn to make safer decisions.  For example, in driving the importance of losses (accidents or penalties) far exceed probable profits (arrive earlier or more interests). In this case, the study of the effects of feedback, either by direct or vicarious experience, is an important part in the process of risky or safe decision making. Feedback is a useful technique to enhance learning of new knowledge, improve task performance, and facilitate beneficial changes in daily behavior (for reviews, see Kluger & DeNisi, 1996; Smither, London & Reilly, 2005).Previous research and experience on safe driving have proved its efficacy (see a recent review and model in driving context by Feng & Donmez, 2013). For example, it has been proved how a negative contingent feedback, as points reductions and penalties for risky decisions, had more influence than a positive one like giving points for safe driving (Maldonado et al, 2015).

In the process of decision making, the effect of feedback seems involved in the "threshold level" that the individual uses for perception and behavioral choice. A reward or contingent feedback modifies the threshold level for any situation, generating a faster and more appropriate decision making (Simen, Contreras, Buck, Hu, Holmes & Cohen, 2009). Applied to risky situations, the effect of contingent feedback should produce not only a faster response, but especially a lower level of risk in the decision making, which probably means a safer behavior (Feng and Donmez, 2013; Maldonado et al, 2015). However, although some studies have investigated the role of feedback on risk taking, very few, if any, have shown the influence of contingency, and especially the effects of non-contingent feedback in risky driving decisions.

Research on animal and human learning has revealed how a previous experience of non-contingency between cues and its consequences (learned irrelevance effects, see Baker and Mackintosh, 1977, Maldonado et al, 1999, among others) or between the own responses and its effects (learned helplessness, see Maier and Seligman, 1976; Maldonado et al, 1991, among many others) produced different cognitive and behavioral deficits and a subsequent learning impairment. These effects of non-contingency have been interpreted assuming that pre-exposure to uncorrelated events may produce a change in their processing and/or the attention given to these cues in the future, reducing its associability and delaying or impairing its subsequent learning (see Bennet et al, 1995).

According to the previous review, the main aim of this research was the analysis of the effect of a non-contingent feedback on decision making in driving risky situations, given its theoretical and applied importance to understand the psychological mechanisms underlying learning of risky and safe responses in complex scenarios, as we will review later. To this end, four groups of participants were used. A control group allowed the study of the participants' decisions under risk as a function of their previous experience. In the contingent (negative) feedback group, the objective was the modification of the decision making, making them more accurate as a function of a system of penalties upon risky decisions. Finally, two non-contingent feedback groups with different probabilities of feedback were used to analyze its effect on risky behavior. A sit happens in human causal learning tasks and in animal conditioning, an impairment of the learning and the behavior are expected in such situations. The non-contingent or inappropriate feedback should produce the opposite effects to the contingent or appropriate one, a less safe and more risk prone decision making.

### 2.2. Method

#### Participants

Eighty participants from the University of Granada volunteered in this study (mean age: 20.3 years; range: 18-25; 49 women and 31 men). All had normal or corrected-to-normal vision. They signed an informed consent form and were treated in accordance with the Helsinki declaration (World Medical Association, 2008).

#### Stimuli

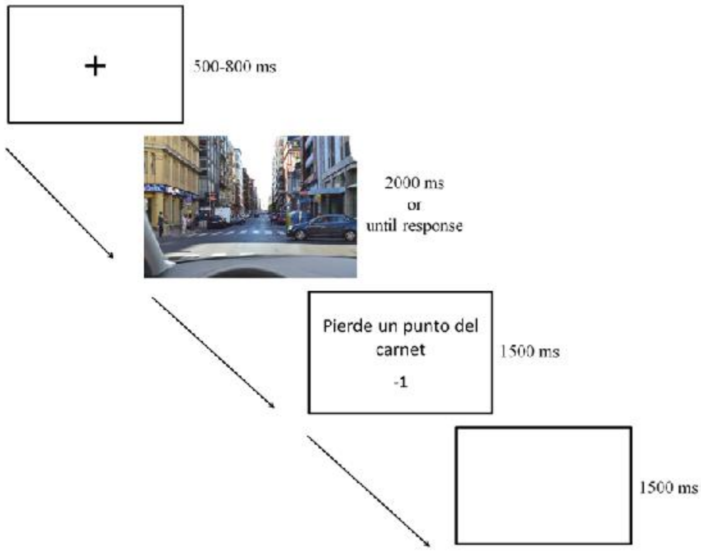
One hundred twenty pictures showing traffic situations from the driver´s perspective were used in the study. Pictures were selected from an extensive image database of traffic situations taken in Spanish and Finnish roads. The 120 selected situations met a set of statistical criteria in order to reduce the interpersonal variability in the interpretation of the traffic situation (see Megías et al, 2015). The criteria were the following: pictures were previously evaluated on the perception of speed at which the vehicle is driven and on the best response to avoid the hazard (if any)by 40 driving instructors. We selected only those pictures with a standard deviation of speed perception lower than 25% of the average, and where the best option to avoid the hazard was always to brake for at least 70% of the driving instructors. In addition, pictures were also evaluated in relation to the perceived risk level by 40 volunteers in possession of driving license. Finally, of the 120 selected pictures, 90 had a medium risk level (average risk = 4.56 [0: no risk; 7: high risk]) and the other 30 showed no risk (average risk = 1.65). The images were displayed on a 15-inch monitor set to 1024x768 resolutions.

**Procedure**

Participants were randomly assigned to one of four experimental groups: Control group, Contingent group, Low non-contingent group, and Medium non-contingent group. The experiment consisted of two blocks of 120 pictures trials each block (images were the same in both blocks). Ninety risk images and thirty no risk ones were displayed in each block. The order of presentation of the trials was randomized.

Each trial (see Figure 1 for a trial example) began with a fixation cross with a variable interval time (between 500 and 800 ms). Next, the traffic situation was displayed and remained on screen until the participant responded or until 2000 ms had elapsed. Participants had to make the decision of braking or not in the given traffic situation. They had to press the left mouse button with their left forefinger to brake and the right mouse button with their right forefinger not to brake. The correspondence between the right and the left mouse button and type of response was balanced across participants.

After the traffic picture, a feedback screen was displayed for 1500 ms. In the Contingent group, feedback reading “pierde un punto de su carnet de conducir” (in English: you lose 1 point of your driving license) was presented in 50% of the risky situations in which the participant did not brake. In the rest of cases the feedback was "mantiene los puntos del carnet” (in English: you keep the points of your driving license). It is important to acknowledge that penalties (negative feedback) appeared in few trials during this phase (mean: 19.8 trial per subject), due to its very high effect. Besides, two groups of non-contingent feedback were used. In the Medium non-contingent group the feedback (penalty: "you lose 1 point of your driving license") was displayed in 50% of risky situations regardless of the participant's response. In the rest of cases the feedback was "you keep the points of your driving license”. The Low non-contingent group was similar to the Medium one, but the percentage of penalties ("you lose 1 point of your driving license") in the risky situations was of 25%, to reach a similar proportion of trials with feedback than in the Contingent one. In the Control group there was no feedback to get the drivers behavior base-rate as a function of the previous experience in similar risky situations. Finally, a white screen was displayed for


+
500-800 ms
2000 ms
or
until response
Pierde un punto del
carnet
-1
1500 ms
1500 ms

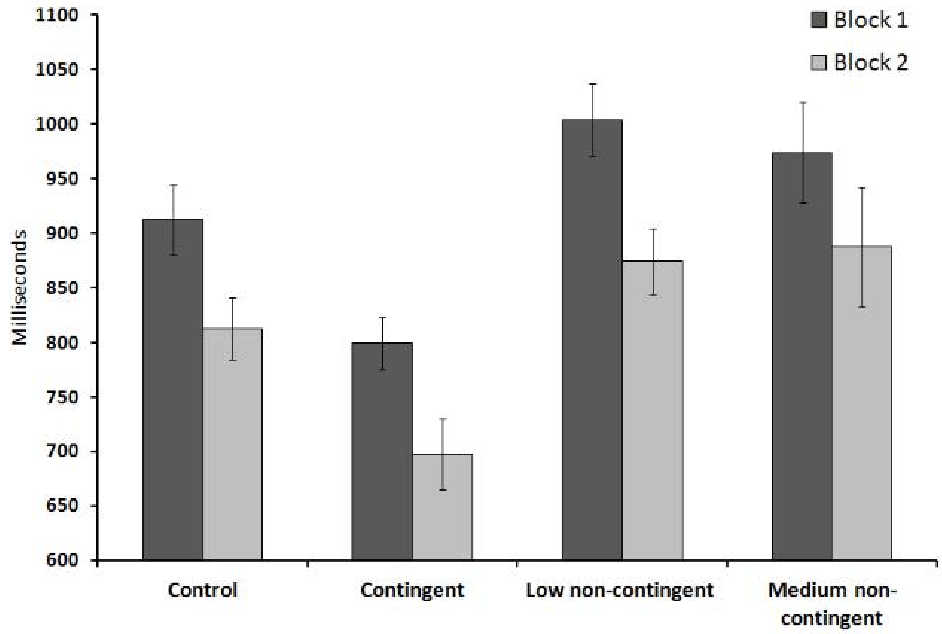
be used as an independent factor. Therefore, two subsequent mixed repeated measures 4 (Group) x 2 (Risk) ANOVAs were performed on the reaction times and probability of braking, to dissociate the feedback effects on risky and non-risky scenarios. An alpha level of 0.05 was set up for all analysis. Partial $\eta^2$ was used as index of effect size.

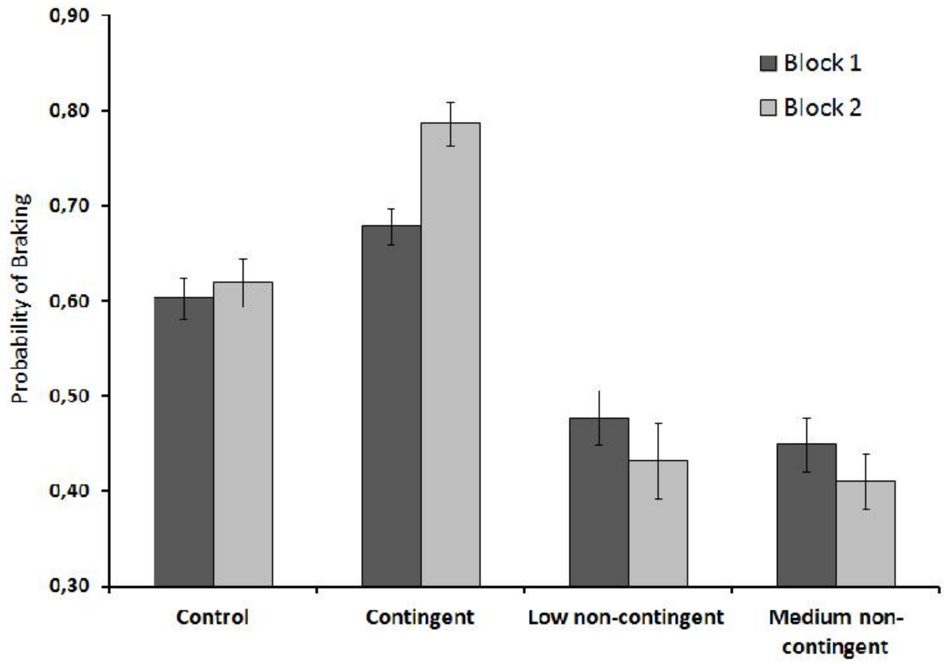
**2.3. Results**

Previous to ANOVAs, Kolmogorov-Smirnov and Levene's tests verified normality of the distribution and homogeneity of the variances of all dependent variables (all *p*'s > .05). Subsequently, two kinds of ANOVAs were performed to demonstrate the effect of feedback contingency on the process of risky decision making in risky situations. On the one hand, the interaction between Group and Block in the four dependent variables: reaction times, probability of response, sensitivity, and response bias effects on brake probability. On the other hand, the 4 (Group) x 2 (Risk) ANOVAs allowed dissociating the effects of feedback contingency on risk and no risk situations on reaction times and probability of braking as dependent variables.

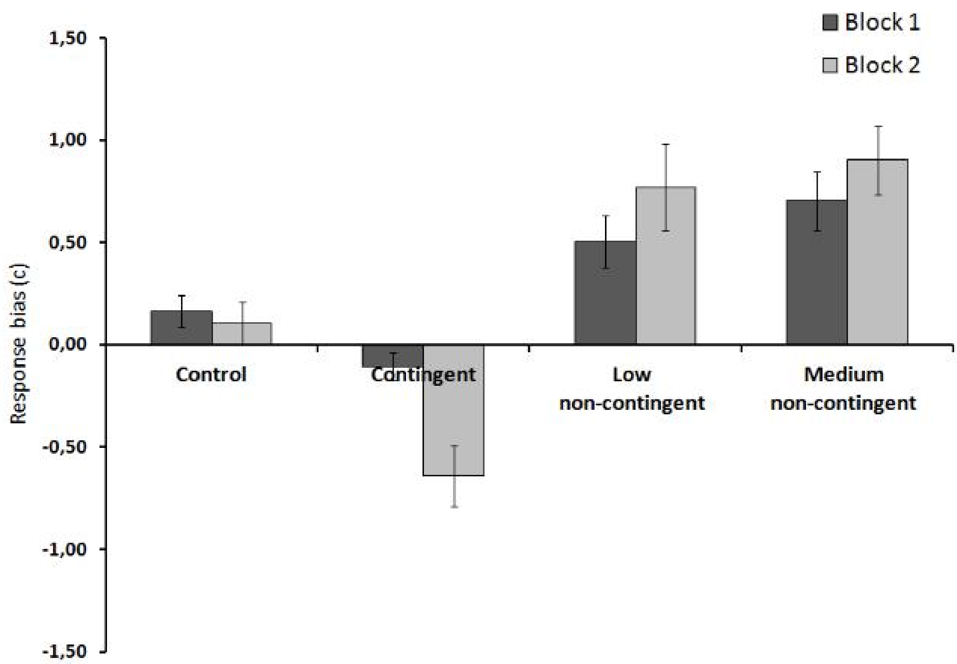
In order to analyze the effect of feedback contingency and learning, the 4 (Group) x 2 (Block) ANOVA on mean reaction times revealed a main effect of Block, $F$ (1, 75) = 55.04, MSE = 7815.12, $p < .0001$, $\eta^2_p = .42$, and Group $F$ (3, 75) = 6.89, MSE = 45103.07, $p < .0001$, $\eta^2_p = .22$. Post-hoc analysis showed faster reaction times in Block 1 than in Block 2 ($p < .05$) in all conditions. With respect to the Group variable, the Contingent group showed faster reaction times than the rest of the groups (all *p*'s < .05). More importantly, the Low and Medium non-contingent groups were slower than the Control and Contingent group (all *p*'s < .05) and did not differ between them (see figure 2).

These results demonstrated a clear feedback effect of both contingency and learning. Firstly, the more experience, the lesser the reaction time in all conditions; secondly, a contingent feedback led to a more rapid decision making; and finally, according to previous hypotheses, a non-contingent feedback produced the opposite result as decisions reaction time increased.

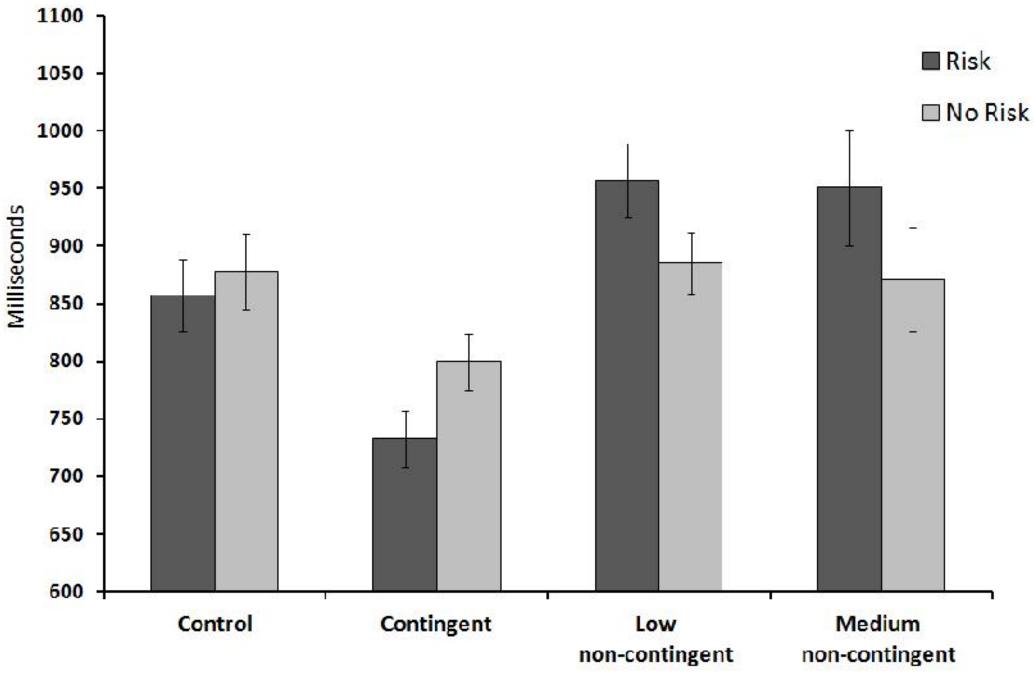

Block 1
Block 2
Milliseconds
1100
1050
1000
950
900
850
800
750
700
650
600
Control
Contingent
Low non-contingent
Medium non-contingent



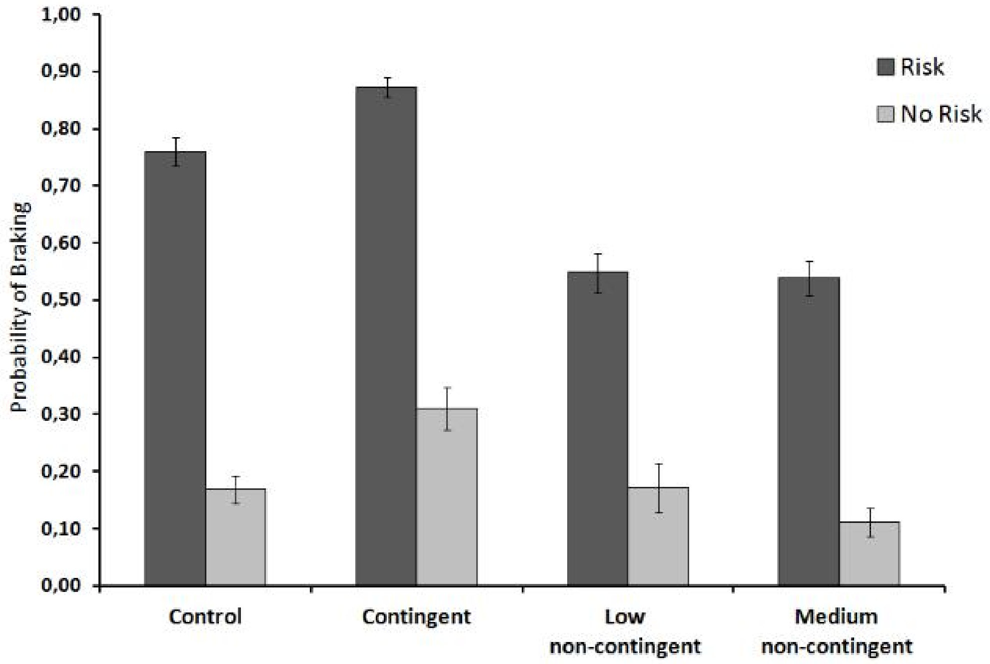
Probability of Braking
0,90
0,80
0,70
0,60
0,50
0,40
0,30
Block 1
Block 2
Control
Contingent
Low non-contingent
Medium non-contingent



Block 1
Block 2
1,50
1,00
0,50
0,00
-0,50
-1,00
-1,50
Response bias (c)
Control
Contingent
Low
non-contingent
Medium
non-contingent



1100
1050
1000
950
900
850
800
750
700
650
600
Milliseconds
Risk
No Risk
Control
Contingent
Low
non-contingent
Medium
non-contingent



1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
Probability of Braking
Risk
No Risk
Control
Contingent
Low non-contingent
Medium non-contingent

First of all, in accordance with previous research (Feng and Donmez, 2013; Maldonado et al, 2015), a contingent feedback led to faster and less risk prone decision making in risk driving scenarios than a control group without any feedback. Moreover, these safer decisions increased in the second block, suggesting that the effect of a contingent feedback was enhanced by the learning experience.

Secondly, the most important and newer results were related to the opposite effect of non-contingency upon the process of risky decision making. At difference with a contingent feedback, a non-contingent one led to slower responses and more risky decisions compared to the control group without any feedback. As it happened with the contingent feedback, these effects increased as a product of experience or learning.

