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Individual differences in risk-taking and behavioural modification

Perfil y modificación del comportamiento de riesgo

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SUMMARY

Risk-taking occurs in a variety of contexts, characterized by a high probability of negative consequences including financial, health, and social harm. Risk-taking is addressed in several decision-making models, one of which is the dual system model. This model proposes that two competitive brain systems - the intuitive and the analytic system - interact to give rise to risky or non-risky behaviours. Several neuroscientific models, widely supported by the literature, propose this hypothesis to explain risk-taking behaviour at the brain level, suggesting brain areas related to reward and emotion processing for the intuitive system and regions related to cognitive control for the analytic system. Besides creating a theoretical framework, research has also identified internal and external factors that influence risk-taking, such as emotions, age, social context, and personality traits that also show brain correlates in overlapping brain areas associated to risk-taking.

Efforts to design intervention programs to reduce risk-taking and mitigate negative consequences usually rely on behavioural approaches using feedback and penalty of risky behaviour. However, these programs have shown several limitations and new approaches are emerging, including components of cognitive interventions, such as mindfulness-based training. Various studies have already shown a positive impact of such interventions on risky behaviour. In addition, post-intervention brain changes seem to be consistent with brain correlates found in risk-taking research.

Based on these previous findings, in the three studies that compose this doctoral thesis, we aimed to study two factors related to risk-taking: the social context and individual differences in related personality traits. In addition, we explored the effectiveness of a mindfulness-based training on risky behaviour. In all studies we used traffic environments because traffic is a risk-taking context common to almost everyone that involves possible negative consequences not only at the personal but also at the societal level.

In study 1 we tested the effect of the presence of peers on the risky behaviour of emerging adults. In adolescents, the presence of peers has been found to trigger risk-taking, supposedly due to adolescents' incomplete brain development, and heightened sensitivity and activity of brain areas supporting emotion and reward processing. In study 1 found reduced risk perception and increased risky behaviour in a driving simulation task when the peers were together. We also observed differential brain activity in areas related to cognitive control and reward and emotion processing. These areas can be classified into social clusters, dependent on the peer´s presence, and non-social clusters, independent of the social context. A lower number of functional connectivity links between these areas accounted for the driving performance in the peer's presence compared to his/her absence. Altogether, these findings indicate that the presence of a peer triggers the activation of a different, less efficient brain network for risk-processing, entailing less risk perception and increased risky behaviour.

In study 2 we focused on the cerebral correlates of individual differences in impulsivity and sensation-seeking in relation to the predisposition to engage in risky behaviour. Previous research has identified similar brain correlates for these individual differences but their relation has not been studied. Comparing highly risk prone and non-risk prone individuals, we observed different associations of functional connectivity during risk discrimination and several facets of impulsivity and sensation seeking traits. Differences were observed in within- and between-network connectivity of cognitive control and reward and emotional related nodes. In general, the results show that risk propensity modulates the links between individual differences in impulsivity and functional connectivity in a way that seems to prepare the brain for an immediate, automatic, and maladaptive response.

In study 3 we aimed to study the effectiveness of mindfulness-based training in risky drivers. In previous research individual differences in dispositional mindfulness have been related to reduced risk behaviour in traffic environments and mindfulness-based programs have been found to reduce risk-taking in other contexts. In study 3 we found less self-reported risky driving after the intervention program and identified the individuals with low dispositional mindfulness as the ones who benefit most of the program. The study provided evidence for the effectiveness of mindfulness-based training programs for traffic rule offenders, highlighting the importance of individual differences in the achievement of behavioural changes.

In conclusion, the studies presented in this thesis build on former research showing risk propensity to be related to brain areas associated to cognitive control and emotional and reward processing. They provide evidence for the brain correlates of influential factors in risk-taking and for the potential of mindfulness-based training to reduce risky behaviour, emphasizing the relevance of individual differences.

RESUMEN

El comportamiento de riesgo existe en diferentes contextos y se caracteriza por una alta probabilidad de conllevar consecuencias negativas a nivel económico, de salud y social. Su estudio está enmarcado en modelos actuales de toma de decisiones, como el modelo del sistema dual, que propone la interacción de dos sistemas competitivos, uno intuitivo y el otro analítico, que podrían llevar a un comportamiento arriesgado o no arriesgado. Varios modelos neurocientíficos, ampliamente estudiados y confirmados en la literatura, se basan en este enfoque para explicar el comportamiento de riesgo a nivel cerebral, incluyendo áreas cerebrales relacionadas con el control cognitivo para el sistema analítico y áreas relacionadas con el procesamiento de emociones y recompensa para el sistema intuitivo. Aparte de la investigación enfocada en modelos teóricos, también se han estudiado factores internos y externos que influencian la toma de riesgo, como la edad, las emociones, el contexto social y los rasgos de personalidad, todos ellos teniendo bases cerebrales que se solapan con las de la propensión al riesgo.

Los programas de intervención orientados a reducir el comportamiento de riesgo se han basada en enfoques conductuales, por ejemplo, aplicando feedback y sanciones en el caso de conductas arriesgadas en conducción. Sin embargo, este tipo de programas ha mostrado limitaciones, por lo que se están desarrollando nuevas estrategias incluyendo componentes de intervenciones cognitivas, como el entrenamiento basado en mindfulness. Varios estudios han confirmado ya un impacto positivo en el comportamiento de riesgo, como también se han observado modificaciones a nivel cerebral congruentes con las bases cerebrales del comportamiento de riesgo.

Los tres estudios que componen la presente tesis doctoral tienen el objetivo de estudiar dos de los factores más importantes que influencian el comportamiento de riesgo, el contexto social y diferencias individuales en rasgos de personalidad relacionados, así como el objetivo de explorar la efectividad de un entrenamiento en

mindfulness para la reducción del comportamiento de riesgo. En todos los estudios usamos el contexto de la conducción, ya que es un contexto cotidiano con el que la gran mayoría de las personas está familiarizada, además de que en este contexto el comportamiento de riesgo entraña posibles consecuencias negativas no solo a nivel personal sino que también tiene un alto impacto negativo para la sociedad.

En el estudio 1 evaluamos el efecto de la presencia de un igual en adultos emergentes, que en adolescentes ha mostrado de forma consistente un aumento en el comportamiento de riesgo, y que está suele explicarse aludiendo a diferencias en el desarrollo de circuitos cerebrales relacionados con la emoción y la recompensa, lo que se traduce en una sensibilidad incrementada a la presencia de iguales. Aunque los estudios en jóvenes adultos no son consistentes en cuanto al efecto de la presencia del igual, nosotros encontramos una reducción en la discriminación de las situaciones de riesgo y un aumento en el comportamiento de riesgo en una tarea de conducción simulada. Además observamos actividad cerebral diferencial en áreas relacionadas con el control cognitivo y el procesamiento de emociones y recompensa, clasificándolas en clústeres sociales, que dependen de la presencia/ausencia del igual, y clústeres no sociales, que se activan independientemente del contexto social. Un menor número de conexiones funcionales explica las variables de la conducción simulada cuando el igual está presente en comparación con la ausencia del igual. Estos resultados indican que la presencia de un igual provoca la activación de una red cerebral diferente y menos eficiente para el procesamiento de riesgo, promoviendo una diminución de la percepción de riesgo y un aumento del comportamiento de riesgo.