Thirdly, the non-contingent feedback had only the effect of slowing the responses and makes them less probable in the risky situations. However the contingent one gives rise to an increment of the probability of responses in both the risk and the safe situations.

Finally, the effect of feedback contingency was clarified by the appearance of an opposite response bias as a function of learning. When the feedback was contingent, participants acquired a more cautious response bias giving rise to less risky responses and consequently to a higher probability of braking even in the safer situations. On the contrary, a non-contingent feedback led to a more risk prone response bias, giving rise to an increment of risky decisions only in the risky situations. However, feedback did not have any influence on the discrimination (sensitivity index) between safe and risky situations.

In order to explain the effect of contingency of feedback in the decision making process in risk situations, the theoretical accounts based upon the feedback influence on the decision threshold level seems to be the best alternative (Simen, Cohen, & Holmes, 2006; Simen et al., 2009). According to this model, the feedback or reward rate provides a global signal to control the decision threshold during a task, in such a way that the larger the reward, the lower the selected decision threshold. It has been also suggested that not only the average rate of recently received rewards, but also the opportunity to escape from an aversive situation may lower the decision threshold (Niv et al., 2007; Contreras, Megías, Maldonado, Cándido, & Catena, 2013).

Thus, we should assume that a negative contingent feedback might lower the threshold for a decision, reflected in our study by changes in the response bias toward more cautious responses. Therefore, this assumption can clarify the current experimental results, indicating that participants in the feedback contingent group adjust their decision threshold in order to avoid the penalties associated to risky decisions. This learning would lead to an enhanced or faster perception of risk, speeding up the responses and making them safer or more cautious in risky situations, as learning takes place. This fact can explain the lower response bias upon safer responses, especially in the second block, and also why in this group there was an overreaction and more probability of braking even in the safer situations.

On the other hand, we need to assume that a non-contingent feedback should entail the opposite effect, an increased decision threshold (a less cautious response bias) as a product of learning, in order to be able to explain its behavioral effects. Accordingly, the participants in this group developed a less rapid detection of risk, giving rise to slower responses and less braking or more risk prone decisions. Therefore, they decided to brake in less number of risk situations, as they seem to have learned a response bias toward a less conservative and more risky behavior, as a product of the experience with the task. But this learning only affected to risk situations, not to the safer ones.

In sum, although feedback did not seem to affect the discrimination ability (sensitivity index) in risky situations, it induced a change in the response tendencies (response bias) in risky contexts, as a function of the “threshold” to perceive and react in these situations. Regarding the control group, the “lower threshold” induced in the contingent group led to faster and more cautious, and probably safer, responses; while “an increased threshold”, in the non-contingent group, led to slower and more risk prone responses in the same risky contexts.

In the search for the psychological mechanism implied in the effect of feedback in driving, a new recent model proposed that feedback effectiveness may act through two main loops as a function of whether feedback is provided during or after driving (see the more general model by Feng and Donmez, 2013, implying other loops).The first -attentional- loop would reflect the feedback provided during driving, which seems to depend on its saliency and modality and has its main influence on attentional processes (Donmez, Boyle & Lee, 2007; Serrano, Di Stasi, Megías, & Catena, 2011). Contingent feedback can affect to this first loop by enhancing attention to the relevant features of the risky situations, reducing the tendency to engage in distractions and speeding up the responses. The opposite effect explaining the effect of a non-contingent feedback should produce attentional deficits, making responses to avoid risk (e.g. braking) slower and less frequent, probably due distracting factors, mental workload or lesser attention to the possible danger or risk signals. It is interesting to acknowledge that these attentional assumptions agree with the learning models explaining the effect of a non-contingent previous experience upon the subsequent learning a new task, due to attentional deficits or lack of attention to the relevant features of the new learning task (Bennet et al, 1995, among others).

More important for the present study results, the second -cognitive (memory)- loop of the Feng and Donmez's model illustrates the effect of feedback given after the decision has been taken, as it happens with penalties. This loop can be powerful to modify a driver's mental model of safe driving, making possible to develop new rules of decision making, reflected in changes in the decision response bias either in risky or non-risky situations, and thus to alter in a more permanent way the driving behavior. As a consequence, a contingent or appropriate feedback would induce safer rules and faster responses. On the other hand, the non-contingent or non-appropriate feedback would induce just the opposite behavioral pattern: a response bias giving rise to slower and more risk prone decision making.

However, all these ideas and whether the effect of contingent and, especially non-contingent feedback may have any influence upon attentional as well as associative-cognitive factors, remain an open question for further research and upcoming studies on the neural mechanisms underlying the process of decision making under risk (see Megías et al, 2015) and the effect of feedback upon them, which could shed light upon the psychological mechanisms responsible of safer or riskier behavior in our daily life.

**2.5. Conclusion**

The main aim of this work was to demonstrate how appropriate (contingent) or inappropriate (non-contingent) types of feedback affects the decision making process under risk, such as the response of drivers in risk driving situations. The results highlight the importance of feedback contingency upon the process of decision making in risky complex scenarios, as a contingent feedback make possible a more accurate behavior whereas a non-contingent or inappropriate one led to the opposite effect, less safer and more risk prone decisions.

The demonstration that non-contingent feedback has substantial effect in the process of learning safer and more accurate decision making in complex risk scenarios may have an important applied role, especially in an era where many devices are developed to help drivers, and workers in general, to be more efficient and safe. When feedback is offered in a non-contingent or random manner, learning and subsequent behavior is impaired, even compared to learning carried out without any feedback. Thus, it is necessary that the feedback received when driving, usually fines or *loss of points in a point-based driving license*, is properly adjusted to the official traffic regulations and to a safe driving style. Moreover, very importantly, the driver must perceive that the relationship between behavior and feedback is real and correct. Otherwise, the effect of feedback could have the opposite effect to the intended. Thus, our results emphasize the importance of accurate feedback in the process of learning driver abilities to confront risky situations, and may help in the development of programs to induce safer tendencies in driving, reducing accidents on the road. For example, our findings would support the use of the point-based penalty system implemented in some countries to control drivers' risk taking, provided that it is applied correctly (Donmez, Boyle, & Lee, 2007; Maldonado, Serra, Catena, Cándido, & Megías, 2016). Moreover, the use of negative/aversive feedback in driving schools (e.g. in combination with driving simulators), rehabilitation programs for traffic offenders or advanced driver assistance systems could make drivers aware of risk behaviors and unsafe habits, improving driving performance (Megías, Cortes, Maldonado, & Cándido, 2016). Of particular relevance would be the case of training new drivers where the use of negative feedback can stimulate the learning of safe driving habits, but an incorrect implementation of feedback can lead to inappropriate behaviors that endure over time.

Some limitations of this research comes from the type of context and participants, as previous research have shown that the same feedback method may lead to differential effects on driver behavior and learning as a function of driver characteristics, such as age and gender (Begg & Langley, 2001, Donmez et al., 2006), driving experience (Williams, Lund & Preusser, 1985), cognitive ability (Owsley, 1994), and personality traits (Gulliver & Begg, 2007), among others. Accordingly, there are open many new research possibilities to clarify the previous results of feedback on the process of risky decision making as a function of these factors. For example, the effect of contingent and non-contingent feedback may differ as a function of expertise level, as more experienced drivers are able to detect hazards more quickly and efficiently than novice drivers (Deery, 2000). The influence of individual differences in risk propensity, extraversion, or impulsivity level may also shed light and limit the generality of the found effects (Nicholson et al., 2005; Edman, Schalling, & Levander, 1983). Moreover, laboratory tasks cannot reflect the full complexity of an on-road driving environment. For example, in our task, slower reaction times in the non-contingent group could also be explained due to the participants are trying to decipher what they are doing wrong, why feedback sometimes does not support their interpretation of the risk. Further research should focus on the effect of the non-contingent feedback in more naturalistic environments in order to clarify some of these issues. Finally, these effects should be investigated in other contexts, like economic or investment (Alos-Ferrer et al, 2014), to expand its theoretical and applied generality. The importance of the feedback contingency effects on the process of risky decision making in other complex scenarios could also help to uncover the neural basis of the risk making decision processes (see Megías et al, 2015).

In sum, this research may increase our understanding of the process of risky decisions and enhances the importance of feedback to learn safer or more accurate behavior in complex risky situations; but it is only a new step looking for the factors and the psychological as well as the neurophysiological mechanisms underlying all these processes.

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# CAPÍTULO 3: DECISIONES ARRIESGADAS Y SEGURAS: EL PAPEL DEL SISTEMA DE PROCESAMIENTO AUTOMÁTICO-EXPERIENCIAL

Torres, M. A., Megías, A., Catena, A., Candido, A., & Maldonado, A. (2017). From riskier to safer decisions: The role of the experiential automatic processing system. (Artículo enviado a Journal of Safety Research y pendiente de revisión)

# From riskier to safer decisions: The role of the experiential automatic processing system.


## Abstract

The main aims of this research were twofold. The first objective was to analyze the effect of feedback on risk evaluation and decision processes in dangerous and harmless driving situations by giving punishment either contingently or non-contingently(negative feedback) upon performance of risky behavior (Experiment 1A). The second objective was to demonstrate the influence of prior experience upon the effect of feedback on the process of decision-making (evaluation, final decisions, and feedback), comparing drivers (participants with a driving license) and participants without any driving license, and who therefore had no such previous experience (Experiment 1B).The results showed firstly a clear difference between evaluations and decisions in complex risky situations. Decisions were faster and more precise than evaluations, and both were improved by contingent negative feedback (Experiments 1A and 1B) or by previous experience with similar tasks, since drivers made better evaluations and decisions than non-drivers (Experiment 1B). The more novel and interesting results come from the behavioral dissociations between risky and non-risky contexts as a function of feedback contingency. In risky situations, contingent feedback led to faster, more precise and safer responses than those observed in the control group, whereas non-contingent feedback led to just the opposite behavioral pattern: faster, but riskier responses. Unexpectedly, the contingent feedback in non-risky situations also resulted in both drivers and non-drivers making somewhat inaccurate risk evaluations and decisions. The cognitive processes underlying these effects point to a response bias rather than to discriminative factors, as suggested by signal detection theory analyses. These findings clarify previous results and they suggest how riskier and safer decision-making could be more dependent on the experiential automatic processing system than on the rational-controlled system. Taken together, all of these results have potentially important applied value in the promotion of safer responses, both in dangerous and harmless contexts.

## 3.1. Introduction

Risk always implies a difficult balance between losses and benefits. In almost any risk situations, risk behavior involves a decision-making process, although there are many differences between such situations (Weber et al., 2002). For instance, in the financial area, it is usually assumed that the greater the risk, the greater the potential benefits. However, when playing games or lotteries, with the exception of those with addictive behaviors, people expect to achieve considerable gains at the expense of very few losses. On the other hand, in many of our everyday contexts, including sexual, working, and driving situations, relatively small gains could bring about hard losses and, possibly, critical or fatal consequences. For example, without simple precautionary measures, a sexual encounter could subsequently produce unexpected diseases; not wearing a helmet may produce serious accidents at work; and an unnecessarily fast driving speed could have fatal consequences. In any case, risk attitudes reflect the weight people give to both risks and benefits in any situation (Figner & Weber, 2011) and it is widely assumed that rational processing almost never underlies most of our daily risk decisions. Therefore, the new models of risky decision-making are based on the existence of a dual processing system (Epstein, 1994; Evans, 2008; Loewenstein et al., 2001; Slovic et al., 2007; Sanfey & Chang, 2008).

According to these dual models, decision-making may come from a controlled-processing system that is assumed to be more conscious and deliberative, requiring more attentional resources and based upon statistical or rational rules, and thus serial and slower in nature. On the other hand, risky decisions are almost always supported by the automatic-processing system that is more irrational and rapid, being influenced by emotional or experiential factors and based on “affect and cognitive heuristics” and personality traits (Slovic et al., 2007).

Research has focused on demonstrating the existence of “affective heuristics” by showing the impact of emotional and contextual factors on either risk perceptions or decisions (Damasio, 2004; Slovic et al., 2007). However, in complex risky situations such as those where the losses far exceed the benefits (i.e. sexual, working, or driving contexts), in addition to emotional factors, it also seems important to look at the effect of previous experience, as well as other factors such as feedback, in order to build safer "cognitive heuristics" that could modify the tendencies to make risky-decisions whilst increasing the likelihood of safer behaviors. Accordingly, the main aim of this work was to analyze how the development of heuristics by the use of a correct feedback or by previous experience with similar tasks could help to avoid risk and develop safer response rules or habits in complex risky contexts such as driving.

It is important to keep in mind that the choice to adopt either a risky or safe behavior in a risky situation always involves a decision-making process. From this perspective, rational decision-making models propose the existence of at least three basic serial components: a) evaluation of the behavioral alternatives, b) the choice of the action, probably based on the previous evaluation, and c) the subsequent evaluation of the consequences of our action (e.g., feedback), which should modulate our future behavior in similar situations (Rangel et al., 2008, among others).

According to these rational models of decision-making, choosing to make a risky or safe decision in a complex situation such as driving should be based on the prior and deliberate evaluation of various alternatives and possible consequences. Thus, risk evaluations should imply the need to integrate information about contextual cues, as well as other cognitive or emotional factors, requiring time and effortful resources to be able to make the safer decision. However, drivers' decisions are usually made under time pressure and strong emotional load, due to the possible negative and important consequences of the final decision. In this way, previous research has demonstrated how risk evaluation differs from urgent risk decisions (Megías, et al., 2011a), and these could even imply different neural circuits (Megías et al., 2016).

In order to explain such dissociations, dual processing models propose the existence of a controlled-rational system and an automatic affective-experiential system (Evans, 2008; Loewenstein et al., 2001; Sanfey & Chang, 2008) that underlie the process of decision-making in risky situations. According to this assumption, it is possible that evaluations and decisions may come from each one of the two different processing systems such that evaluations could be more strongly linked to the rational controlled system, whereas decisions may depend more on the affective-experiential automatic system.

In the study of risky decision making, previous research has focused more on the influence of “emotional” factors, assuming the existence of an “affective heuristic” that can explain risk perception and decisions (Slovic et al., 2007). However, in complex dangerous situations, such as driving, the emotional-experiential system also implies the previous existence of “cognitive heuristics” primarily developed by the influence of previous feedback and learning after similar experiences. For the learning of safer behaviors, feedback has proved to be a useful technique for improving performance on many different tasks and facilitating changes in our daily behavior, including safe driving (for reviews, see Kluger & De Nisi, 1996; Smither et al., 2005; Torres et al., 2017).

Feng and Donmez (2013) have proposed a model of the effectiveness of feedback on driving contexts, based on three loops that could be applied to other contexts. A first attentional loop appears to be more strongly related to feedback provided during the task. Accordingly, salient signals may enhance a safer response, avoiding unnoticed or unattended risks (Scott & Gray, 2008). The second loop comes from an introspective cognitive process that occurs after the task. A driver may make the decision to avoid speeding in the future if he/she was to nearly have a fatal accident while driving. Finally, a third more important and cognitive oriented loop concerns the effect of feedback after the task is completed. It is assumed that the stronger the feedback, the stronger the effect of changing future behavior by the development of new habits or rules which will be helpful for making future decisions in similar situations. According to this assumption, the type and content of reinforcement, among other factors (such as type of penalties during driving or working), may have a strong influence on future decisions (Kluger & DeNisi, 1996; Maldonado et al., 2016).

From this perspective and looking at the effect of this third loop, the current study set out to examine firstly the effect of feedback upon the development of cognitive rules or heuristics for increasing the likelihood of making safer decisions in risky driving situations. The main assumptions were that feedback should give rise to a change in the process of decision-making, based on changes in the automatic processing system, enhancing attentional resources, increasing the response threshold level, and building new habits and rules (heuristics) for future safer behavior.

However, changes in automatic processing also depend on prior experience with similar tasks. Accordingly, safe driving requires training in different risk situations, and the acquisition of cognitive abilities such as visual search patterns, hazard perception, and control skills, among other factors (Lehtonen et al., 2014; Megías et al., 2012; Sagberg, & Bjørnskau, 2006). These skills are usually acquired through learning and prior experience, and they introduce permanent structural and functional brain changes that give rise to new and safer automatic processing in these situations (Megías et al., 2017; Sagi et al., 2012). From this perspective, the aim of the second experiment of this study was to show the influence of previous experience with similar tasks on promoting safer behaviors, assuming the existence of "cognitive heuristics" that constitute a main part of the automatic processing implied in the development of any expert mental model.

In sum, the aims of this research were twofold. The first objective was to analyze the effect of feedback on evaluative and decision-making processes in dangerous and harmless contexts by the use of contingent and non-contingent negative feedback on risky behavior (Experiment 1a). The second objective was to demonstrate the influence of previous experience on the decision-making process (i.e. evaluation, final decisions, and feedback) in drivers (implying long and supervised training) and participants without any driving license, and therefore without any previous driving experience (Experiment 1b).

### 3.2. Experiment 1a

In the study of feedback effects, one way to analyze the cognitive processes involved in animal and human learning -particularly attentional resources, cognitive associative learning and behavioral factors - is the use of non-contingent feedback. Previous research on animal and human learning has revealed how prior experience of the non-contingency between cues and its consequences (learned irrelevance effects, see Baker & Mackintosh, 1977, Maldonado et al., 1999, among others) or between the own responses and their effects (learned helplessness, see Maier & Seligman, 1975, Maldonado et al., 1991, among many others) produce different cognitive and motivational deficits and a subsequent impairment in associative learning. In a similar vein, a previous studying driving (Torres et al., 2017) demonstrated how non-contingent feedback led to riskier behavior, whilst contingent feedback produced quite the opposite effect, that is, more conservative and probably safer behavior.

Therefore, our first study aimed to examine the influence of contingent and non-contingent aversive feedback upon risky behaviors in both risk evaluations and decisions, analyzing separately the influence of these types of feedback in both risky and safe situations. According to previous results (Megías et al., 2011a), we firstly expected to find that decisions under risk should be faster and safer than risk evaluations, as they may depend more upon the "automatic processing system" as a function of previously learned heuristics in similar situations while driving. Secondly, contingent feedback upon risky behaviors should have a strongly influence the likelihood of making safer decisions, whereas non-contingent feedback should lead to riskier decision-making. However, when analyzing separately the risky and safe contexts, we anticipated there to be a stronger influence of feedback in the riskier situations in comparison with the safer situations. Finally, by using signal detection theory, we evaluated whether the effects of feedback are more related to response bias than to discriminative factors, given the strong influence of feedback on the "threshold level" of decisions proposed earlier (Maldonado et al., 2016; Torres et al., 2017; Simen et al., 2009).

**Method**

Participants

Seventy-seven participants from the University of Granada voluntarily took part in this study (mean age: 20.3 years; range: 18-25; 44 women and 31 men). All participants possessed a legal driving license and had normal or corrected-to-normal vision. They signed an informed consent form and were treated in accordance with the

Helsinki declaration (World Medical Association, 2008).The research was also approved by the “ethics committee” of the University, as part of a large project granted by the I+D+I Spanish MEIC national agency. Participants were randomly assigned to one of three groups: a control group without any feedback (CONT, n=28), a contingent feedback group (CF, n=27), and a non-contingent feedback group (NCF, n=22).

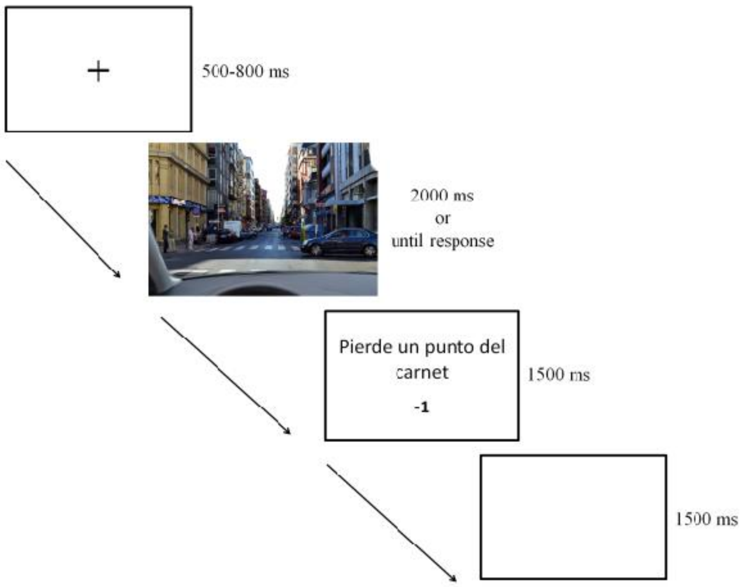
Stimuli

One hundred and twenty pictures showing traffic situations from the driver´s perspective were used in the study. The pictures were selected from an extensive image database of traffic situations taken on Spanish and Finnish roads. The 120 selected situations met a set of statistical criteria in order to reduce the interpersonal variability in the interpretation of the traffic situation. To this end, 40 driving instructors had previously evaluated the pictures. They selected only those pictures with a standard deviation of speed perception lower than 25% of the average, and where the best option to avoid the hazard was always to brake for at least 70% of the driving instructors. In addition, 40 volunteers with a driving license evaluated the pictures in relation to the perceived risk level. Sixty of the selected pictures had a medium risk level (average risk = 4.56 [0: no risk; 7: high risk]) and the other sixty showed no risk (average risk = 1.65). The images were displayed on a 14-inch monitor, with the resolution set to 1024x768.