El estudio 2 está enfocado a las bases cerebrales de la relación entre diferencias individuales en impulsividad y búsqueda de sensaciones dependiendo de la predisposición a comportarse de forma arriesgada. Aunque estudios previos han identificado bases cerebrales similares a los de estas diferencias individuales, no se ha estudiado la relación entre esos rasgos de personalidad. Comparando personas arriesgadas con no arriesgadas, observamos diferentes asociaciones entre la conectividad funcional durante la evaluación de riesgo y varias facetas de los rasgos de impulsividad y búsqueda de sensaciones. Encontramos diferencias en función de la tendencia al riesgo en la conectividad funcional entre nodos de la misma red y entre redes asociadas al control cognitivo y el procesamiento de emociones y recompensa. En suma, los resultados demuestran que la propensión al riesgo modula la relación entre diferencias individuales en impulsividad y conectividad funcional de tal forma que parece preparar el cerebro para una respuesta inmediata, automática y poco adaptativa.

El objetivo del estudio 3 fue estudiar la efectividad de un entrenamiento en mindfulness en conductores arriesgados. En estudios previos se ha encontrado que diferencias individuales en la tendencia de ser mindful están relacionadas con menor comportamiento de riesgo en contextos de conducción, además de que el entrenamiento en mindfulness ha sido eficaz para reducir la toma de riesgo en otros contextos. Encontramos menor conducción arriesgada autoinformada después de la intervención, el mismo nivel de mindfulness disposicional, e identificamos a las personas con menor tendencia a ser mindful como las que más se beneficiaron de la intervención. En este sentido, demostramos la efectividad de un entrenamiento en mindfulness para conductores infractores, destacando la importancia de las diferencias individuales en mindfulness disposicional para el cambio conductual.

En conclusión, los estudios muestran que la propensión al riesgo está relacionada con áreas cerebrales asociadas al control cognitivo como también al procesamiento de emociones y recompensa. Aportan evidencia clara de las bases cerebrales de factores que influencian el comportamiento de riesgo, así como de la

efectividad de un programa de intervención basado en mindfulness para la reducción del comportamiento de riesgo, y enfatizan la relevancia de las diferencias individuales.

INTRODUCTION

Theoretical framework of risk-taking behaviour: The two brain systems hypothesis

Risk-taking behaviour can be defined as actions or activity characterized by a heightened, but uncertain probability to obtain negative, significant consequences (Rayner & Cantor, 1987; Yates & Stone, 1992). As risk-taking behaviour can be done in different contexts (Weber, Blais, & Betz, 2002), negative outcomes of these behaviours also depend on these contexts, and can be classified, besides others, into health consequences (e.g. disabilities, death, illness/disease), economic consequences (e.g. loss of savings, job loss), and social consequences (e.g. disdain of others, social isolation), apart from psychological consequences, which might be entailed by the former ones (e.g. anxiety, depression, feeling of guilt).

To explain why people engage in risk-taking, it is worth it looking into decision-making processes preceding these behaviours. Most decision-making models distinguish five different stages: beginning with the representation of the situation; evaluation of possible behaviours with its associated outcomes; the decision about action and its performance; the valuation of outcomes and consequences of the behaviour; and finally, a learning process, which influences the evaluation stage of following similar decisions to make, thus, postulating that risk-taking is greatly influenced by previous, positive or negative, experience (Rangel, Camerer, & Montague, 2008).

Cognitive decision-making models have focused on this first stage, such as the dual system model, which is one of the most used at the moment. It proposes that we decide and select options using one or the interaction of two different brain systems: one system being analytical, slow, rational, and conscience; and the other being intuitive, fast, emotional, and automatic (Evans, 2008; Frankish, 2010; Kahneman & Frederick, 2002; Loewenstein, Weber, Hsee, & Welch, 2001; Reyna, 2004; Slovic, Finucane, Peters, & MacGregor, 2004). The analytic system would evaluate different variables and possible outcomes of potential behaviours, calculating the most appropriate election, while the intuitive system would depend on previous experience and the current emotional state, generating an automatic, learned behaviour (Frankish, 2010). An example would be a young person driving to a concert of his/her favourite band getting late. Under this emotional state, the decision might be more influenced by the intuitive system resulting in exceeding the speed limits to get on time. Hereby, the activation of the intuitive system might lead, in this situation, to heightened risk-taking behaviour. Nonetheless, in other situations the activation of the intuitive system might result in lowered risk-taking through emotions like anxiety, which inhibit the person to act in a risky way. For instance, if the youth sees an accident on the way to the concert, he/she might be sensitised and would drive slower. The contribution of the analytic system would be greater in low emotional situations and without time pressure. To sum up, it depends on the situation and other factors if the activation and interaction of the two systems involved in the decision-making process lead to a safer or a riskier behaviour.

This dual system model was confirmed, besides others, in our research group, in an experiment using risk perception in traffic pictures, comparing an urgent task, under time pressure, triggering the intuitive system, and an evaluative task, without time pressure, triggering the analytical system. The mere observation and evaluation of traffic scenes caused higher reaction times, less risk perception, and a better discrimination of risk vs no-risk situations, while the decision to brake or not if the person would see his-/herself in this traffic situation was faster and more cautious (perceiving more risk), but being less accurate in the discrimination of risk vs no-risk. The results for the urgent task are congruent with a faster and emotion based decision-making processing, and the results of the evaluative task with a slower and rational one (Megías, Cándido, Maldonado, & Catena, 2018; Megías, López-Riañez, & Cándido, 2013; Megías et al., 2015; Megías, Maldonado, Cándido, & Catena, 2011).

At brain level, the analytic system would be represented by cortical areas and networks related to cognitive control and executive functions (especially prefrontal and parietal, as well as cingulate cortices) and the intuitive system by mostly subcortical structures linked to rewarding and emotional processing (mainly striatum, ventral prefrontal cortex, insula, and amygdala) (Casey, Jones, & Hare, 2008; Steinberg, 2010). We tested the cerebral correlates of the beforehand mentioned two tasks experiment, showing greater activity of prefrontal areas in the evaluative and greater activity of the insula and the anterior cingulate cortex, an emotion-related areas, in the urgent task (Megías et al., 2015).

Moreover, in other neuroimaging studies risk-taking was often done in a financial framework, such as inversion and bets, using tasks with risk being defined with mostly known, exact probabilities to lose or win, while more naturalistic tasks modelling real-world situations, that is, are more similar to situations in different life-domains, were less used (Schonberg, Fox, & Poldrack, 2011). However, in general, and despite of the great variety in task characteristics, such as ambiguity, uncertainty, similarity to real-world situations, and type of reward and feedback, brain areas involved in different tasks seem to be roughly comparable. Differential brain activity related to risk-taking was found mostly in prefrontal and parietal areas (Blankenstein, Schreuders, Peper, Crone, & van Duijvenvoorde, 2018; Coutlee, Kiyonaga, Korb, Huettel, & Egner, 2016; Tom, Fox, Trepel, & Poldrack, 2007), subcortical areas, like the striatum (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Pletzer & Ortner, 2016; Tom et al., 2007), the insula (Canessa et al., 2017; Morriss, Gell, & van Reekum, 2019; Pletzer & Ortner, 2016), and the amygdala (Hsu et al., 2005). This provides evidence of the participation of the two brain systems in risky decision-making.

Influential factors in risk-taking

As risk-taking is the result of a decision-making process, it is not surprising that a lot of factors are influencing the process of the evaluation of benefits and costs of the potential behaviours and its outcomes. In this way, several factors can increase or reduce this type of risky choices and activities. The most prominent in research are gender and age, with men and younger people being more risk prone. While for differences between men and women controversial findings in different risk-taking contexts (Nelson, 2018; O'Dowd & Pollet, 2018; Reniers, Murphy, Lin, Bartolomé, & Wood, 2016) make it difficult to draw general conclusions, age seems to be negatively associated to risk-taking all over the world, independently from cultural differences (Mata, Josef, & Hertwig, 2016), and peaking between adolescence and emerging adulthood (Duell et al., 2018). Actually, in traffic environments it was found that repeat offenders are normally men under 40 (Barry Watson, Watson, Siskind, Fleiter, & Soole, 2015), and that risk-taking behaviour is one of the most important cause of the high accident rate among youths (World Health Organization, 2007, 2018).