Procedure

In this experiment, each participant completed two consecutive tasks: evaluation and decision. Each task was divided into two blocks of 120 trials (the pictures were the same in both blocks and tasks) and sixty risk and sixty no-risk images were displayed in each block. The order of presentation of the trials was always randomized and the tasks counterbalanced among participants.

Each trial began with a fixation cross with a variable time interval (between 500 and 800 ms). The picture with the traffic scenario was then displayed and remained on the screen until the participant responded or until 2000 ms had elapsed (see Figure 1).


500-800 ms
2000 ms
or
until response
Pierde un punto del
carnet
-1
1500 ms
1500 ms

before starting the next trial. The whole experiment lasted approximately 50 minutes, with 25 minutes for each task.

Design and analysis

The mean reaction times and the probability of a positive response (i.e. evaluating risk or braking) for risky and non-risky situations were submitted to separate 3 (Group: control, contingent feedback, and non-contingent feedback) x 2 (Task: evaluation and decision) mixed repeated measures ANOVAs with Group as between-subjects factor and Task as a within-subjects variable. The gender of the participants was included as a covariate to control for possible differences.

Finally, Signal Detection Theory was used to calculate response bias (c) and sensitivity (d') scores (Macmillan & Creelman, 2005). Risk situations were taken as the signal to be discriminated from noise (no-risk situations), and the brake and no brake responses were treated as the "yes" and "no" responses in standard yes/no signal detection applications. Signal detection indices (response bias and sensitivity) were also submitted to 3 (Groups) x 2 (Task) mixed repeated measures ANOVAs. An alpha level of 0.05 was set for all analyses.

**Results and discussion**

Prior to conducting the ANOVAs, Kolmogorov-Smirnov and Levene's tests verified the normality of the distribution and homogeneity of the variances of all dependent variables (all *p*'s > .05). We present the results of the ANOVA conducted on both the reaction times and probability of positive response separately for risky and non-risky situations. Finally, the ANOVA results for response bias (c) and sensitivity (d') scores according to the Signal Detection Theory are presented.

1. Risky situations.

Firstly, with respect to reaction times (Table 1), the results of the 3 (Groups) x 2 (Task) ANOVA, yielded only a main effect of Group, $F(2, 74) = 4.59$, $MSE = 45242.49$, $p < .01$, and Task, $F(1, 74) = 7.81$, $MSE = 10470.30$, $p < .01$. These results showed how decisions were faster than evaluations in all groups. Follow up analyses on the main effect of Group revealed that responses took significantly less time in both the contingent and non-contingent groups than in the control group (*p*<.01).

Secondly, the results of the 3 (Group) x 2 (Task) ANOVA on positive responses (braking or estimated risk) probability (Table 1) also revealed a main effect of Group, F(2, 74) = 26.63, MSE = 0.04, *p*< .01; but now, the Group x Task interaction was also significant, F(2, 74)=3.89, MSE=0.02, *p*= .02. Subsequent analyses of the interaction showed firstly that non-contingent feedback gave rise to a lower probability of positive responses both on evaluations and decisions in comparison with the other two groups (all *p*< .01). However, the contingent feedback group significantly differed from the control group (*p*< .01) in evaluations, but not in decisions.

| **Context** | **RISK** | | **NO-RISK** | |
|---|---|---|---|---|
| **Groups** | **Decision** | **Evaluation** | **Decision** | **Evaluation** |
| | **Reaction times: Mean** (SD) | | | |
| **CONT.** | **842** (100) | **881** (139) | **799** (99) | **866** (142) |
| **C-FEED.** | **728** (168) | **778** (125) | **725** (156) | **844** (146) |
| **NC-FEED.** | **729** (200) | **780** (254) | **657** (173) | **731** (246) |
| | **Response Probability: Mean** (SD) | | | |
| **CONT.** | **0.73** (0.14) | **0.68** (0.18) | **0.13** (0.08) | **0.15** (0.10) |
| **C-FEED.** | **0.75** (0.19) | **0.82** (0.18) | **0.57** (0.32) | **0.42** (0.24) |
| **NC-FEED.** | **0.53** (0.20) | **0.45** (0.16) | **0.16** (0.20) | **0.17** (0.24) |

*Table 1. Reaction time and probability of response*

These results are in accord with previous findings. The dissociation between risk evaluations and decisions suggests that decisions may rely more on faster "experiential-emotional" automatic processing, whereas evaluations may be more strongly related to slower, rational-controlled processing (Megías et al., 2011a). Moreover, these findings confirmed how previous experience with a correct feedback may produce even faster and safer responses in both evaluations and decisions(Evans, 2008; Loewenstein et al., 2001; Sanfey & Chang, 2008), whilst they also showed the detrimental effect of non-contingent feedback, which made the responses -particularly decisions - faster but riskier (Torres et al., 2017).

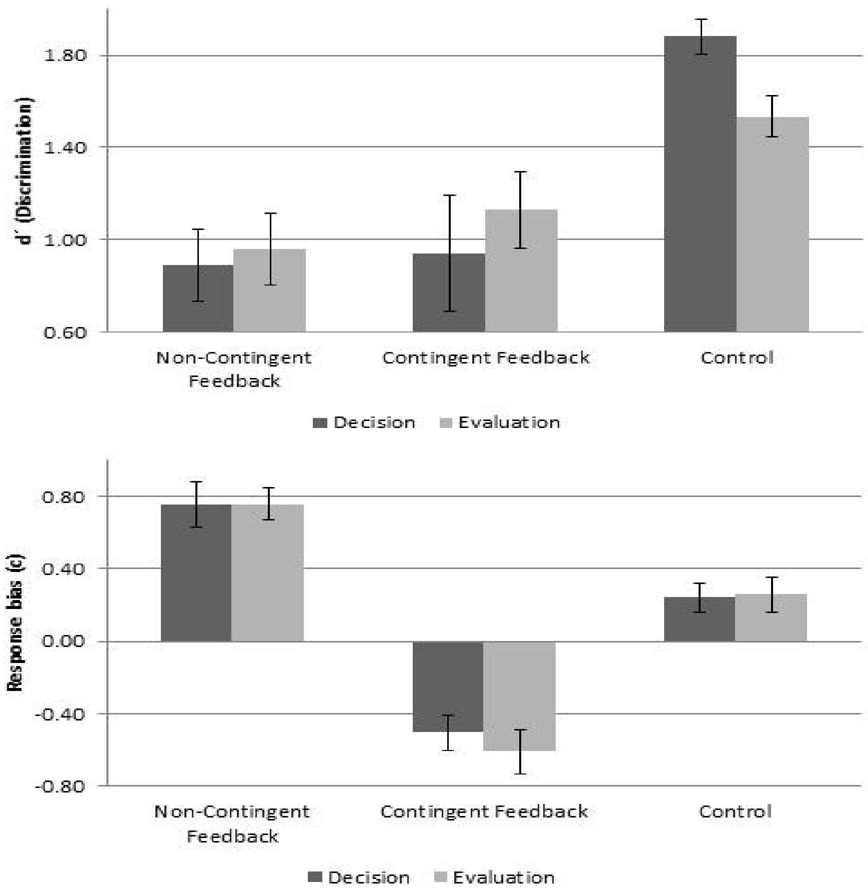
2. Non-risky situations.

Firstly, the 3 x 2 ANOVA conducted on reaction times (Table 1) yielded again a main effect of Group, $F(2, 72)=5.35$, $MSE=44477.85$, $p<.01$, and Task, $F(1, 72)=34.56$, $MSE=8228.62$, $p< .0001$. As previously found, decisions were faster than evaluations in all groups ($p<.05$) and in this case only the non-contingent group differed from the two other groups, being faster both on decisions and evaluations of risk ($p<.05$).

Secondly, the 3 x 2 ANOVA conducted on the probability of a positive (braking or estimated risk) response (Table 1), yielded a main effect of Group, $F(1, 74) = 38.94$, $MSE=0.03$, $p< .001$, and the interaction Group x Task, $F(1, 74) = 3.83$, $MSE = 0.03$, $p<.03$. However, the pattern of the results was very different from that found in the risky situations. The contingent feedback gave rise to a higher number of inaccurate positive responses on both evaluations and decisions compared with the other two groups, and risk decisions (braking) were significantly higher than risk evaluations in the contingent feedback group. However, the non-contingent feedback and control groups did not differ between them, and their responses rather accurately reflected the absence of risk in these situations. These findings are particularly interesting, given boththeir novelty and the fact that they confirm the influence of feedback upon both risky and safe decisions made in complex situations. This issue will be taken up later in the discussion.

3º Signal Detection Theory analysis

In order to achieve a better understanding of the previous results, and in an attempt to discriminate between the possible existence of discriminative factors and/or a response bias underlying the effects of feedback upon the process of risk evaluations and decision-making, a signal detection analysis was conducted, as explained above.



d' (Discrimination)
1.80
1.40
1.00
0.60
Non-Contingent Feedback
Contingent Feedback
Control
Decision
Evaluation
Response bias (c)
0.80
0.40
0.00
-0.40
-0.80
Non-Contingent Feedback
Contingent Feedback
Control
Decision
Evaluation

of results i.e. a positive bias, giving rise to a riskier style of response in the dangerous situations, as indicated by the results for the probability of response in both situations (see Table 1).

Overall, our results point to the asymmetrical influence of feedback contingency on the process of decision making in risky and non-risky situations, and they suggest how making a risky or safe decision in dangerous and harmless situations may depend more on automatic processing, which is faster and independent of previous risk evaluations. Therefore, the next step in the study of the influence of the "experiential automatic processing system" during the process of decision-making under risk will be to explore the influence of previous experience with similar tasks in developing safer heuristics.

**3.3. Experiment 1b**

In the first experiment, all participants had a driving license. The aim of this experiment was to study how this previous driving experience influences evaluations and decision-making in risky and non-risky situations. It is important to acknowledge that in complex contexts, such as driving or finance, the accuracy of both evaluations and decisions depends on previous experience and learning with similar tasks. As previously mentioned in the introduction section, optimal driving requires the acquisition of a set of skills (attentional and visual search patterns, hazard perception skills, etc.; Megías et al., 2017; Sagberg & Bjørnskau, 2006) and the automation of behaviors that lead to the development of habits and cognitive heuristics aimed at producing fast and appropriate decision-making (Sagi et al., 2012) in complex situations. Thus, modulation of driving behavior (e.g. through feedback) should depend to a large extent on previous driving experience.

The experiment consisted of two groups of participants (with and without driving experience). Half of the participants in each group performed a task without any feedback (control group) and the other half received negative contingent feedback (Group CF). Focusing on the control groups, we analyze how a driving license, which implies previous learning experiences, influences both risk evaluation and decision making. We hypothesize that the behavior of drivers should be more appropriate than that of non-drivers when both evaluating risk, and (particularly) when making safer decisions.

In a second step, we studied the effect of negative contingent feedback on both groups of participants: drivers and non-drivers. Our hypothesis assumes that the impact of feedback must be greater on non-drivers than on drivers, since their mental model of driving is weaker and they have not yet acquired the necessary automated skills and behaviors. The behavior of drivers should be guided by a previously-learned mental model, whilst feedback should act as the main guide in participants who lack such prior experience (non-drivers). Finally, as in Experiment 1, we conducted separate analyses for the risk and non-risk situations in order to explore whether there are differences in the effects of experience and feedback between each type of driving situation.

**Method**

Participants, Stimuli, and Procedure

One hundred participants from the University of Granada - half with and half without a driving license -voluntarily participated in this study (mean age: 20.6 years; range: 18-25; 71 women and 29 men). The driving participants were the same as those used in the previous experiment (the contingent feedback group of Experiment 1A), whereas the non-driving participants were new to the experiment. Stimuli and procedures were similar to those used in the first experiment.

Accordingly, the design of the experiment was a 2 (Driving license: with and without groups) x 2 (Feedback: experimental feedback and control groups) x 2 (Task: Evaluation and Decision groups) mixed repeated measures with Driving license and Feedback as between- group factors and Task as the within-subjects variable. Again, the gender of the participants was included as a covariate to control for any possible differences. As in the previous experiment, the mean reaction times and the probability of a positive response were submitted to separate mixed repeated measures ANOVAs for the risky and non-risky situations. An alpha level of 0.05 was set for all analyses.

**Results and discussion**

Before conducting the ANOVAs, Kolmogorov-Smirnov and Levene's tests were used to verify the normality of the distribution and homogeneity of the variances of all dependent variables (all *p*'s > .05). Subsequently, the two 2 (Driving license) x 2 (Feedback) x 2(Task) ANOVAs were conducted for both the risky and the non-risky situations to demonstrate the effect of previous experience and feedback on the process of decision-making in both types of situations.

1. Risky situations.

In risky situations, the 2 (Feedback) x 2 (Driving license) x 2 (Task) ANOVA conducted on the reaction times revealed only a main effect of Feedback, F(1,99) =27.05, MSE= 27272.83, *p*< .001, and of Task, F(1,99)=13.31, MSE= 9654.46, *p*< .001. The effect of having a driving license or not, along with any possible interactions with the other factors were far from significant (all *p*> .05). Therefore, the only significant effects were due to the fact that feedback gives rise to faster responses, and decisions being made faster in all conditions. These effects further replicated previous findings (see Table 2).

The main and novel results emerged from the analysis of the probability of positive responses (Table 2). The 2x2x2 ANOVA again revealed a main effect of feedback, F(1, 99)= 29.35, MSE= 0.04, *p*< .001. In this case, a main effect of Driving license, F(1,99) = 6.46, MSE= 0.04, *p*< .01 and the interactions between Feedback and Driving license, F(1,99) =5.55, MSE= 0.04, *p*< .02; and Feedback and Task, F(1,99)= 5.40, MSE= 0.02, *p*< .02, were also significant. Moreover, the interaction between Driving license and task was also marginally significant, F(1, 97) = 3.38, MSE= 0.02, *p*= .07.

In order to address our previous hypotheses and to clarify the previous interactions, a subsequent 2 (Driving license) x 2 (Tasks) ANOVA conducted only on the control group data yielded a main effect of Driving license, F(1,49) = 9.56, MSE =

0.05,*p*< .01, and Task, F(1,49) = 9.56, MSE = 0.01,*p*< .01). However, the same analysis in the feedback group did not show any significant effect (all *p* = .12), because the feedback experience tended to remove any effect of having a Driving license.

These results emphasize how previous learning with similar tasks improves the performance in new tasks, particularly in decisions, as a product of a more "experiential-automatic processing". In contrast, contingent feedback abolished any effect of driving license and task and all participants made a similar faster and higher number of responses both in evaluations and decisions under risk in comparison with the control groups.

| **Context** | **RISK** | | **NO-RISK** | |
|---|---|---|---|---|
| **Groups** | **Decision** | **Evaluation** | **Decision** | **Evaluation** |
| | | **Reaction time: Mean** (SD) | | |
| **CONT-DL** | **842** (100) | **881** (139) | **799** (99) | **866** (142) |
| **CONT-WDL** | **882** (143) | **905** (130) | **793** (116) | **838** (115) |
| **FEED-DL** | **728** (168) | **778** (125) | **725** (156) | **844** (146) |
| **FEED-WDL** | **717** (136) | **806** (139) | **685** (150) | **805** (161) |
| | | **Prob (Resp): Mean** (SD) | | |
| **CONT-DL** | **0.73** (0.14) | **0.68** (0.18) | **0.13** (0.08) | **0.15** (0.10) |
| **CONT-WDL** | **0.62** (0.19) | **0.54** (0.17) | **0.12** (0.10) | **0.13** (0.12) |
| **FEED-DL** | **0.75** (0.19) | **0.82** (0.18) | **0.7** (0.32) | **0.42** (0.24) |
| **FEED-WDL** | **0.80** (0.13) | **0.77** (0.10) | **0.58** (0.41) | **0.34** (0.26) |

*Table 2. Reaction time and probability of response*

2. Non-risky situations.

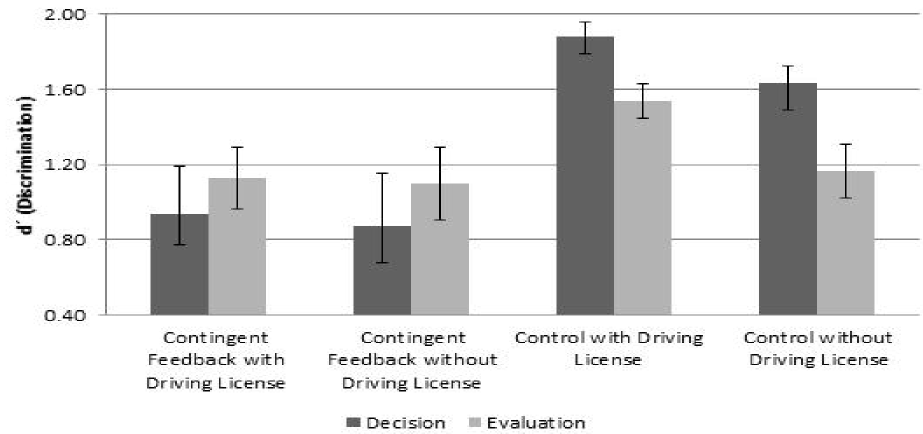
The 2x2x2 ANOVA conducted on the reaction times (Table 2) yielded in this case an effect of Feedback, F(1, 99)= 6.06, MSE=29894.74, *p*< .02, and Task, F(1, 99)= 49.52, MSE= 7960.82, *p*< .001, along with the interaction between these factors, F(1, 99)= 6.44, MSE=7960.82,*p*< .01; because feedback made decisions faster for both drivers and non-drivers. As in risky situations, neither the main effect nor any of the interactions of the Driving license factor were significant (all *p*> .05).

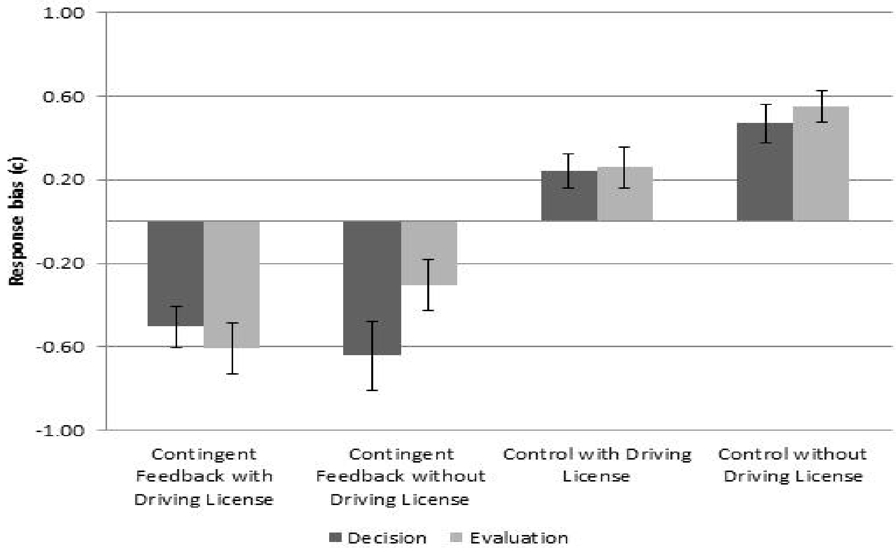
As in the previous experiment, the most interesting results emerged from the analysis of response probability (Table 2). The 2x2x2 ANOVA yielded only a main effect of Feedback, F(1, 99) = 79.98, MSE=0.08, *p*< .001, and Task, F(1, 99) = 12.86, MSE=0.03,*p*< .0001, as well as the interaction between these factors, F(1, 99) = 16.18, MSE=0.03,*p*< .0001. As in the case of reaction times, neither the main effect nor any of the interactions of the Driving license factor reached significance (all *p*> .05).

Further analysis of the Feedback x Task interaction showed how contingent feedback gives rise to a higher number of positive responses in both tasks, but particularly in decisions, making both drivers and non-drivers overestimate the risk of these situations. However, the control participants' behavior was similar in both tasks, beingsomewhat accurate in reflecting the actual probability of risk in these situations. It is important to note that, unlike the case of dangerous situations, driving license had no effect at all when there was low or no risk

3º Signal Detection Theory analysis

As in Experiment 1a, to better understand these results, a signal detection analysis was performed. The 2x2x2 ANOVA conducted on the sensitivity (d´, see Figure 3, upper panel) yielded a significant main effect of Feedback, F(1, 99) = 13.14, MSE=1.15, *p*< .001, and its interaction with Task, F(1, 99)=10.74, MSE=0.45, *p*< .001. Further analysis of this interaction showed that previous training with feedback gives rise to poor discrimination, but only for decisions. However, in order to address our previous hypotheses and to examine the differences between drivers and non-drivers in the control groups, a 2 (Driver license) x 2 (ask) ANOVA revealed a clear significant effect of both factors, F(1,49) = 7.29, MSE = 0.34,*p*< .01, and Task, F(1,49) = 23.81, MSE = 0.18, p< .001), but no interaction between these factors (*p*> .05). No significant effects were found in the feedback group, (all *p*> .05).


2.00
1.60
1.20
0.80
0.40
d' (Discrimination)
Contingent Feedback with Driving License
Contingent Feedback without Driving License
Control with Driving License
Control without Driving License
Decision
Evaluation


1.00
0.60
0.20
-0.20
-0.60
-1.00
Response bias (c)
Contingent Feedback with Driving License
Contingent Feedback without Driving License
Control with Driving License
Control without Driving License
Decision
Evaluation

These latter results highlight the most important findings of this study and confirm all the previous results, as we will analyze next in the discussion section. Our findings clearly point to the possibility that feedback experience tends to produce changes in the "response threshold", which could explain the poorer discrimination between dangerous and harmless situations.

### 3.4. General discussion

The main findings of this research come from the emergence of two different dissociations: firstly, between evaluations and decisions; and secondly, between the asymmetrical influence of contingent and non-contingent feedback on the behavioral pattern observed in dangerous and harmless complex situations such as driving. Taken together, the results suggest the main influence of the automatic processing system in the process of risky and safe decision-making in such a complex situation and, at the same time, show the importance of previous experience and a correct feedback for the development of heuristics for generating safer responses.

Firstly, the results showed a clear difference between evaluations and decisions in risky situations. Decisions were usually faster and safer than the mere evaluations of risk. The speed of decisions, rather than evaluations, was improved by any feedback experience. However, the frequency of safer decision-making was enhanced in risky situations by both, contingent feedback and the previous experience acquired by holding a driving license. These results support and confirm previous findings (Maldonado et al., 2015; Megías et al., 2011a), and they suggest how evaluations may be related to the slower and less precise rational-controlled system, whereas decisions may rely more on faster and more accurate "experiential-emotional" automatic processing, possibly by the use of associative rules, habits or "cognitive heuristics" that are developed through previous training.

Secondly, the results also showed an asymmetrical influence of feedback contingency both on decisions and evaluations in risky and non-risky contexts. In dangerous situations, contingent feedback led to faster and more accurate responses than control groups that received no feedback, whereas non-contingent feedback led to the opposite behavioral pattern: faster, but riskier responses, again confirming previous findings (Evans, 2008; Loewenstein et al, 2001; Sanfey & Chang, 2008; Torres et al., 2017). Moreover, in such risky situations, learning with a correct feedback abolishes any differences between decisions and evaluations, and even between the responses of drivers and non-drivers.

The more novel findings emerge from the behavioral effects found in harmless situations. In this case, it is important to acknowledge how both the non-contingent and the control groups were able to accurately estimate the absence of risk in these harmless situations. However, the previous experience of negative contingent feedback upon risky responses in dangerous situations led these participants to overreact in harmless contexts, giving rise to faster and a greater number of risk evaluations and inaccurate decisions (braking responses), which could endanger other drivers who are unaware and unprepared for these wrong and fast decisions. These results could serve to clarify the influence of feedback upon both risky and safe decision-making in complex situations, and how the final decisions depend more on the automatic processing system, which is faster but more difficult to modify.

Finally, the results obtained by the use of signal detection theory may help to shed more light on the previous results. First, these analyses tend to confirm how drivers, as a function of previous experience with similar tasks, were able to discriminate more accurately than non-drivers between dangerous and safe scenarios. Discrimination was better due to the higher number of safer decisions in risky situations, even though decision-making was faster than evaluations, probably due to its automatic component. At the same time, drivers showed almost no response bias, whereas non-drivers showed a slight positive bias, giving rise to a significantly riskier performance only in the dangerous situations.

Second and more importantly, discrimination was similarly worse regarding the control group, particularly in decisions, as a consequence of both the contingent and non-contingent feedback experiences. However, the response bias clearly discriminates between them, explaining all previous results. Non-contingent feedback led to a positive bias, giving rise to faster and riskier reactions, but only in the dangerous situations. On the other hand, the experience of a negative contingent feedback led both drivers and no-drivers toward a significant negative response bias. This last effect comes from a safer performance in dangerous contexts, but also from a rather inaccurate and more conservative response in harmless situations, which could endanger the other drivers that are unaware of this unpredictable behavior.

From a theoretical perspective, the first dissociation between decisions and evaluations in risky situations has been discussed in earlier studies (Megías et al., 2011a, 2015). Overall, our results are in accord with the notion than decisions do not only depend on previous risk evaluations, since they were generally faster and positive responses in decisions (to brake)were more frequent than in evaluations (to evaluate risk), suggesting that they are based upon the “automatic processing system”. Regarding the asymmetrical feedback effects, it is worth noting how in risky situations, both the contingent and non-contingent feedback lead to faster decisions and evaluations in comparison with the control group, but to a safer behavioral pattern in the first case and to take more risks in the second. These findings further suggest a main role for the automatic processing system, particularly in decision-making. This assumption becomes more evident from our new results in harmless situations, in which we found an increased speed and particularly a high frequency of wrong decisions in such situations, due to the previous contingent feedback on the riskier responses made in dangerous situations.

Further, the results obtained in the analysis based upon signal detection theory provide a possible response explanation of the previous findings. The asymmetrical influence of feedback contingency does not seem to be related to a “discrimination” effect, with both groups being similarly biased, but instead could be due to the opposite effect based on “response bias”. This proposal accords with the assumption that the effect of feedback on the process of decision-making appears to be involved with the "threshold level" that the individual uses for perception and behavioral choice (Simen et al., 2009).

Accordingly, non-contingent feedback may weaken the response “threshold” producing a rather unsafe behavior in risky contexts. However, contingent feedback should produce a “threshold” enhancement, giving rise not only to faster responses, but also to a particularly lower level of risk tolerance in the final decisions, which is likely to translate to a safer behavior in risky contexts (Feng & Donmez, 2013; Maldonado et al, 2015). Unfortunately, this bias can also cause overreactions in contexts in which there is very low or no danger. These assumptions imply the learning of “riskier or safer rules of decision making” involved in a “mental model” based upon the “automatic (unconscious and faster, but also difficult to change) processing system”, rather than the controlled system. Finally, the influence of such an acquired “mental model” on automatic processing, particularly when making decisions, appears to be compatible with the faster and safer decision-making of drivers, due to previous experience with similar tasks, as shown by the differences found between drivers and non-drivers in risky situations.

The cognitive mechanisms underlying such acquired “cognitive heuristics” (rules or habits involved in a “mental model”) and their influence on the automatic processing system of risk evaluations and decisions in dangerous and safe contexts, seem to be more related to the previously described third “cognitive” loop proposed by the Feng & Donmez model (2013), which concerns the influence of feedback on more accurate decision-making in driving. However, whether these mechanisms depend more on perceptual, attentional, or more cognitive and associative (rules or habits) factors remains an open question for future research. Moreover, it is worth acknowledging some limitations of the present research. First, it may be necessary to use a wider sample that covers a range of variables such as age and experience, which have been shown to have an influence on the process of decision-making in driving. In addition, the use of a simulated task in a driving context also reduces its generalizability and it will be necessary to confirm these findings in more ecological settings.

From an applied point of view, in order to give an adequate answer to the question of how to promote safer behavior, it seems important to know what happens when people are forced to deal with a risky situation, such as the case in which a driver arrives at a dangerous intersection with a possible stop or traffic light, a pedestrian is crossing the driveway, or another vehicle makes a dangerous or unexpected move.

Clearly, in these cases, any driver should stop paying attention to anything else that they could be doing (talking to someone, thinking about other things, listening to music, etc.) in order to focus on the risk context and carry out the safest possible behavior in that specific situation.

From this perspective, we should assume two different effects. First, the appearance and perception of a dangerous situation implies the interruption of the relatively automatic processing of driving and an increased demand on attentional resources directed toward the risks of the new scenario. Second, it is obvious that the decision should be faster and safer when the individual is well prepared and experienced in this activity. Therefore, the decision-making process in these situations could be influenced by experience with similar tasks and previous feedback, as shown in the present research, as well as other variables such as drug consumption, emotional state, and age, which can severely limit our abilities of perception and decision-making, as shown in previous work (Begg & Langley, 2001; Donmez et al., 2006; Gulliver & Begg, 2007; Megías et al., 2011b; Owsley, 1994).

Accordingly, it is important to acknowledge that the process of risk decision-making is a complex concept that needs an improved experimental and theoretical approach. Unlike simpler risky choices (games or lotteries), the behavior that occurs in manyof our risky everyday situations involves a number of different factors. As in the case of accurate investing (see Alos et al., 2014), accurate driving implies the previous learning of safer decision-making in various risky scenarios, which depends on the acquisition of higher-order cognitive and decision-making skills, such as visual search, hazard recognition, safety motives, attentional processes, and vehicle handling control among other skills (Lehtonen et al., 2014; Megías et al., 2017; Sagberg & Bjørnskau, 2006). These cognitive skills are acquired by learning and experience, since they require practice and on-road experience, which should develop “automatic processing skills” (Sagi et al., 2012). Therefore, unlike other automatic processes such as those thought to occur in games or the learning of simpler laboratory tasks, an experienced driver must develop increased abilities in perception, attention, and handling skills, which requires improved "mental models" and rules of safer driving (Bjørnskau & Sagberg, 2005).

From this perspective, when the possibility of losses is so important, as in many of the risk situations in our daily lives (sexual encounters, risky investments, working in dangerous places and so on), the individual should learn to make safer decisions. In this case, our results highlight how the effects of feedback, either by direct or vicarious experience, are the most important part of the process that determines risky or safe decision-making. In the case of driving, our results seem to indicate that negative contingent feedback such as points reductions and penalties for risky decisions, had a stronger influence on behavior than positive feedback such as awarding points for safe driving, either in real life (Izquierdo et al., 2011) or in experimental settings (Maldonado et al, 2015).

Finally, our results further highlight that whilst contingent negative feedback is a very effective tool for increasing the likelihood of making safer decisions, it must be given with care to avoid any non-contingent perception, which could lead to quite the opposite result i.e. a riskier and faster response due to its automatic and unconscious component. Moreover, even contingent feedback may have unwanted side effects. In particular, the impact of previous negative feedback seems to be so strong that it also produces an over-reaction, even in "non-risky" contexts. In the case of driving, it leads to an over-evaluation of the possible danger, and, more importantly, to an over-reaction in the presence of minimal threats, which can be the cause of "rear-end accidents" due to the unaware reactions of the other drivers. The knowledge of these effects highlights the importance of preventive measures such as keeping a safe distance between drivers, learning to take into account the possible decisions of other drivers, and appropriate education based on correct feedback.

## 3.5. Conclusion

Taken together, the results of this research have confirmed, firstly, how prior experience with similar tasks led drivers to make more accurate (better discrimination and almost no response bias) and faster and safer styles of decision-making in risky situations. However, non-driving participants showed poor discrimination and a positive response bias, since they showed less accurate evaluations of risk and above all, more risky decisions in dangerous situations.  A similar behavioral pattern emerges as a consequence of non-contingent feedback, since this kind of experience produced poor discrimination and a more positive response bias, giving rise to riskier responses in dangerous situations. Finally, our findings point to the somewhat different influence of contingent negative feedback upon risky behaviors in risk and safe situations, as a result of poor discrimination and a negative response bias. In the dangerous contexts, this kind of experience gives rise to a more accurate evaluation of risk and a safer style of responses. However, in the harmless situations, it leads to rather inaccurate performance, poor evaluation, and faster and more frequent inappropriate conservative decisions, which could endanger the life of the other drivers. All of these findings highlight the necessity for correct education designed to promote safer decision-making in many different contexts, including driving.

The theoretical importance of these findings points to the main influence of the “experiential automatic processing system”, when people make decisions in complex and dangerous situations. This system requires the previous learning of “rules or habits”, becoming part of any “expert mental model” and is primarily affected by the feedback received during these previous experiences. Feedback also appears to be related to the “threshold level” that people use to make decisions in any situation, either making it narrow, when it is contingent, or wider, as in the case of non-contingent feedback, and is likely to be linked to other factors such as inexperience, drug consumption.  In any case, these changes appear to be more strongly related to the third “cognitive” loop proposed by the Feng & Donmez model (2013) to explain the influence of feedback on the decision-making process while driving. Finally, whether the cognitive mechanism depends more on attentional or associative processes (mental rules, habits, and so on) or both, remains a question that is open to further investigation.

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# CAPÍTULO 4: INDICADORES CEREBRALES DE LA MODIFICACIÓN DEL COMPORTAMIENTO DE RIESGO INDUCIDOS POR LA CONTINGENCIA DEL FEEDBACK

Megías, A., Torres, M. A., Catena, A., Cándido, A., & Maldonado, A. (2018). Electrophysiological brain indices of risk behavior modification induced by contingent feedback. *International Journal of Psychophysiology*.

Abstract

The main aim of this research was to study the effects of response feedback on risk behavior and the neural and cognitive mechanisms involved, as a function of the feedback contingency. Sixty drivers were randomly assigned to one of three feedback groups: contingent, non-contingent and no feedback. The participants' task consisted of braking or not when confronted with a set of risky driving situations, while their electroencephalographic activity was continuously recorded. We observed that contingent feedback, as opposed to non-contingent feedback, promoted changes in the response bias towards safer decisions. This behavioral modification implied a higher demand on cognitive control, reflected in a larger amplitude of the N400 component. Moreover, the contingent feedback, being predictable and entailing more informative value, gave rise to smaller SPN and larger FRN scores when compared with non-contingent feedback. Taken together, these findings provide a new and complex insight into the neurophysiological basis of the influence of feedback contingency on the processing of decision-making under risk. We suggest that response feedback, when contingent upon the risky behavior, appears to improve the functionality of the brain mechanisms involved in decision-making and can be a powerful tool for reducing the tendency to choose risky options in risk-prone individuals.

Keywords: Decision-making; Contingency; Risk behavior; EEG; Non-contingent; Driving.

## 4.1. Introduction

Adapting our behavior to the needs of the environment is crucial in our day to day lives. The success of our decisions partially depends on our ability to evaluate and learn from the consequences of our previous decisions. Decision-making models are mainly based on reinforcement learning, in which the selection of actions is guided by its consequences (Holroyd& Coles, 2002; Rangel, Camerer, & Montague, 2008). Accordingly, decisions that are contingently followed by rewards (positive feedback) are more likely to be repeated, whereas response punishment (negative feedback) will decrease the probability of these responses (Baker& Holroyd, 2011). Contingent feedback has been proved to be a valuable tool in facilitating behavioral changes in order to improve performance and encourage safer decision-making in many situations (Smither, London, & Reilly, 2005). However, in general, non-contingent feedback seems to be detrimental to decision-making, increasing risk-prone behaviors and negative moods (Maldonado, Catena, Cándido, & García, 1999; Torres, Megías, Catena, Cándido & Maldonado, 2017).The main aim of this research was to study the neural processes and cognitive mechanisms underlying changes in decision-making as a function of feedback contingency.

We focused on decision-making in risky environments. The use of feedback has special relevance in this context because our decisions can lead to material losses, injuries, or human casualties. Previous research has shown how contingent feedback may help learning and lead to safer decision-making (Maldonado, Serra, Catena, Cándido & Megías, 2016). For this reason, contingent feedback is widely used in clinical practice (e.g. surgery), transport (e.g., speed control or distractions), safety critical sectors (e.g. air traffic control or nuclear industry), and a large number of tasks where risk control is of great importance.

From the early days of associative learning theory, it has been well known that feedback must be applied contingently to behavior in order to achieve successful learning (Shanks, 2010). In the study of risky decision-making, it appears that contingent feedback modifies the individual‘s decision criterion (response bias) towards a greater perception of risk and risk-averse behaviors (Kluger & DeNisi, 1996; Maldonado et al., 2016). However, when feedback is applied in a non-contingent way, it can lead to the opposite effect. Torres et al. (2017), using a punishment point system in risky driving, have shown that the lack of contingency between the driver's responses and the negative feedback (punishment) leads to riskier and slower decision-making, even when performance is compared with actions not followed by any feedback at all.

At the brain level, many of the mechanisms underlying the effect of feedback contingency on risk behavior are still poorly understood. Among the three different stages comprising the stimulus-response-feedback sequence, research has mainly focused on the feedback signal itself (Stage 3; see below), but little is known about its effect on the processing of the risky situation to which the individual must respond (Stages 1 and 2).Previous research has highlighted two ERP components related to the feedback signal (Stage 3): stimulus-preceding negativity (SPN) and feedback-related negativity (FRN).

The SPN is a slow negative cortical potential with a frontal distribution which is observed preceding an informative feedback or a relevant stimulus with affective-motivational content related to the outcome of an action (Morís, Luque, & Rodríguez-Fornells, 2013). SPN size has been linked to psychological uncertainty, growing in amplitude as an upcoming outcome becomes more unexpected (Catena et al, 2012; Fuentemilla, Cucurell, Marco-Pallarés, Guitart-Masip, Morís, & Rodríguez-Fornells, 2013). Catena et al. (2012), manipulating the contingency between a cue and an outcome, found a stronger SPN anticipating the presence of the outcome when the contingency between both was null (i.e. the outcome was uncertain) than when this contingency was positive (i.e. the outcome was partially predictable).

The FRN is a negative deflection, observed primarily at the fronto-central regions, which reaches its maximum around 300 ms after feedback onset (Nieuwenhuis, Holroyd, Mol, & Coles, 2004; Torres et al., 2013). FRN is sensitive to the valence of the feedback, being more pronounced for negative feedback associated with unfavorable outcomes than for positive feedback (Cohen, Elger, & Ranganath, 2007). Variation in FRN amplitude is considered to be part of an outcome monitoring system encoding whether feedback of our actions is better or worse than expected. It has been related to reinforcement learning mechanisms evaluating the difference between expectations and actual outcomes in order to update our stimulus-outcome associations (predictions) and improve our future performance (Cohen et al., 2007; Mushtaq, Stoet, Bland, & Schaefer, 2013). Thus, the amplitude of the FRN can be related to how much informative value or new relevant information provide the outcome on our performance. In accordance with these ideas, previous studies have demonstrated that FRN decreases in magnitude as learning proceeds (Eppinger, Kray, Mock, & Mecklinger, 2008; Holroyd & Coles, 2002). For instance, Luque, López, Marco-Pallares, Càmara, & Rodríguez-Fornells (2012) observed that once participants learned the cue-outcome relationship, there was a decrease in the difference between the FRN amplitude of the non-rewarded and rewarded cues. This FRN difference progressively declines when the outcome becomes less informative for learning (Bellebaum & Daum, 2008; Luque et al. 2012).

On the other hand, as mentioned above, no previous studies have explored how feedback modulates the processing of a risky situation at the neural level (Stages 1 and 2 of the stimulus-response-feedback sequence). The modification of risk behavior using feedback must first entail the suppression of the prepotent response associated with the situation and then the substitution of this by a less prepotent or less habitual response associated with the feedback. This process entails the resolution of a conflict between response tendencies (our previous response vs. the response suggested by feedback), which implies the use of cognitive control strategies. Previous research studying the neural basis of cognitive control has identified the anterior cingulate cortex (ACC) as a critical region in conflict processing (Botvinick, Cohen, & Carter, 2004; Pastötter, Dreisbach, & Bäuml, 2013). The N2 and N400 ERPs are two components whose brain sources are located at the ACC and have been shown to be sensitive to tasks involving conflict processing between competing responses (Bland & Schaefer, 2011, 2012; Forster, Carter, Cohen, & Cho, 2011; Hanslmayr et al. 2008; Megías, Gutiérrez-Cobo, Gómez-Leal, Cabello, Fernández-Berrocal, 2017; Larson, Kaufman, & Perlstein, 2009). Both components have a similar topography characterized by a negative deflection at fronto-central electrodes, peaking around

150-250 ms post-stimulus onset for the N200 and around 400-450 ms post-stimulus onset for the N400.