According to the dual system model, the effect of age appears because of the slow and incomplete maturation of the analytic system which in emotional situations is still not able to downregulate the intuitive system which is highly sensitive (Steinberg, 2010). This is congruent with findings in brain development, where cortical areas, and especially cognitive control areas involved in the analytic system, develop slowly and are not fully mature until the mid-twenties, whilst subcortical structures like the ventral striatum, associated with the intuitive system, are readily developed in the adolescence (Casey, Heller, Gee, & Cohen, 2019; Casey et al., 2008; Giedd, 2004; Steinberg, 2008). As a consequence, adolescence is often seen as a large period starting in puberty and ending in emerging adulthood, and risk taking is progressively reduced with age (Casey, 2015). This is an important point, as many of the real life risk-taking behaviours causing a high rate of fatalities does not begin until legal age, for example in driving or alcohol consumption.

Another influential factor, already mentioned in the dual system model, are emotions. They can alter the decision-making process through the activation of the intuitive system, and lead to an emotion-driven behaviour, more than to a rational choice. For instance, it was shown that emotional loaded pictures can shorten reaction times and generate more cautious behaviour in risk-taking tasks (Megías, Di Stasi, Maldonado, Catena, & Cándido, 2014; Megías, Maldonado, Catena, et al., 2011; Serrano, Stasi, Megías, & Catena, 2014). On the other hand, positive emotions seem to elicit more risk behaviour (Megías, Maldonado, Catena, & Cándido, 2012).

Moreover, a factor that also influences the risk, benefits, and costs evaluation of certain behaviour is the social context, likely being related to emotions produced by the people who are around us. In this way, decision-making is dependent on whom we are with, in a specific moment, and whom we would harm. For instance, mothers driving with her children were found to perceive more risk than when being with a colleague (Megías, Cándido, Catena, Molinero, & Maldonado, 2014), showing the influence of the social context to more cautious acting.

Now, this is different for young people when they are with peers, showing that heightened risk-taking at this age is even more boosted in the context of same aged colleagues. Getting back to the example of the youth exceeding the speed limits, we can add that he/she is not alone but with a friend. The thrill and excitement level, in this case, would be much higher being enhanced by the admiration of the other peer. As the opinion and acceptance of peers is essential in this life period, the presence of another peer acts as a positive emotional reinforcement, rewarding risk-taking and bravery of the acting peer. The interaction of these three different influential factors (emotions, social context, and age) is called the peer-effect (Albert, Chein, & Steinberg, 2013; Casey et al., 2008; Gardner & Steinberg, 2005; Steinberg, 2007, 2010).

At brain level, this could be explained with the highly sensitive intuitive system at this developmental stage showing high activity to peer presence, and lowered activity of the analytic system related to cognitive control areas and networks, together leading to a heightened risk-taking (Albert et al., 2013; Chein, Albert, Brien, Uckert, & Steinberg, 2011; Leung, Toumbourou, & Hemphill, 2014; Sherman, Greenfield, Hernandez, & Dapretto, 2018; Sherman et al., 2019; Telzer, Fuligni, Lieberman, Miernicki, & Galván, 2015; Vorobyev, Kwon, Moe, Parkkola, & Hämäläinen, 2015).

In the literature it is discussed at what age this effect is present, and findings are controversial, since many studies found the peer-effect in early adolescence and low or no effect in older participants (for instance, Breiner et al., 2018; Chein et al., 2011; Smith et al., 2018), while other studies still found the same effect in the emerging adults (for instance, Gardner & Steinberg, 2005; O'Brien, Albert, Chein, & Steinberg, 2011; Sherman et al., 2019; Silva, Chein, & Steinberg, 2016; Weigard, Chein, Albert, Smith, & Steinberg, 2014).