The size of the N2 and N400 depends on the demand for cognitive control, and therefore on the level of conflict between competing response alternatives during the behavior modification process. For example, Bland and Schaefer (2011), studying the electrophysiological correlates of decision-making under conditions of uncertainty, observed that the N2 and N400 were more sensitive to modifications in the stimulus–response–outcome association (volatility) when the contingency between the response and outcome was higher (more reliable), that is, when the level of conflict between the previous and the new correct response was greater. In the context of our study, a higher response-feedback contingency in the risk behavior modification process should entail a stronger response conflict in order to inhibit/modify the previous behavior and, thus, a greater demand for cognitive control reflected in larger N2 and N400 components.

The present research aimed at studying the behavioral effects and the neural signatures of feedback on decision-making in risky situations as a function of its contingency. We manipulated feedback at three levels: A control group without feedback, and two experimental groups (contingent and non-contingent feedback) were used to explore brain electrophysiological activity related to each of the stages of the stimulus-response-feedback sequence. We focused on one of the daily life contexts where risk taking is more common, i.e. driving situations. In our view, this context appears to be particularly relevant for two reasons. First, traffic authorities use negative feedback in an attempt to change drivers' risky behavior, and, second, high rates of human casualties and injuries are produced by risky driving.

In our study, feedback was applied to risky decisions in driving contexts following a punishment system similar to that of the point-based driving license implemented in many countries (Castillo-Manzano, Castro-Nuño, & Pedregal, 2011).On the basis of the literature reviewed above, we expected to find that contingent feedback would lead to changes in response bias (Torres et al., 2017), that is, faster and less risk-prone decision-making in comparison with the control group without any feedback; whereas non-contingent feedback should lead to exactly the opposite outcome, i.e. slower responses and more risk-taking behavior than the control and contingent groups.

Accordingly, we propose the following hypotheses: *Hypothesis 1*. Contingent feedback, compared with non-contingent and no-feedback conditions, will require greater cognitive control during the processing of the driving situation in order to force a change in behavior, which should be reflected in larger N2/N400 amplitudes. *Hypothesis 2*. Non-contingent feedback, in which uncertainty about the consequences of the response is higher, will result in a larger SPN than the contingent and no-feedback groups. *Hypothesis 3.*With regard to differences in FRN amplitude (negative feedback FRN – positive feedback FRN), different results can be expected as a function of whether participants decide to persevere at discovering the rules governing the response-feedback relationship: a) Non-contingent feedback should evoke smaller FRN differences (less negative) than contingent feedback, just after the null contingency has been learned. b) Non-contingent feedback could lead to larger FRN differences (more negative) if participants continue trying to learn the rules.

**4.2. Method**

**Participants**

Sixty volunteers from the University of Granada participated in the study (44 women and 16 men). The average age of the participants was 20.2 years (SD = 1.92; range: 18-26 years). The study sample was composed of young drivers, due to their greater tendency to take risks (Megías, Cándido, Catena, Molinero, & Maldonado, 2014). The criteria for participation were to have a valid driver's license and normal or corrected-to-normal vision. Participants were randomly assigned to one of the three groups (n=20). The distribution of gender and age was the same in the three groups. All participants signed an informed consent form and were treated in accordance with the Helsinki declaration (World Medical Association, 2008).The Ethics Committee in Human Research of the University of Granada approved the study.

**Stimuli & Apparatus**

One hundred and twenty images displaying actual driving situations from the driver's point of view were used in the experiment. Images were selected from an extensive database, depicting both risky and non-risky driving situations (see Megías et al. 2015). All of the images were taken on Spanish and Finnish roads. To select the driving situations, a set of possible problematic factors were considered: a) perception of the speed at which a vehicle is driven may vary between participants when static images are presented (see Vlakveld, 2011); b) the response requested of the participants during the experiment was to decide whether they would brake or not to avoid a possible hazard in each of the driving situations. However, drivers may typically perform different maneuvers in order to avoid a hazard. With the aim of reducing the possible inter-individual variability in the interpretation of these issues, forty driving school instructors evaluated all the images from the driving situations database with respect to perceived speed and the best response needed to avoid the hazard. We considered only those images where the mean standard deviation of the perceived speed was lower than 25%, and the best option to avoid the hazard (if any) was to brake for at least 70% of the instructors. Finally, the risk level of the images that met these criteria were evaluated by 40 normal drivers with a valid driver's license using *a Likert scale questionnaire* (where 0 = no risk, and 7 = high risk). The final sample of images used in the experiment included 90 driving situations with a medium risk level (average risk = 4.56, SD = 1.39) and another 30 without risk or a very low risk level (average risk = 1.65, SD =1.08). Appendix 1 includes some examples of the images included in the study.

To carry out the experimental task, the participants were seated in an electrically shielded room located at the Mind, Brain, and Research Center, University of Granada, Spain. Two computers with Intel Core 2 Duo processors operating at 2.8 GHz with 4 GB of RAM and running under Windows 7 were used for controlling the task and recording EEG activity. The task was displayed on a projection screen (size: 120 x 90 cm; resolution: 1200 x 800) placed 180 cm away from the participant. The experiment was developed and run in E-Prime software (Psychology Software

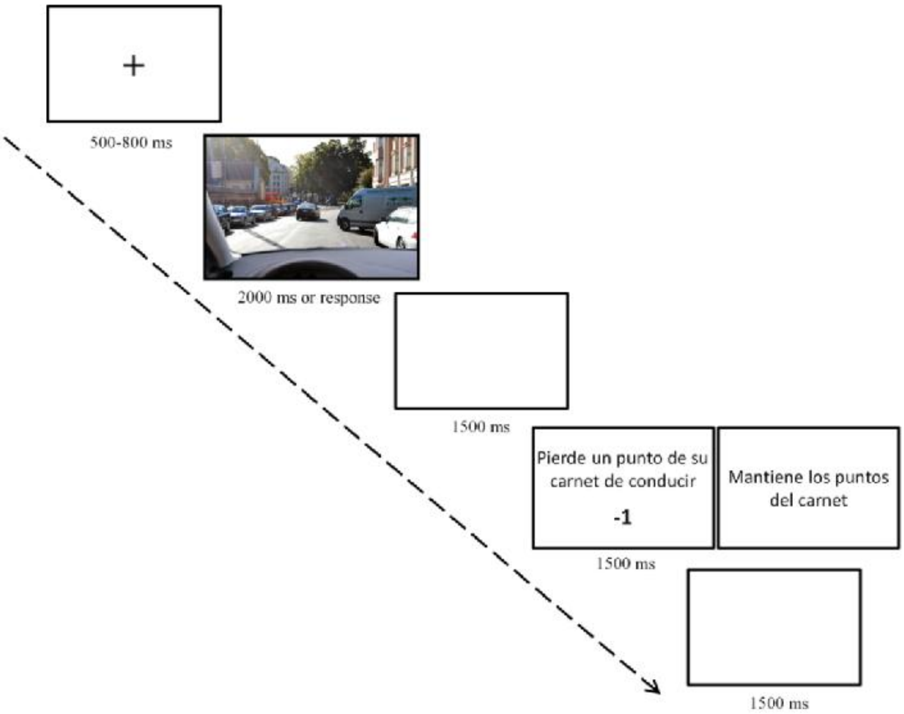
ToolsInc., Pittsburgh, USA). The EEG recording was done using Neuroscan NuAmps system (NeuroScan Inc., USA) through 34 electrodes placed according to the international 10-20 system and referenced online to the left ear lobe (see Figure 2). Moreover, two additional vertical and horizontal electro-oculogram electrodes (EOG) were placed below and on the outer can thus of the left eye. EEG was sampled at 1 kHz with a band pass filter of 0.5–100 Hz. All electrode impedances were inferior to 20 kΩ.

**Procedure**

The study employed two groups with feedback (contingent and non-contingent groups) and a control group without feedback. The experimental task performed by the participants included two blocks of 120 trials (240 in total). Each trial showed an image of a driving situation. Ninety images depicted a risky situation and thirty showed no risk. The images were the same in both blocks but the order of the trials and blocks was randomized across participants to avoid order effects.

Following a system similar to that of the point-based driving license (Castillo-Manzano et al., 2011), the negative feedback displayed in the groups with feedback was a message reading “pierde un punto de su carnet de conducir” (you lose one point on your driving license), whilst the message "mantiene los puntos del carnet” (you keep the points on your driving license) was displayed as positive feedback. A blank display without a message was presented to the non-feedback group. Contingency was computed as the difference between the probability of negative feedback when participants opted for risky behaviors in risk situations (not to brake) and the probability of negative feedback when participants chose safe behaviors in risk situations (to brake). No feedback was provided in the non-risky scenes (a blank display). In the contingent group, the probability of negative feedback following a risky behavior (i.e. not to brake in a risky situation) was 0.5, but the negative feedback was never displayed after a safe response (i.e. to brake in a risky situation; in these cases positive feedback was displayed). Thus, contingency was moderate and positive, $\Delta P$ = 0.5-0.0 = 0.5. In the non-contingent group, the probability of receiving negative feedback in a risky situation was 0.25 regardless of the participant’s response, that is, negative feedback could be displayed with equal probability following both a risky and a safe behavior in risky scenes (in the remaining cases positive feedback was displayed). Thus, the contingency level was null, ΔP = 0.25-0.25 = 0. It is important to note that the number of negative feedback displays received by each participant in the contingent group depends on their response. Therefore, although the probability of receiving negative feedback after a risky behavior in the contingent group is similar for all participants, risky participants will receive more negative feedback than prudent participants. The possible influence of the number of negative feedback displays received on ERP differences was controlled in the analyses (see Results section). In addition, following the results of Torres et al. (2017), the probability of negative feedback for the non-contingent group was set at 0.25 in order to reach a similar proportion of trials with negative feedback as the contingent group.

The trial sequence was as follows (Figure 1). Trials began with a fixation cross of variable duration ranging from 500 to 800 ms, centered around 650ms. Next, the driving situation was displayed and remained on the screen until the participant's response or until 2000 ms had elapsed. Participants had to "brake" or not by pressing the left mouse button (with their left forefinger) or the right button (right forefinger), respectively. The correspondence between mouse buttons and type of response was counter-balanced across participants. Following the response, a white screen was displayed for 1500 ms before the feedback in order to allow the development of the SPN component. The feedback screen was then presented for 1500 ms for the two feedback groups. In the Control group, a blank screen was presented for these same temporal windows. Finally, a blank screen was displayed for 1500 ms before starting the next trial. The entire task lasted for approximately 30 minutes (excluding the EEG preparation time).


+
500-800 ms
2000 ms or response
1500 ms
Pierde un punto de su carnet de conducir
-1
Mantiene los puntos del carnet
1500 ms
1500 ms

EEG data were epoched in three types of segment depending on the ERP component being analyzed. For the analysis of the driving situation (N2 and N400), the recording was epoched in segments of 2100ms from -100 to 2000 ms time-locked to the onset of the driving image. For the SPN component, we epoched the EEG recording in segments of 1600ms from -100 to 1500 ms time-locked to the response onset. For the FRN, the recording was epoched in segments of 1600ms from -100 to 1500ms time-locked to the feedback onset. Baseline correction for the three epoch types was conducted using the first 100 ms. Artifact components were identified and corrected byusing the SOBI ICA decomposition algorithm (Joyce, Gorodnitsky, &Kutas, 2004; Tang, Pearlmutter, Malaszenko, & Phung, 2002) and Multiple Artifact Rejection Algorithm tool(MARA; see Winkler, Haufe, & Tangermann, 2011).Epochs with an amplitude exceeding +/-75 mV were excluded from analysis.

Driving image ERPs calculation. Following the N2 and N400 literature (Bland& Schaefer, 2011), both components were computed for each participant and condition at fronto-central-parietal electrodes (FP1, FP2, F3, F4, FC3, FC4, C3, C4, CP3, CP4, P3, and P4, see Figure 2) as the average amplitude of the +-16 ms period around the most negative peak in the 180-280 (for the N2) and 400-500 (for the N400) time interval after image onset. Peak latency intervals were selected using the grand average waveforms.

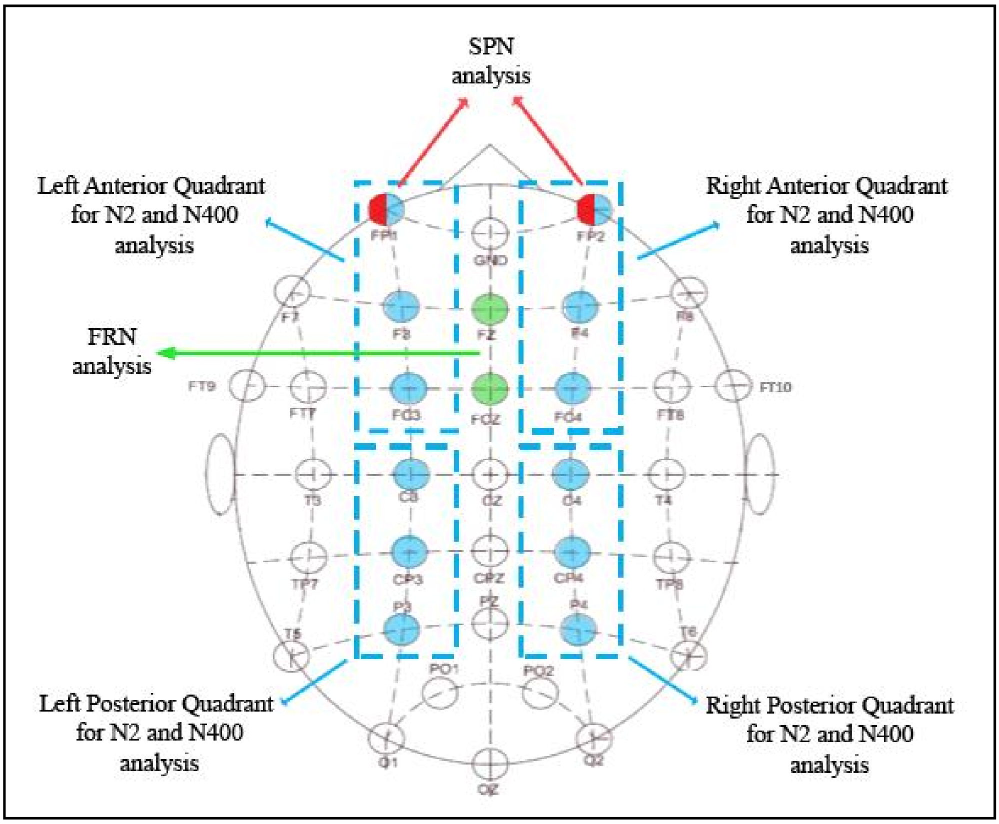
*SPN score calculation*. The SPN component was computed for each participant and condition by averaging the amplitude of the 200 ms time window preceding the feedback onset on the SPN epochs at electrodes Fp1 and Fp2 (see Figure 2; Catena et al., 2012; Masaki, Yamazaki, & Hackley, 2010).

*Differential FRN score*. With the aim of studying the FRN amplitude differences between negative and positive feedback trials (hereinafter Differential FRN score) in the contingent and non-contingent group (control group had no feedback), a FRN component was computed for each condition and participant at electrodes Fz and FCz (see Figure 2; Torres et al., 2013).Both mean and peak amplitude measures have been used in previous studies to compute the FRN component (see Banis and Lorist [2012] for a comparison of both methods). We decided to use a peak-to-peak approach, computing FRN as the voltage difference between the lowest peak in a pre-defined time window following feedback onset and the preceding positive peak. Numerous studies in the literature have applied this method (Bellebaum, Polezzi, & Daum, 2010; Chase, Swainson, Durham, Benham, & Cools, 2010; Mushtaq, Stoet, Bland, & Schaefer, 2013; Yeung & Sanfey, 2004). FRN is an ERP component with a well-defined negative-going peak. In these cases, the peak amplitude can be determined with little ambiguity and the component can be accurately captured (Handy, 2005). Moreover, peak-to-peak methods offer a partial correction for overlap between FRN and other ERP components. (Luck, 2005).

The FRN (hereinafter FRN score) was calculated on the FRN epochs as the difference between the amplitude of the most negative peak in the 250-400 ms time windows after feedback onset and the amplitude of the preceding positive peak in the 150-300 ms post-feedback onset interval for each participant (Mushtaq et al. 2013; Yeung, Holroyd, & Cohen, 2005). Finally, we computed the differential FRN score by subtracting the FRN score of the positive feedback from the FRN score of the negative one (FRN negative feedback – FRN positive feedback; see Torres et al., 2013).

**Statistical analysis**

For behavioral analysis, four dependent variables were considered: probability of braking, reaction times, response bias, and sensitivity index. The average values of these variables for each subject were submitted to four separate unifactorial ANOVAs with Group (3 levels: control, contingent, and non-contingent) as the independent variable. Response bias (c) and sensitivity (d') are performance indices of the Signal Detection Theory (SDT; Macmillan and Creelman, 2005). Risk (risky situations) was the signal to discriminate from the noise (non-risky situations), and the behavior of “braking/no braking” was the “yes/no” response corresponding to the standard parameters used in SDT calculation (Megías, Maldonado, Cándido, & Catena, 2011; Serrano, Di Stasi, Megías, & Catena, 2011). The level of significance was set at $p < 0.05$ for all analyses and multiple comparisons were Bonferroni corrected. Partial $\eta^2$ was used as an index of effect size.


SPN
analysis
Left Anterior Quadrant
for N2 and N400
analysis
Right Anterior Quadrant
for N2 and N400
analysis
FRN
analysis
Left Posterior Quadrant
for N2 and N400
analysis
Right Posterior Quadrant
for N2 and N400
analysis
GND
FT9
FT10
PO1
PO2
OZ

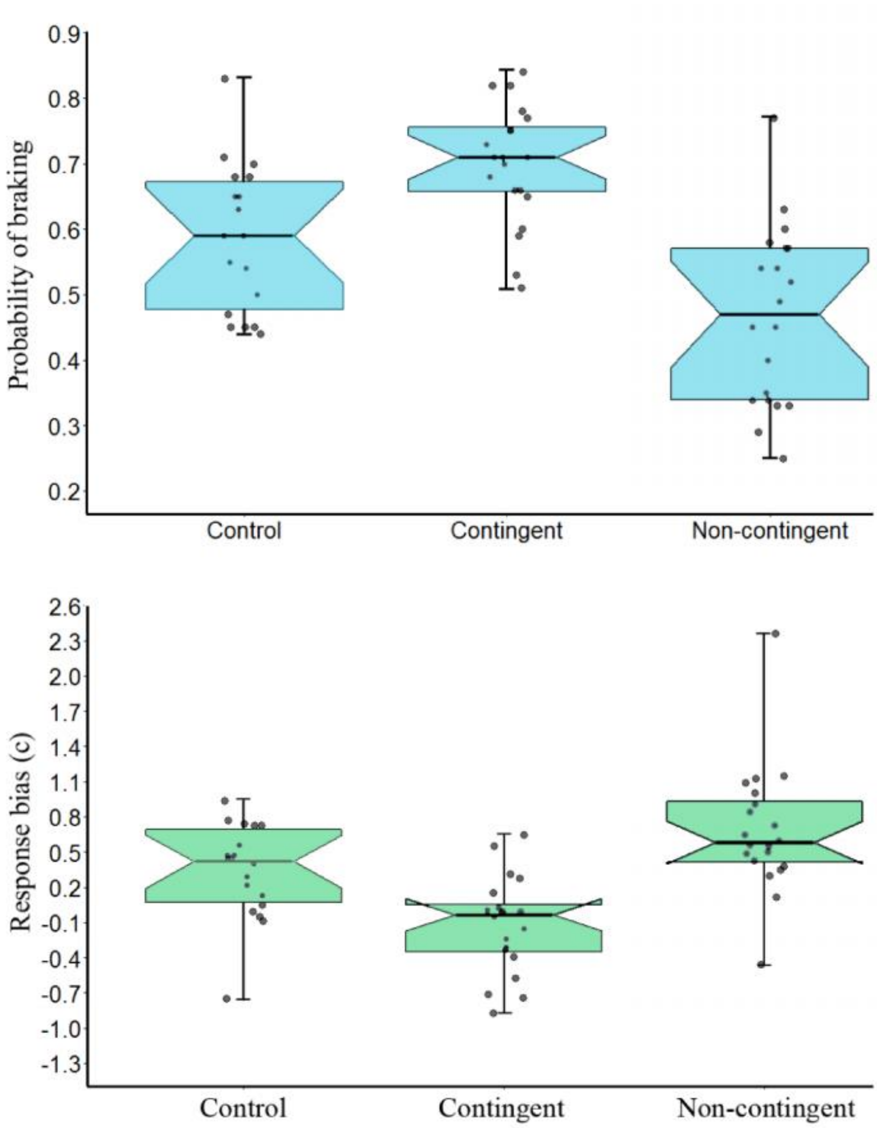
## 4.3. Results

### Behavioral Task

Three participants were excluded from the study due to poor quality EEG recordings. The final sample included 19 participants in the control group, 18 in the contingent group, and 20 in the non-contingent group.

The unifactorial ANOVA conducted on the average probability of braking revealed a main effect of Group, $F$ (2, 54) = 21.96, MSE = 0.01, $p< .001$, $\eta^2_p = .45$ (see Figure 3). Post hoc analysis revealed significant differences between the three group conditions ($p$'s < 0.05, Bonferroni corrected). Probability of braking was higher in the contingent group (0.70) than in the control (0.58) and non-contingent (0.46) groups. The control group also showed a higher probability of braking than the non-contingent group. The ANOVA conducted on average reaction times revealed non-significant results ($F < 1$).

With respect to the SDT indices, the ANOVA conducted on the response bias parameter (c) revealed a main effect of Group, $F$ (2, 54) = 16.97, MSE = 0.21, $p< .001$, $\eta^2_p = .39$. Post-hoc analysis showed a lower response bias in the contingent group (-0.12) compared with the control (0.33) and non-contingent group (0.68)($p$'s < 0.05, Bonferroni corrected). The control group showed a marginally significant lower response bias than the non-contingent group ($p$ =0.06, Bonferroni corrected). A higher score in the response bias is associated with a tendency to brake less often, that is, a response bias toward risky behavior. The ANOVA conducted on the average sensitivity index (d') showed non-significant results ($p$ = 0.09).


Probability of braking
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Control
Contingent
Non-contingent
Response bias (c)
2.6
2.3
2.0
1.7
1.4
1.1
0.8
0.5
0.2
-0.1
-0.4
-0.7
-1.0
-1.3
Control
Contingent
Non-contingent

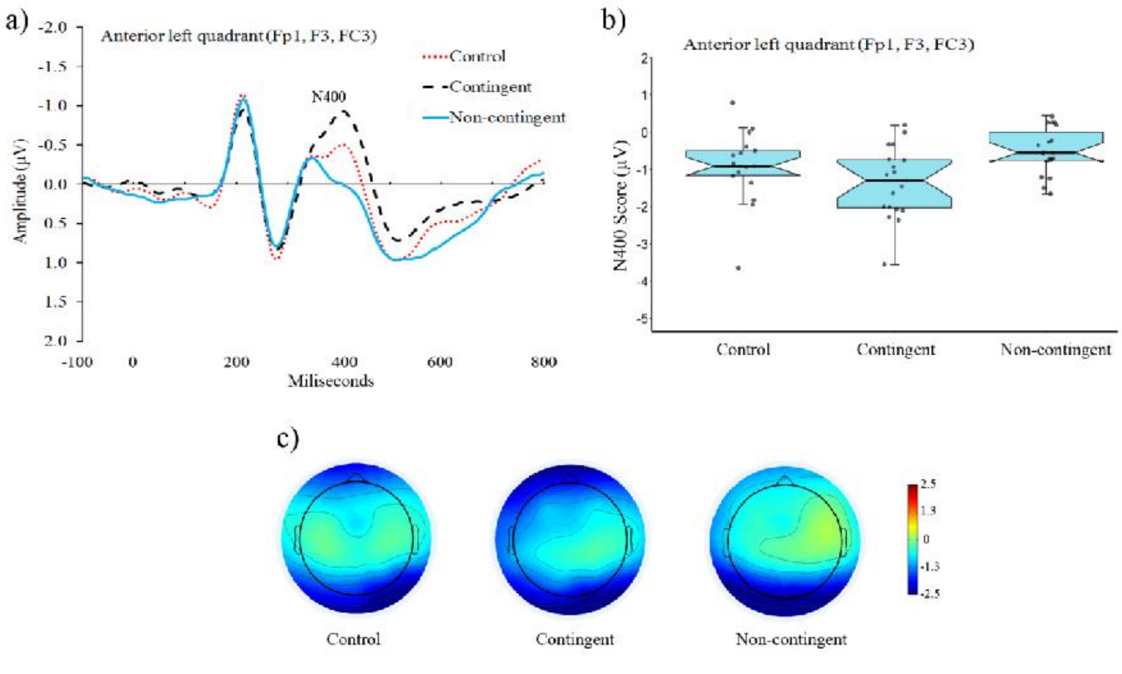
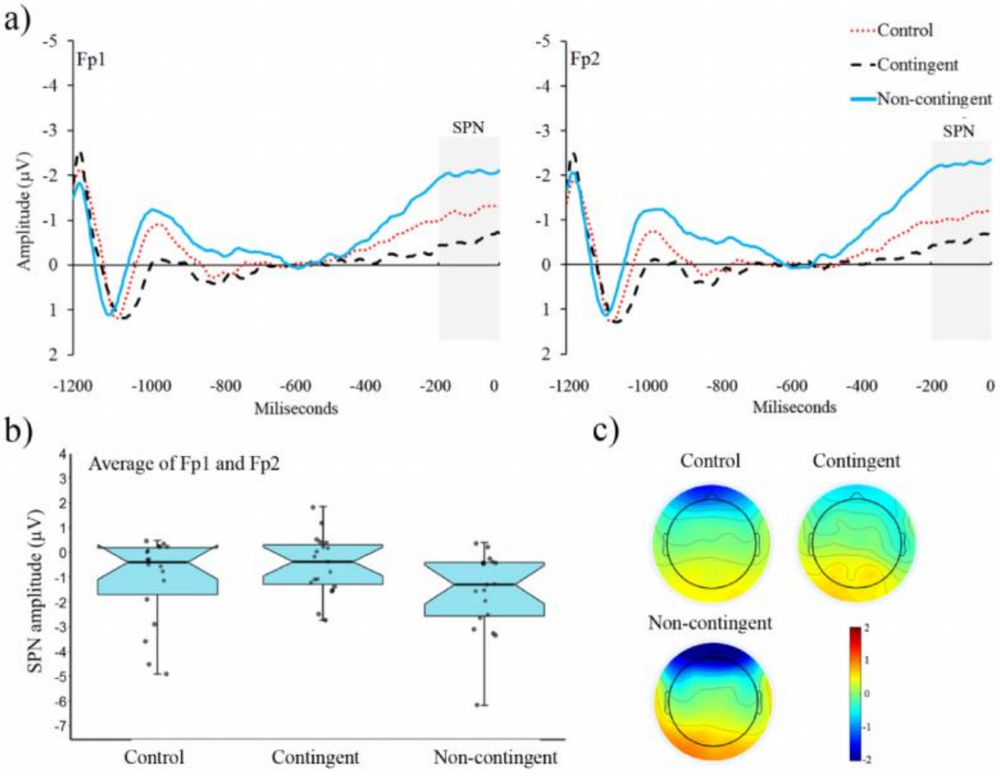

a)
Anterior left quadrant (Fp1, F3, FC3)
Control
Contingent
Non-contingent
N400
Amplitude (µV)
Miliseconds
b)
Anterior left quadrant (Fp1, F3, FC3)
N400 Score (µV)
Control
Contingent
Non-contingent
c)
Control
Contingent
Non-contingent

*Figure 4. a) Grand average waveforms for each group condition across left anterior quadrant electrodes (Fp1, F2, and FC3) in the −100 to 800 ms interval time-locked to the driving image onset. b) Boxplots combined with scatterplots representing the N400 values across left anterior quadrant electrodes (Fp1, F2, FC3) for each group condition. The central horizontal line indicates the median. Upper and lower limit of the boxplots represent 75% and 25% quartile ranges. Vertical bars indicate values within 1.5 times the interquartile range. Dots represent the average value of each participant. c) Topographic maps showing the scalp distribution of the N400 component for each group condition.*

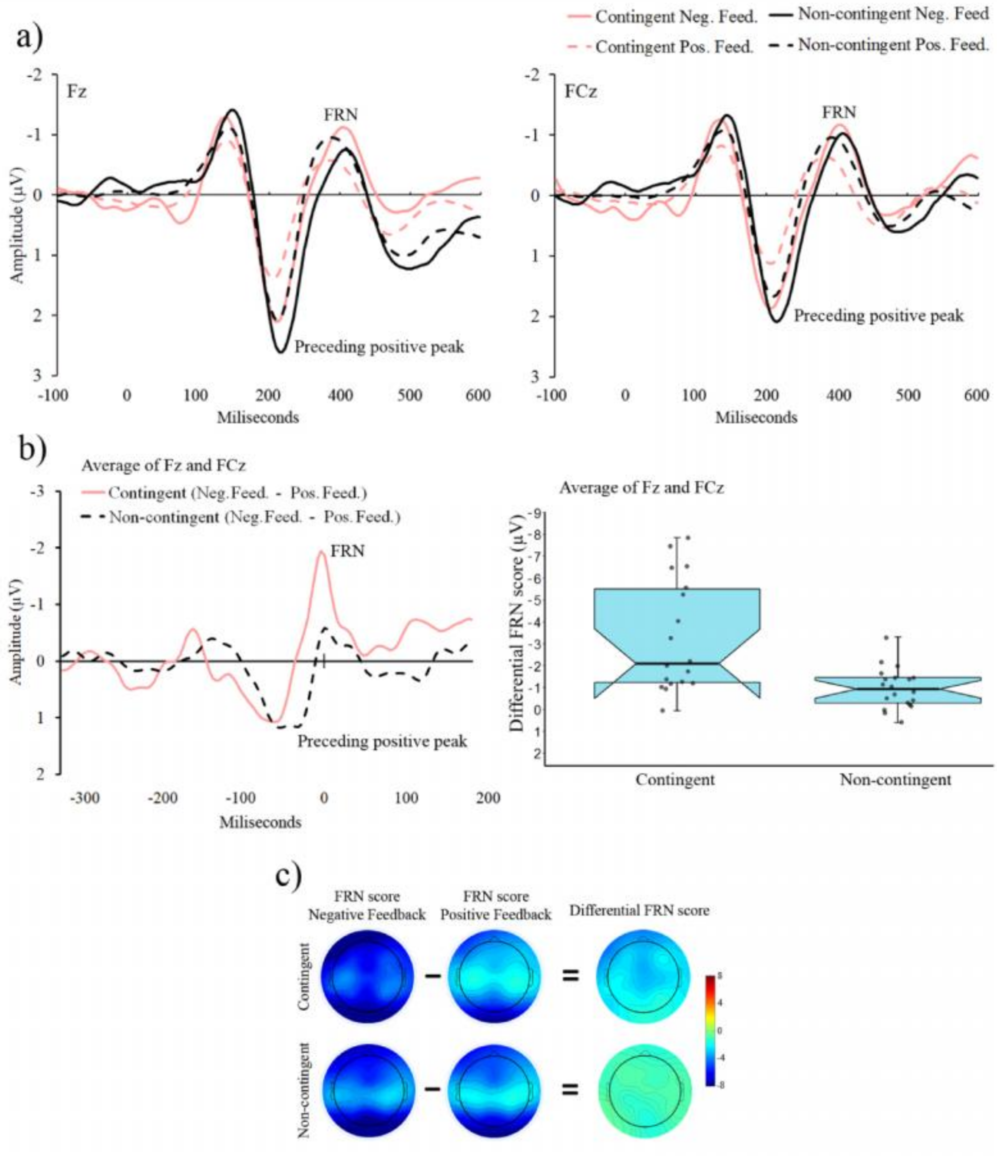
Additionally, given the limited literature exploring EEG activity in risk decision-making, we decided to explore the P300 and P500 components observed on the grand average waveform. The statistical analyses were similar to those carried out for N2 and N400. Group x Risk x Quadrant analyses conducted for P300 and P500 failed to find significant differences for the variables of interest. Only Quadrant was significant for both components.

**SPN score**

The Group x Electrodes ANOVA on the SPN score revealed a main effect of group $F$ (2, 54) = 3.22, MSE = 8.32, $p < .05$, $\eta^2_p = .11$. SPN score was more negative (i.e. larger SPN component since more negative scores reflect a larger SPN) in the non-contingent (M=-2.12) group than in the contingent group (M=-0.51) ($p = .05$, Bonferroni corrected). No other comparisons were significant. Figure 5 shows the grand average wave forms for each group and electrode in the SPN epoch, the average SPN scores, and the topographic maps.



a)
Fp1
Fp2
Control
Contingent
Non-contingent
SPN
Amplitude (µV)
Miliseconds
b)
Average of Fp1 and Fp2
SPN amplitude (µV)
Control
Contingent
Non-contingent
c)
Control
Contingent
Non-contingent



a)
Contingent Neg. Feed.
Contingent Pos. Feed.
Non-contingent Neg. Feed
Non-contingent Pos. Feed.
Fz
FCz
FRN
Preceding positive peak
Amplitude (µV)
Miliseconds
b)
Average of Fz and FCz
Contingent (Neg.Feed. - Pos.Feed.)
Non-contingent (Neg.Feed. - Pos.Feed.)
FRN
Preceding positive peak
Amplitude (µV)
Miliseconds
Differential FRN score (µV)
Contingent
Non-contingent
c)
FRN score Negative Feedback
FRN score Positive Feedback
Differential FRN score
Contingent
Non-contingent

*Figure 6. Grand average ERP waveforms for group conditions (contingent and non-contingent) and type of feedback (positive and negative feedback) in the −100 to 600 ms interval time-locked to the feedback onset are presented for electrodes of interest (Fz and FCz). b) Left panel shows grand average waveforms of the difference between negative feedback and positive feedback averaged across Fz and FCz electrodes for group conditions (contingent and non-contingent) time-locked to the FRN peak. Right panel shows boxplots with scatterplots showing differential FRN score across average Fz and Fcz electrodes for contingent and non-contingent groups. The central horizontal line indicates the median. Upper and lower limit of the boxplots represent 75% and 25% quartile ranges. Vertical bars indicate values within 1.5 times the interquartile range. Dots represent the average of each participant. c) Topographic maps showing the scalp distribution of the FRN score and FRN differential score for contingent and non-contingent groups.*

Additionally, in order to address one of our previous hypotheses regarding the FRN, we explored whether the smaller differential FRN score found in the Non-contingent group was a function of the learning task (participants learning that contingency is null). For this purpose, we divided the trials in the non-contingent group into two blocks taking into account the fact that the driving images displayed in block 1 and block 2 were the same (see Procedure).The contingent group was not included in this analysis for two reasons: 1) The contingent group showed a strong differential FRN score on the whole task; 2) the number of negative feedback displays received by each participant was small (M = 15.2), due to its very strong effect on the modification of behavior. Thus, there were few negative feedback trials in the second block with which to conduct an appropriate ERP analysis. The Block (block 1 and block 2) x Electrodes (Fz and FCz) ANOVA conducted on the differential FRN score in the non-contingent group did not reveal any significant main effects or an interaction. According to these results, the participants appear to have learned very quickly about the lack of contingency between feedback and response.

### 4.4. Discussion

The main aim of the present study was to investigate the brain markers of the cognitive processing underlying risk behavior modification by feedback. To this end, we focused on the differences during the processing of the stimulus-response-feedback sequence as a function of the feedback contingency.

In line with the findings of previous research, we observed that contingent feedback on the participants' risky behaviors led to safer decision-making. These results support the widespread use of feedback as a useful behavior modification tool (Kluger & DeNisi, 1996; Megías, Cortes, Maldonado, & Cándido, 2016;Serrano, Di Stasi, Megías, & Catena, 2014).In stark contrast, the application of non-contingent feedback gave rise to the opposite behavior, i.e. less safe and more risk prone decision-making compared with both the contingent and control groups. Moreover, the results also showed that the behavioral modification induced by feedback could be explained by changes in the response bias during decision-making, replicating previously reported results (Maldonado et al, 2016; Torres et al. 2017).

The most important results, however, were those related to our hypotheses about the brain electrophysiological activity underlying these behavioral changes. First of all, contingent feedback, as opposed to non-contingent feedback, lead tolargerN400 amplitude during the processing of the driving image on which they had to make the decision (Hypothesis 1). This ERP has been linked to cognitive control and conflict resolution (Bland & Schaefer, 2011, 2012; Hanslmayr et al. 2008; Larson et al., 2009). As we previously observed in the behavioral results, behavior modification through contingent feedback is due to changes in the participants' response bias. These changes imply the suppression of a prepotent risk tendency that is replaced by a new safer response in order to adapt our behavior to the current rules. This process is guided by cognitive control mechanisms. Moreover, the higher the response-feedback contingency, the greater the force for the behavioral change, and therefore more cognitive control strategies will be targeted to suppress and modify the previous behavior. Thus, in our study, the response bias changes guided by contingent feedback are related to a higher demand for cognitive control (conflict-processing) reflected in the N400 amplitude during the decision-making process. In addition, according to Hypothesis 1, we also expected to find differences between the contingent and no-feedback group. This comparison did not reach significance; however, the fact that the no-feedback group shows intermediate N400 amplitude compared with those of the other two groups could be in line with our hypothesis. With respect to the N2 component analysis, unlike previous studies (Bland & Schaefer, 2011; Forster et al., 2011; Megías et al., 2017), we failed to observe differences in this component. Our task has certain particularities that differentiate it from prior research studying N2. Driving is a complex task that requires consideration of multiple aspects of the environment. Thus, the processing of the driving situations employed in this research could be sensitive to later neural processes such as the N400, given the complexity of the visual scenarios. Moreover, studies focusing on N2 present differences from each other in terms of the paradigms (stroop tasks, go/no go tasks, or contingency learning tasks) and the experimental procedures used, which could explain possible discrepancies among results. For example, the referencing scheme in our study was a common average reference whilst Bland & Schaefer's (2011) study employed a mastoid average reference. Further research is needed for a better understanding of this issue.

Secondly, once participants gave their response, a stronger SPN anticipating the presence of the feedback signal was found in the non-contingent group compared with the contingent group (Hypothesis2). Previous research has shown (Catena et al., 2012; Fuentemilla et al., 2013) how the SPN component may be related to uncertainty about the consequences of a response. In the present study, the lack of contingency between the response and the negative feedback (non-contingent group) led to a higher uncertainty preceding the outcome, giving rise to a stronger SPN (Catena et al., 2012).As with the N400 component, the no-feedback group showed an intermediate SPN score compared with the other two groups, although these differences were not significant.

Finally, regarding the processing of the feedback itself, we anticipated two possible alternative findings related to how relevant and informative the feedback was for the participant. Hypothesis 3a) proposed that the absolute value of the differential FRN score should decrease in the non-contingent group (less negative), after the participants learn that feedback is not an informative signal of their performance. In contrast, Hypothesis 3b) proposed that the differential FRN score should be larger (absolute value) in the non-contingent group if participants persevere in trying to learn the rules governing the response-feedback association, although no response-feedback relationship can be derived. The results support Hypothesis 3a, since a smaller differential FRN score (less negative) was found in the non-contingent feedback compared with the contingent feedback. Accordingly, it appears that the non-contingent feedback was less relevant for performance monitoring (less informative) than contingent feedback. Participants quickly learned the lack of a relationship between their responses and its consequences (feedback). The results showed that by the first block of trials the presence of feedback had already ceased to be relevant to the task and less attention was paid to the situation, giving rise to riskier responses (Holroyd & Coles, 2002; Luque et al., 2012). Thus, our findings are in agreement with those of previous studies in the reinforcement learning literature, where FRN score variation has been considered as a neural index of an outcome monitoring system encoding the value acquired by the outcome throughout the learning process (Cohen, Elger, & Ranganath, 2007).

Taken together, our findings provide a new and interesting perspective of the decision-making processing of the stimulus-response-feedback sequence in risky situations. In summary, providing feedback on risky decisions provoked changes in the risk-related response bias, resulting in behavioral adaptation. The direction of these changes depended on the feedback contingency, that is, contingent feedback lead to safer behaviors, whereas non-contingent feedback gave rise to riskier behaviors. In addition, when feedback was applied contingently to the response, the behavioral adaptation entailed a greater conflict between the old and the new behaviors, which was reflected in a higher demand for cognitive control resources (larger N400). Following the response, as expected, participants more easily predicted the feedback when it was contingent upon the response. A greater uncertainty was associated with the non-contingent feedback, giving rise to a stronger SPN. Finally, the contingent feedback entailed a greater salience (larger differential FRN score) compared with the non-contingent feedback.

From an applied point of view, this study makes several contributions to the field of risk prevention and control. In particular, the use of feedback is an effective tool for modifying risky behaviors. However, it is necessary to emphasize that it must be applied contingently upon the behavior, in order to achieve a safer behavioral change in risky situations. If the stimulus-response-feedback association is not adequate or is not correctly learned, it could produce the opposite effect. A clear example of the dangers that this situation may entail is presented in the context of the current study. If the driver fails to correctly perceive an association between penalties or lost points and his/her driving behavior, this could lead to more violations of the traffic regulations and more risky behaviors.

With respect to the brain processes underlying the impact of feedback on decision-making, the N400 amplitudes could be considered an index of the conflict level generated by the risk situation. As the new behavior is better learned and replaces the old one, the between-responses conflict must diminish, and therefore, the demands for cognitive control associated with N400 will also decline. Thus, this ERP component may be a useful tool for evaluating learning processes. Moreover, FRN amplitude could also be used as an index of the relevancy and efficacy of feedback. Feedback characteristics could be adapted in accordance with this index to enhance the effectiveness of behavior modification techniques.

Future research should focus on other risk contexts in order to generalize our results to other relevant fields of study such as health, occupational hazards, drugs and alcohol abuse, or gambling problems. Moreover, a chief aim must be to develop interventions based on our findings and apply them to real life environments. However, preliminary work is needed using more ecological tasks or other virtual environments such as driving simulators, given the vital importance of studying risk behavior on the road and the difficulty of using brain recording techniques in real contexts. For example, mechanisms such as attention and emotional processing are crucial in hazard perception (Megías et al., 2011; Tagliabue, Da Pos, Spoto, & Vidotto, 2013; Tagliabue, Gianfranchi, & Sarlo, 2017; Tagliabue & Sarlo, 2015), but are difficult to study by static images. The study of the neural processes underlying the attention-emotion relationship and its interaction with the ERP components investigated in the current research could be an interesting future line of research to pursue using driving simulators (see Carretié, Mercado, Tapia, & Hinojosa, 2001, for similar studies outside of the driving context). Finally, it would be interesting to investigate the brain mechanisms underlying the effect of feedback contingency on decision-making by using techniques with a higher spatial resolution such as fMRI, in order to explore particular brain areas implied in these processes.

### 4.5. Conclusion

This research aimed to explore the neural and cognitive mechanisms underlying risk behavior modification through feedback. We observed differences at both behavioral and electrophysiological level in the processing of the stimulus-response-feedback sequence as a function of the feedback contingency level. The influence of the feedback contingency, particularly the non-contingent feedback, on the neural processing of decision-making in risky situations had not been previously studied. The current findings suggest that giving correct feedback contingent upon the response produce a behavioral adaptation in the desired direction (less risky behavior), as predicted by reinforcement learning models. This adaptation is a result of changes in the individual's response bias, which leads to greater cognitive control during the decision-making learning process, reflected at brain level by the N400 ERP component. Moreover, the contingent feedback was more easily predictable (smaller SPN) and provided more informative value than when it was applied non-contingently (larger differential FRN score). On the other hand, non-contingent feedback provoked a greater number of risky behaviors guided by a more risk-prone response bias, which required less cognitive control. At a theoretical level, our findings offer a novel and more complex account of the mechanisms underlying the stimulus-response-feedback sequence in decision-making in risky situations. Moreover, it is important to emphasize the practical relevance of this research given that the study context (driving) is very closely related to our daily lives. Further research should be directed towards exploiting our results in real-world situations.

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# CAPÍTULO 5: DISCUSIÓN GENERAL

# 5. DISCUSIÓN GENERAL

El objetivo principal de este trabajo ha sido estudiar el proceso de toma de decisiones en situaciones complejas que implican comportamiento de riesgo. Para ello, hemos investigado los diferentes componentes que influyen en dicho proceso: evaluación de alternativas, elección de la acción a realizar y las consecuencias derivadas de nuestra elección. Además, también estudiamos la incidencia de la experiencia previa y el uso de feedback en el proceso de decisión, así como los mecanismos neurales implicados en dicho proceso.

## 5.1. COMPORTAMIENTO DE RIESGO

Como comentamos en la introducción, el riesgo es cualquier comportamiento consciente o inconscientemente controlado, con una incertidumbre percibida sobre su resultado y/o los posibles costes y beneficios para el bienestar físico, económico o psicosocial de uno mismo o de los demás (Trimpop, 1994). Aunque existen diferencias entre contextos, la toma de decisiones en situaciones de riesgo siempre implica un difícil balance entre pérdidas y beneficios (Weber et al., 2002).

Uno de los factores más citados en la definición de riesgo es la incertidumbre de la situación (Dickhaut et al., 2003; Pushkarskaya*,* Liu, Smithson y Joseph, 2010; Tversky y Kahneman, 1992). Doya (2008) consideró distintos modos de incertidumbre en el entorno: a) la ambigüedad de respuesta que ofrece un entorno siempre cambiante (p.ej. el entorno de conducción); b) la variación inesperada en una situación conocida o considerada segura (p.ej. la aparición de un elemento en la vía como un peatón, un animal u otro vehículo); o c) la incertidumbre resultante de un limitado conocimiento de las circunstancias (p.ej. conducir de noche o bajo climatología adversa)

Por otro lado, ha sido de interés en la literatura sobre el comportamiento de riesgo diferenciar entre dos tipos de decisiones: unas, basadas en fríos y deliberativos cálculos y otras, basadas en procesos más afectivos (Metcalfe & Mischel, 1999). Los procesos afectivos y las emociones pueden influir en la decisión de diferentes formas: por ejemplo, dirigiendo la atención hacia las diferentes características de las opciones que tenemos para elegir (Weber et al., 2005) o influyendo la percepción subjetiva de las probabilidades y resultados (Tversky & Kahneman, 1992). En estudios de juegos de azar se ha observado que cuando a una persona se le ofrece una apuesta que conlleva un castigo adicional en el caso de no acertar (pierde el dinero apostado y una cantidad adicional), suele apostar con mayor frecuencia que cuando se le ofrece otra apuesta que es idéntica pero no incluye ese castigo (tan sólo pierde el dinero apostado), algo que racionalmente no es comprensible. La explicación a este hecho es que la opción en la que hay castigo es mucho más atractiva porque las posibles ganancias tienen un marco de referencia diferente con el que compararlas, es decir, el valor emocional que se le da a la recompensa es mayor cuando existe la posibilidad de un castigo adicional porque comparamos la recompensa con el posible castigo (Slovic et al., 2007).

Las conductas de riesgo pueden ser diferenciadas si implican, en términos de Metcalfe & Mischel (1999), procesamientos deliberativos o afectivos. Por ejemplo, el juego de azar es más afectivo que una inversión financiera. En la misma línea, las conductas de riesgo reflejan el valor que las personas dan a los beneficios y pérdidas, quedando demostrado que no siempre se sigue un criterio racional (Figner & Weber, 2011). Por ejemplo, en el ámbito financiero se asume que cuanto mayor es el riesgo, mayor será el potencial beneficio. En cambio, en juegos como la lotería, esperamos obtener el mayor beneficio posible con la menor cantidad de pérdidas. Por el contrario, en contextos diarios como el laboral o el tráfico, la búsqueda de pequeñas ganancias conlleva duras pérdidas o consecuencias fatales. Un profesional de la construcción que decide no ponerse el casco para evitar el calor puede conllevar un traumatismo grave, al igual que un conductor que decide superar los límites de velocidad para llegar unos minutos antes al destino.

En definitiva, el comportamiento de riesgo, ya sea guiado por comportamiento más afectivos o más deliberativos, siempre va a implicar una toma de decisión. Desde el punto de vista de las aproximaciones más actuales del análisis de la toma de decisiones (Rangel, Camerer, y Montague, 2008; Sanfey, 2008), los procesos de decisión se consideran articulados en cuatro etapas: primero, se reconoce la situación presente (percepción o representación); segundo, se valoran los comportamientos disponibles en términos de las recompensas y castigos que se puedan alcanzar (evaluación); tercero, se selecciona una acción en función de la evaluación previa y de las propias necesidades (selección de la decisión), y finalmente, una vez la acción ha sido realizada, se produce una reevaluación del proceso basándose en las consecuencias obtenidas (aprendizaje).

Sin embargo, la falta de relación encontrada en los diferentes estudios incluidos en este trabajo entre la evaluación y la posterior decisión no parece acorde con la estructura serial que se le atribuye al modelo. Debemos tener en cuenta dos tipos de procesamiento del riesgo asociados a cada uno de los sistemas propuestos por los modelos de doble vía: comportamiento urgente (por ejemplo, decidir frenar o no ante una situación de riesgo) y comportamiento evaluativo (por ejemplo, evaluar si una situación conlleva riesgo o no). El primero se lleva a cabo bajo presión temporal, desencadenado por estímulos y puede conllevar consecuencias negativas. Estaría basado en el Sistema 1 o automático, el cual implica un procesamiento basado en la experiencia previa y de naturaleza vivencial y emocional de la situación. Por el contrario, el comportamiento evaluativo consiste en una mera evaluación de la situación, la decisión ejecutada no es decisiva y no conlleva consecuencias negativas. Este tipo de tareas requieren activar un modo de procesamiento más controlado en el que la evaluación de la situación es más incisiva y los resultados están basados en reglas lógicas (Megías et al., 2011, 2015). Esta descripción coincide con las características del sistema racional-analítico o Sistema 2. Esta diferenciación entre un procesamiento más racional y otro más afectivo habilitaría la posibilidad de que nuestras conductas no se adapten exclusivamente a la evaluación previa de la situación. A través de los resultados obtenidos en nuestros estudios podemos ofrecer una visión de las distintas variables que explican estos procesos. A continuación, abordaremos la discusión de los resultados obtenidos siguiendo la aproximación al proceso de toma de decisiones descrito.

## 5.2. PROCESO DE TOMA DE DECISIONES

### 5.2.1. PERCEPCIÓN

La percepción o representación de la situación es el primer paso a la hora de tomar una decisión en situaciones de riesgo. Debemos conjugar el curso de la acción con los valores externos e internos de nuestra conducta. Es decir, a la hora de representar una situación de riesgo entran en juego variables cognitivas (p.ej. creencias previas, expectativas, funciones atencionales), conductuales (p.ej. experiencia con la situación, habilidades motoras) y emocionales.

Aunque el objetivo principal de este trabajo es estudiar los pasos posteriores a esta primera fase de percepción de la situación, creemos necesario destacar la influencia de las variables emocionales dada la diferenciación previamente realizada entre procesos más afectivos o más deliberativos. En este sentido, son reseñables los trabajos que han mostrado cómo cada estado de ánimo influye diferencialmente la percepción de riesgo y nuestras decisiones durante la conducción (Fuller, 2011). Según el modelo "affect infusion model" propuesto por Forgas (1995), ante un estado de ánimo con valencia emocional positiva, la persona tenderá a asumir más riesgos, ya que los aspectos positivos de la situación tomarán mayor peso y percibirá consecuencias más favorables; sin embargo, si el estado de ánimo es negativo es probable que realice menos acciones arriesgadas debido a que relacionará la acción con consecuencias negativas. En esta misma dirección, Megías et al. (2012) realizaron un estudio donde, mediante la inducción de estados emocionales negativos y positivos a través del visionado de vídeos y el recuerdo autobiográfico de sucesos con diferente valencia emocional, encontraron que el estado de ánimo negativo fue asociado con una mayor frecuencia de conductas de frenado ante situaciones arriesgadas de conducción, en comparación con el estado de ánimo positivo. De igual modo, numerosos estudios (ver Mesken, 2006, para una revisión más completa) han demostrado que un estado emocional con alta valencia positiva, como puede ser la "euforia", generaría una peor conducción, dando lugar a una mayor violación de las normas de tráfico y a un sesgo hacia conductas más arriesgadas, debido a un cambio en el umbral de percepción del riesgo.

Así, las representaciones de las situaciones en las que debemos decidir serán influidas por diversos tipos de variables, destacando en este caso, la variable emocional. Pero, como ya hemos comentado, el objetivo principal de este trabajo es estudiar los pasos posteriores a esta primera percepción de la situación.

### 5.2.2. EVALUACIÓN

El siguiente paso del proceso de toma de decisiones de riesgo en el que fijamos nuestro interés es la evaluación de alternativas. A priori, asumimos que la decisión será llevada a cabo en función del proceso de evaluación orquestado por el procesamiento racional y controlado. Por ejemplo, ante la situación de superar los límites de velocidad para llegar a tiempo a una reunión de trabajo, serán evaluadas las diferentes alternativas en función de las recompensas y castigos, en este caso, acelerar o mantener la velocidad. Si se decide acelerar, la recompensa será llegar a tiempo a la cita; a cambio, el castigo consistirá en sufrir un accidente o recibir una multa. La elección de la conducta que se crea más conveniente será consecuencia de esta evaluación previa e irá ligada al riesgo percibido. En general, cuanto mayor sea este último, mayor será la probabilidad de decidir evitar este tipo de situaciones. Pero, como veremos, la decisión tomada a raíz de una evaluación lenta y reflexiva de alternativas, no siempre se cumple.

De igual manera, este procesamiento racional y controlado permite tanto a conductores como no conductores dirimir correctamente si una situación conlleva riesgo o no, como hemos visto en nuestros resultados. Aunque los conductores obtienen menor sesgo de respuesta, los no conductores no estarían muy lejos de las respuestas adecuadas, es decir, todos los participantes detectan claramente cuando existe un peligro. La diferencia entre los grupos radica en la decisión finalmente tomada, en este caso, decidir frenar o no, la cual parece depender de otros sistemas de procesamiento que discutiremos en el siguiente apartado.

### 5.2.3. DECISIÓN

El tercer paso en el proceso descrito es la selección de la decisión que llevaremos a cabo en el contexto de riesgo. Si el modelo fuera estrictamente serial, la decisión se produciría en función de la evaluación previa. En cambio, los resultados obtenidos en nuestros estudios indican que la decisión puede corresponderse con un proceso diferenciado.

Debemos recordar que para valorar las situaciones de riesgo utilizamos dos sistemas de procesamiento que, de forma conjunta, determinan nuestra elección. Según la teoría de Epstein (1994) o la teoría del heurístico afectivo de Metcalfe & Mischel (1999), uno de los sistemas de procesamiento se caracteriza por ser predominantemente emocional y basado en conexiones asociativos aprendidas a través de la experiencia: "sistema experiencial-afectivo"; mientras que el otro sistema realizaría un análisis más racional de la situación de acuerdo a un conjunto de reglas lógicas o estadísticas: "sistema racional-analítico". El sistema experiencial-afectivo generaría respuestas rápidas y eficaces con un coste reducido en el momento de realizarlas. Este sistema estaría guiado principalmente por el concepto de "marcador somático" o "affect heuristic" (Damasio, 1994; Slovic et al., 2007).

Para analizar estos dos sistemas de procesamiento, hemos trabajado con la diferenciación conceptual entre conductas urgentes y evaluativas, las cuales han sido previamente definidas. Investigaciones previas muestran diferencias entre estos dos tipos de tareas tanto a nivel conductual como neural (Megías et al., 2011; 2015). Las tareas urgentes muestran mayor uso de áreas motoras, emocionales y activación frontal (Megías et al. 2015).

Nuestros resultados confirman una clara diferencia entre los dos tipos de tarea, evaluación y decisión (urgente). Las decisiones fueron más rápidas y más seguras que las respuestas de la tarea de evaluación. Los resultados coinciden con hallazgos previos (Megías et al, 2011, Maldonado et al, 2015) que sugieren cómo la tarea de decisión se encuentra relacionada en mayor medida con un procesamiento automático mientras que la tarea de evaluación es mediada por un procesamiento racional y controlado. En contextos de urgencia, el análisis racional (evaluación de coste-beneficio y de posibles alternativas) puede ser excesivamente demandante y requiere demasiado tiempo de procesamiento (Gilovich, Griffin, & Kahneman, 2002). Por ello, los conductores a la hora de tomar una decisión en carretera estarán guiados, en mayor medida, por heurísticos procedentes del comportamiento automático que por procedimientos inferenciales (Kinnear, Stradling, & Mcvey, 2008).

Así, en situaciones de riesgo, cuando nuestras acciones suceden bajo presión temporal y las consecuencias pueden ser muy negativas, los conductores deben haber aprendido y practicado, hasta que se convierte en un hábito, la respuesta de frenar para evitar un riesgo potencial, incluso siendo leve o poco probable. En dichos contextos, el procesamiento automático que engloba los hábitos y la experiencia sería ventajoso, ya que produciría una pronta reacción para evitar el peligro (Kinnear et al., 2008). De este modo, cuando los conductores toman la decisión de frenar podrían estar llevando a cabo un procesamiento más automático (experiencial) de las situaciones de riesgo que cuando realizan juicios evaluativos, en los que es posible un análisis más lento y racional de costes y beneficios (Gilovich et al., 2002). Guiándonos por el sistema automático, las respuestas son más rápidas y más frecuentes que la evaluación de las situaciones como arriesgadas, es decir, el riesgo está siendo evitado con el coste de tener más errores o un criterio menos conservador. El uso de estas diferentes estrategias podría explicar la falta de relación entre la evaluación del riesgo y el comportamiento real de riesgo en muchas situaciones (Reyna, 2004), así como las diferencias encontradas entre tareas en la probabilidad de respuesta, tiempo de reacción, sesgo de respuesta y sensibilidad en nuestros estudios.

Más concretamente, contemplamos la hipótesis de la existencia de dos tipos de procesamientos automáticos aplicados a la ejecución del comportamiento. Por un lado, tareas sencillas y aprendidas que implican toma de decisiones de riesgo como por ejemplo, evitar un peatón que cruza de forma inesperada. En este caso, implican un uso de heurísticos afectivos con las características descritas en el Sistema 1 o automático y basado en emociones (Slovic et al, 2007). Por otro lado, también hablamos de procesamiento automático cuando forma parte de un tipo de comportamiento experto. En este caso, a la hora de decidir en escenarios complejos, como son los de conducción, asumimos la existencia de heurísticos cognitivos o modelos mentales aprendidos a través de la experiencia y del feedback (Frank, Cohen, & Sanfey, 2009). Nuestros resultados son igualmente acordes con este último modo de procesamiento, ya que los resultados del segundo estudio muestran que la tarea de evaluación fue realizada de manera más eficaz y segura por parte de los sujetos con experiencia. Si analizamos solo las respuestas de evaluación, en el segundo experimento comprobamos cómo las personas con cierta experiencia a la hora de evaluar diferencian mejor la posibilidad de riesgo que las personas sin experiencia. Este dato guarda relación con estudios previos que demostraban que los conductores expertos detectaban peligros de manera más rápida y eficiente (Deery, 1999). Como discutiremos más tarde, las experiencias previas están modificando los modelos mentales que utilizan los conductores para decidir.

El proceso de aprendizaje hasta convertirse en un experto implica un procesamiento lento, reflexivo y demandante de recursos atencionales. En cambio, cuando el conductor se convierte en experto, desarrolla reglas procedimentales, heurísticos cognitivos, que permiten disminuir la demanda de recursos atencionales y por tanto, realizar otras tareas mientras conduce, como por ejemplo, seguir la ruta indicada en una pantalla. El aprendizaje, las reglas aprendidas y los hábitos están incidiendo sobre el comportamiento automático y sobre el proceso de evaluación.

A la hora de adquirir estas habilidades son fundamentales dos variables estudiadas, la experiencia previa con la situación y las consecuencias obtenidas, es decir, el feedback. En cuanto a la primera, en uno de los estudios incluidos en la tesis (capítulo 3), observamos que las decisiones fueron más seguras en situaciones de riesgo por parte de sujetos que tenían experiencia, es decir, los que poseían carnet de conducir. Además, eran capaces de discernir las situaciones que conllevaban riesgo de las que carecían de él mejor que los no conductores. Por tanto, los conductores no mostraban un sesgo de respuesta cuando analizamos los resultados de la teoría de detección de señales.

En cuanto a la segunda variable, hemos comprobado que los conductores también son sensibles al efecto del feedback, ya sea contingente o no-contingente, consiguiendo igualar las respuestas de los conductores y no conductores. Así, el feedback guió el comportamiento de los participantes siendo capaz de eliminar, en parte, el efecto de la experiencia.

Por tanto, como hemos visto, la experiencia en conducción permite tomar decisiones más seguras debido al aprendizaje de reglas y procedimientos que permiten la identificación ágil de señales que indican peligro. Se trataría de un "modelo mental" adquirido a través de la experiencia. De igual forma, el uso del feedback podría modificar dichos procedimientos a través del tercer "loop" descrito en la teoría de Feng y Donmez (2013) (ver Introducción, Apartado 1.5), de corte más cognitivo. Obviamente, debemos tener en cuenta que en el proceso influirán tanto componentes atencionales como cognitivos.

Si analizamos los resultados del feedback y de la experiencia en su conjunto, vemos que el sistema automático utilizaría reglas para tomar decisiones seguras. Por un lado, mediante la experiencia en conducción se consigue discernir mejor si una situación conlleva riesgo o no. Por otro lado, el feedback está modificando esa toma de decisiones promovida por el sistema automático.

Concretamente, hemos comprobado que las diferencias entre las respuestas en la tarea de evaluación y decisión tienden a desaparecer con el uso del feedback. Así, podemos declarar que el tiempo de reacción es una medida menos fiable que la probabilidad de respuesta ya que mientras que el feedback contingente está produciendo respuestas más rápidas, no siempre son las más adecuadas; en situaciones sin riesgo se está manteniendo una probabilidad de respuesta elevada.

A continuación desarrollaremos en más profundidad los resultados obtenidos en nuestros estudios relacionados con el efecto del feedback y de la experiencia previa.

### 5.2.4. FEEDBACK

Uno de los principales hallazgos del estudio es la precaución que debemos tomar con el uso del feedback. Como hemos visto, se trata de una herramienta útil para mejorar el proceso de toma de decisiones, pero debemos evitar la posibilidad de que dicho feedback sea percibido como no-contingente, ya que puede provocar la respuesta contraria a la deseada. El feedback no-contingente ha provocado una menor probabilidad de respuesta que un grupo sin feedback en nuestros estudios, llevando a cabo más comportamientos de riesgo, es decir, no decidir frenar en situaciones que conllevan peligro. Por otro lado, el feedback contingente, a pesar de producir un comportamiento más cauto ante las situaciones de riesgo, también puede producir efectos adversos como una reacción innecesaria en situaciones que no implican riesgo. Este dato se encuentra relacionado con estudios previos que analizan el tipo de feedback utilizado (Lewis, Watson, Tay, & White, 2007). Por ejemplo, el uso de una valencia excesivamente emocional puede provocar temor y maniobras erróneas, perjudicando y obstaculizando la conducción (Taylor, Deanem, & Podd, 2002).

Para clarificar los resultados, el análisis de los datos procedentes de la teoría de detección de señales fue fundamental. La discriminación, en todos los casos, fue mejor en la tarea de decisión que en la evaluación. Este resultado puede ser controvertido si conocemos las características del sistema automático, el cual está siendo utilizado en este tipo de tareas y está funcionando de manera más óptima que el procesamiento más racional, utilizado en la tarea de evaluación. Sin embargo, cuando analizamos el sesgo de respuesta, obtenemos más información sobre los procesos que están ocurriendo. El feedback de tipo no-contingente está provocando errores en la respuesta en situaciones de riesgo, produciendo respuestas más peligrosas. Por el contrario, y como hemos comentado anteriormente, el feedback contingente está produciendo errores de tipo conservador, es decir, está llevando a cabo decisiones cautelosas en situaciones en las que no hay necesidad, como son las situaciones que no implican riesgo.

Para explicar el resultado del feedback contingente nos basamos en la teoría del umbral de decisión (Simen, Cohen, & Holmes, 2006; Simen et al., 2009). Según este modelo, el feedback ofrece una señal global que ayuda a controlar el umbral de decisión durante la tarea. Cuanto mayor es la recompensa, menor es dicho umbral. Este sistema es referido tanto a la probabilidad de respuesta como a la velocidad, es decir, el tiempo de reacción. En estudios previos, se ha mostrado el análisis de un equilibrio entre el coste de respuesta rápida y el beneficio de recompensa rápida. No solo se produce con recompensas, también con la posibilidad de escapar de consecuencias hostiles. Un estímulo desagradable puede disminuir el umbral de decisión y aumentar la velocidad de respuesta, sin escoger necesariamente la opción correcta (Niv et al., 2007; Contreras, Megías, Maldonado, Candido, & Catena, 2013).

En el segundo estudio (capítulo 3), la respuesta con feedback no-contingente fue también más rápida que la del grupo control, a diferencia de lo ocurrido en el primer estudio (capítulo 2), donde el feedback no-contingente disminuía la velocidad en la respuesta. Este dato plantea dudas en cuanto a su explicación y debe ser tenido en cuenta para investigaciones futuras. Lo que sí clarifica es la necesidad de insistir en el análisis de la probabilidad de respuesta en mayor medida que el tiempo de reacción, siendo la probabilidad una medida más fiable.

La teoría del umbral de decisión aportaría evidencias sobre la mayor velocidad de respuesta con feedback contingente o la menor velocidad utilizando un feedback no-contingente, pero no termina de explicar el efecto producido en la probabilidad de respuesta, es decir, escoger opciones de peligro con el feedback no-contingente. En nuestro caso, no frenar en situaciones de riesgo. Para indagar en los efectos producidos es necesario recurrir a modelos mentales complejos como el descrito a continuación.

El modelo general de Feng y Donmez (2013), resumido en la introducción, pretende abordar la efectividad del feedback mediante diferentes procesos. Basándonos en el modelo, la contingencia del feedback podría tener dos efectos principales en el proceso de toma de decisiones de riesgo en escenarios complejos como la conducción.

En primer lugar, el feedback contingente podría afectar el primer proceso, aumentando la atención hacia las características de la situación y aumentando la velocidad de la respuesta. El resultado opuesto, obtenido por el uso del feedback no-contingente, podría producir déficits en la atención dedicada a la escena, provocando respuestas más lentas y menos frecuentes en este tipo de situaciones (más arriesgadas). Es interesante reseñar que las teorías atencionales coinciden con modelos de aprendizaje que explican el efecto de la experiencia previa con un feedback no-contingente. Dicha experiencia previa provocaba dificultad en el aprendizaje de una nueva tarea por pérdida o déficit en la atención a las características de la tarea (Bennet et al., 1995). Por otro lado, el feedback puede afectar, siguiendo la teoría de Feng y Donmez (2013), a un proceso de corte más cognitivo, produciendo un cambio en el modelo mental utilizado por los conductores. Así, es posible desarrollar reglas para ser utilizadas en el proceso de toma de decisiones en conducción. Un feedback de tipo contingente permitirá desarrollar decisiones más seguras, menos arriesgadas, al contrario que un feedback de tipo no-contingente.

### 5.2.5. APRENDIZAJE

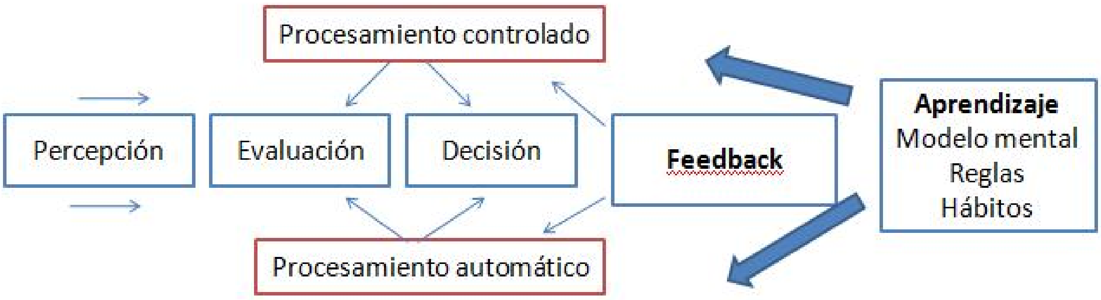
Como ya hemos comentado, la conducción constituye una actividad compleja que implica el aprendizaje previo de reglas y conductas seguras en diferentes situaciones y escenarios, las cuales dependen de habilidades cognitivas y de habilidades de toma de decisiones, por ejemplo, el reconocimiento de peligro, la búsqueda visual o control atencional y del vehículo. Así ha sido constatado en estudios previos (Megías et al. 2017; Lehtonen, Lappi, Koirikivi, & Summala, 2014; Sagberg, & Bjørnskau, 2006). Dichas habilidades cognitivas son adquiridas mediante aprendizaje y experiencia, por lo que la práctica en carretera desarrollará habilidades de procesamiento automático, como fue demostrado en otras investigaciones (Sagi et al., 2012).

La complejidad de este aprendizaje es una de las características que diferencia esta actividad (conducción) de otras que también implican procesamientos automáticos. Un conductor con experiencia ha desarrollado habilidades de atención, percepción y reglas de conducción segura (Bjørnskau and Sagberg, 2005). Todo ello permitirá evaluar de manera adecuada las situaciones de riesgo y tomar la decisión más acertada, como ha quedado demostrado en nuestro trabajo.

En la misma línea, como comentamos al inicio, la conducción es una actividad en la que realizar comportamientos de riesgo incluye unos beneficios mínimos en comparación con los elevados costes. Por ejemplo, viajar en autovía a 140km/h para conseguir llegar al destino quince minutos o media hora antes. El coste es elevado, sufrir un accidente. Para evitarlo y elegir la decisión más adecuada, es decir, viajar a una velocidad máxima de 120km/h, se debe producir un correcto aprendizaje.

Gran parte de los estudios previos han focalizado el interés en los primeros pasos del proceso, en la manipulación del contexto (Slovic et al, 2007) o en el papel de los factores emocionales (Pessoa, 2009; Megías et al, 2011). Nuestro estudio reconoce

Proceso de toma de decisiones en situaciones de riesgo



## 5.3. MECANISMOS CEREBRALES

Para estudiar los mecanismos cerebrales subyacentes al proceso de toma de decisiones en situaciones de riesgo partimos del estudio de resonancia magnética funcional realizado por Megías et al. (2015). En dicho estudio se muestra cómo las decisiones en contextos urgentes, como el abordado a lo largo de nuestro trabajo, está guiado por emociones y conexiones estímulo-respuesta asociadas al contexto. Este proceso fue reflejado en un incremento en la activación de la ínsula y en el córtex cingulado anterior, regiones implicadas en el procesamiento emocional (Bechara & Damasio, 2005). Además, también se encontró activación de áreas ejecutivas incluyendo corteza prefrontal ventrolateral y dorsolateral derecha en la realización de la tarea urgente.

Así, la toma de decisiones de riesgo en contextos urgentes no es solo el resultado de mecanismos de razonamiento deliberado sino también mecanismos más automáticos, como el sistema experiencial-afectivo, ejecutados por señales emocionales de peligro (Vorhold et al., 2007).

El tercer estudio de la tesis (capítulo 4) aporta datos sobre el funcionamiento del feedback en tareas urgentes a nivel neuronal. El grupo con feedback contingente, comparado con el no-contingente y un grupo control, obtuvo una mayor amplitud del potencial evocado N400 durante el procesamiento de la imagen en la que tenían que decidir. Dicho potencial ha sido asociado con el control cognitivo y con resolución de conflictos (Bland & Schaefer, 2011; Wang et al., 2004). Este resultado apoya la modificación del comportamiento a través del feedback debido a cambios en el sesgo de respuesta. Los cambios implican suprimir una tendencia de respuesta previa y sustituirla por una respuesta más segura para adaptar nuestro comportamiento a las nuevas reglas establecida por el feedback. Cuanto mayor sea la diferencia entre las respuestas previas y las nuevas, más control cognitivo será necesario para resolver la situación (Bland, & Schaefer, 2011). Este esfuerzo cognitivo fue reflejado en la amplitud del N400 durante el proceso de toma de decisiones.

En segundo lugar, se mostró un potencial evocado SPN, anticipando la señal del feedback, mayor en el grupo con feedback no-contingente comparado con el contingente y el control. Estudios previos han mostrado cómo el componente SPN puede estar relacionado con la incertidumbre sobre las consecuencias de la respuesta (Catena et al. 2012; Fuentemilla et al., 2013). En este caso, la falta de contingencia entre la respuesta y el feedback negativo provocaba una alta incertidumbre ante el resultado, reflejada en un elevado SPN.

Por último, fue analizado un tercer potencial, el FRN. La variación en la puntuación del FRN ha sido estudiada en la literatura como un índice neural sensible a la valencia del feedback, que indica el valor adquirido por los resultados a lo largo del proceso de aprendizaje (Cohen, Elger, & Ranganath, 2007). La puntuación del FRN fue menor en el grupo no-contingente comparado con el contingente, pudiendo reflejar que el feedback no-contingente fue menos relevante a la hora de tomar una decisión. En el grupo no-contingente, los participantes aprenden rápidamente la falta de relación entre sus respuestas y las consecuencias (feedback) y, por tanto, el feedback deja de ser relevante para la tarea. Esto lleva a prestar una menor atención a la situación, provocando un mayor número de respuestas arriesgadas. Estos resultados guardan relación con estudios anteriores (Holroyd & Coles, 2002; Luque et al., 2012).

Así, los datos obtenidos a través de técnicas encefalográficas sustentan los resultados obtenidos en los dos primeros bloques experimentales. Utilizar el feedback en el proceso de toma de decisiones provoca cambios en el sesgo de respuesta. Dichos cambios dependen de la contingencia del feedback. Cuando es aplicado de manera contingente a la respuesta, la adaptación provoca un conflicto entre el anterior y el nuevo comportamiento, reflejado en una mayor demanda de recursos de control cognitivo y, por tanto, mayor N400. Una vez producida la respuesta, los participantes predijeron de manera más sencilla el feedback cuando era contingente a dicha respuesta. Además, la mayor incertidumbre provocada por el feedback no-contingente fue reflejada en un mayor SPN y la puntuación del FRN fue esclarecedora en cuanto a las diferencias entre los dos tipos de feedback; el de tipo no-contingente perdía su relevancia para la tarea de decisión.

En definitiva, los datos electroencefalográficos enmarcados en este trabajo apoyan la distinción de situaciones de riesgo complejas donde se debe tomar una decisión. Demuestran los diferentes procesos que se llevan a cabo en función de la tarea que demanda una respuesta (urgente o evaluativa) y dependiente de las consecuencias obtenidas por la decisión, es decir, el diferente tipo de feedback. Es útil e interesante seguir esta línea de investigación y una propuesta futura será utilizar técnicas como la resonancia magnética funcional para explorar las áreas particulares implicadas en el proceso.

## 5.4. APLICACIONES

La presente tesis aporta información sobre el proceso de toma de decisiones en situaciones complejas que implican riesgo. Hemos comprobado que, a diferencia de los modelos seriales de toma de decisiones, es pertinente un estudio más integrado de los modelos mentales utilizados. Han quedado demostradas las interacciones entre los componentes del sistema automático y del sistema racional. El procesamiento y toma de decisiones en situaciones de riesgo depende de la experiencia previa y pueden ser modificados mediante un uso adecuado del feedback.

El estudio del proceso de toma de decisiones en situaciones de riesgo cuenta con importantes aplicaciones en el ámbito de la seguridad vial. A la hora de desarrollar programas de penalización (p.ej. multas o pérdida de puntos), los resultados obtenidos en nuestra investigación sobre el uso del feedback pueden ayudar a mejorar la efectividad de estos programas. Aunque la efectividad del feedback contingente ha sido nuevamente demostrada, hemos observado que en situaciones que no implican riesgo, dicho tipo de feedback puede provocar un comportamiento excesivamente conservador. En el ámbito de la seguridad vial, este hallazgo se encuentra directamente relacionado con los accidentes de alcance. De ahí la importancia del cumplimiento de normas de seguridad como mantener una distancia prudente con el automóvil que viaje delante.

Además, uno de los principales hallazgos del estudio es que el feedback no-contingente o la percepción de no contingencia entre el comportamiento y las consecuencias pueden tener resultados indeseados. Por ejemplo, recibir una multa por una actuación que el conductor considera adecuada puede provocar una decisión menos segura en futuras ocasiones. El tipo de contexto puede también motivar que un mismo tipo de feedback provoque efectos diferentes en distintos conductores debido a características personales como la edad (Begg & Langley, 2001, Donmez et al., 2006) o rasgos de personalidad (Gulliver & Begg, 2007) entre otras. La influencia de la propensión al riesgo, extraversión o impulsividad, debe ser tenida en cuenta para limitar la generalización de los resultados (Nicholson et al., 2005; Edman, Schalling, & Levander, 1983).

En la misma línea, hemos observado la importancia de la experiencia previa a la hora de decidir en situaciones que implican riesgo. En el ámbito de la seguridad vial, los participantes de nuestro estudio que contaban con experiencia en la conducción discriminaron mejor las situaciones de riesgo en comparación con los participantes sin carnet. Esto demuestra la importancia de desarrollar programas de prácticas y entrenamiento aplicando el feedback de manera adecuada para poder desarrollar modelos mentales capaces de tomar la decisión más segura en situaciones de riesgo.

Además, los datos que extraemos de este estudio pueden aportar información útil para el desarrollo de dispositivos programados para realizar la función de feedback de manera eficiente durante y después de la conducción. Dicha eficiencia del feedback puede contribuir a la mejora de la seguridad vial.

Por último, el ámbito estudiado ha sido limitado al de la conducción y seguridad vial. Debemos ser cautos si extrapolamos los resultados obtenidos a otros procesos de toma de decisiones de riesgo como pueden ser los juegos de azar o inversiones económicas (Alos-Ferrer et al, 2014).

## 6. GENERAL CONCLUSION

The main aim of this work was the study of the decision-making process in complex situations involving risk. The context of driving was chosen to analyze this process. The present thesis includes three experimental studies which show different information related with the decision making process.

The first experimental study (chapter 2) focused on the feedback effect in risky driving situations. Results showed how a contingent feedback led to faster and safer responses than a control group without any feedback; whereas a non-contingent one gives rise to slower responses and, more importantly, an enhanced risk-taking behavior that could be the cause of undesirable effects on road safety. The feedback effect was even more evident in the appearance of an opposite response bias as a function of contingency and enhanced by learning. These results accord with the theoretical accounts based upon the feedback influence on the threshold level of decision making. These findings suggest how riskier and safer decision-making could be more dependent on the experiential automatic processing system than on the rational-controlled system. Unexpectedly, in the second experimental study (chapter 3), the contingent feedback in non-risky situations also resulted in both drivers and non-drivers making somewhat inaccurate risk evaluations and decisions. In the case of driving, it leads to an over-evaluation of the possible danger, and, more importantly, to an over-reaction in the presence of minimal threats, which can be the cause of “rear-end accidents” due to the unaware reactions of the other drivers. The knowledge of these effects highlights the importance of preventive measures such as keeping a safe distance between drivers, learning to take into account the possible decisions of other drivers, and appropriate education based on correct feedback.

The second experimental study (chapter 3) differentiated between urgent and evaluative behaviors. Urgent behavior depends on stimulus, involves time pressure and negative consequences. It is based on system 1 or automatic, which uses previous experience and emotional characteristics of the situation. On the other hand, evaluative behavior consists in merely evaluating the risk of a situation without negative consequences. This task involves a more controlled process based on logical rules; it is system 2 or rational-analytic. The results of the study confirmed a clear difference between evaluations and decisions in complex risky situations.

An objective of the thesis was to study the interaction between feedback effect and driving experience. Any type of feedback, contingent or not, decreased the reaction time but non-contingent feedback involved riskier responses. It is important the fact that feedback effect eliminates differences between decision and evaluation task. When we analyze the effect of experience, participants with driving license distinguished better between risky and not risky situations than novel participants. But this learning effect was eliminated by the feedback effect. Thus, the use of feedback could be a useful tool to develop rules that influence the automatic system, building a mental model with safety behavior.

Third experimental study (chapter 4) analyzed neural and cognitive mechanisms involved in risk behavior and the processing of the feedback using electrophysiological techniques (EEG). The results were focused on three evoked potentials. The N400 amplitudes can be considered an index of the conflict level generated by the risk situation. As the new behavior is better learned and replaces the old one, the between-responses conflict must diminish, and therefore, the demands for cognitive control associated with N400 will also decline. Thus, this ERP component may be a useful tool for evaluating learning processes. Moreover, FRN amplitude can also be used as an index of the relevancy and efficacy of feedback. Finally, once participants gave their response, a stronger SPN anticipating the presence of the feedback signal was found in the non-contingent group compared with the contingent group. SPN component may be related to uncertainty about the consequences of a response. In the present study, the lack of contingency between the response and the negative feedback (non-contingent group) led to a higher uncertainty preceding the outcome, giving rise to a stronger SPN (Catena et al., 2012). Feedback characteristics can be adapted in accordance with this index to enhance the effectiveness of behavior modification techniques.

In summary, taking all the results together, we provide useful information about the decision making process in complex risky situations like driving. Feedback could be a useful tool to prevent risky behaviors but it is important the efficiency of the application. Moreover, the analysis of the automatic system has shown the importance of developing mental models which involve safety behavior. It can help drivers to learn, and repeatedly practice until it becomes in a habit, the response of braking to avoid any potential risk, even when this is small or uncertain.

The data for this work were obtained using driving contexts so we should be cautious if we talk about other types of complex risky situations. Nonetheless, this study contributes to knowing more about the decision making process. It can be used to encourage the use of feedback in integrated devices in cars or to develop road safety penalty programs with the objective of reducing the number of accidents caused by risky behavior.

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