Finally, and although this thesis is focused on age, emotions, and social context, which are factors with a large amount of research in the literature, and which generally influence risk-taking in most contexts, there are multiple more factors that have an important role in more specific tasks. For instance, fatigue was found to trigger risk-taking behaviour in long monotone tasks (Di Stasi, Álvarez-valbuena, et al., 2009; Di Stasi, Marchitto, Antolí, Baccino, & Cañas, 2010; Morales, Ruiz-Rabelo, Diaz-Piedra, & Di Stasi, 2019).

Altogether, a great amount of external factors was observed to influence decision-making resulting in risky behaviour and should therefore be controlled for, explored as main effects, as well as their interaction between each other.

The influence of personality traits on risk-taking behaviours

We have seen until now that risk-taking behaviour depends on a wide variety of external factors, influencing the everyday activities of everyone. However, there are individuals that assume more risks for the same benefits than others, so that not only external, but also internal variables seem to be important in risk-taking research. Actually, individual differences in risk-taking behaviour itself can be considered a personality trait-like characteristic of a person. It can be categorized in different types, according to the context in which it is performed: financial, recreational, health and security, ethical, or social risk-taking. This differentiation is crucial, since individuals are not equally risk prone in all contexts, seemingly to be different in rating different types of risks, benefits or costs of the behaviour and outcomes (Weber et al., 2002).

Neuroimaging studies on individual differences in risk propensity have focused on behaviour in risky situations or decisions, exploring risk aversion and seeking. Some evidence has been provided that similar regions as general risk-taking show differential activity (Canessa et al., 2017, 2013; De Martino, Camerer, & Adolphs, 2010; Tom et al., 2007). Nonetheless, most of these studies used the behavioural parameters of the task to calculate loss aversion and risk seeking. This fact is important to take into account when generalizing results, as these measurements may not be the same in different contexts and real-life situations. Thus, more research is needed into risk propensity as personality trait which may be related to differential brain activation and structural brain variance.

Other individual differences extensively related to risk-taking behaviour in the literature are impulsivity, sensation seeking, and dispositional mindfulness. The first two are quite similar, actually, there are models including sensation or novel seeking as a facet of impulsivity (Cyders et al., 2007; Whiteside & Lynam, 2001), while others define sensation seeking as an independent personality trait with a disinhibition facet which represents impulsive behaviour (Zuckerman, 1971). Distinctive facets of impulsivity are lack of planning, mood-based impulsive behaviour, and lack of perseverance or premeditation (Cyders & Smith, 2007), and distinctive facets of sensation seeking are thrill and adventure seeking, experience seeking, and boredom susceptibility (Zuckerman, 1971). Together they may be resumed as a mainly emotion-driven behaviour without reasoning much about outcomes, and thereby their association to risk-taking is fairly reasonable and confirmed in different risk-taking contexts (Beanland, Sellbom, & Johnson, 2014; Donohew, Zimmerman, Cupp, & Novak, 2000; Wong & Carducci, 1991; Zuckerman & Kuhlman, 2000). Coming back to the previous example, thinking of a more impulsive individual, it seems much more probable that he/she speeds to get on time to the concert, as well as thinking of a person with high sensation-seeking who probably even enjoys the sensation of speeding.

Actually, research in risky behaviour in adolescence and emerging adulthood used impulsivity and sensation seeking as indicators to explore the reasons of risk-taking, although different researcher propose different models (Shulman et al., 2016). It seems that impulsivity reduces progressively with age, representing the maturing of cognitive control areas and networks, and sensation-seeking has its highest expression in the adolescence, representing the maturing and sensitivity of brain regions and networks related to rewarding processes, thereby being in line with developmental approaches (Shulman et al., 2016; Steinberg, 2010)

In fact, impulsivity has been linked to very similar brain regions as risk-taking behaviour, focusing on prefrontal areas, mostly the inferior frontal gyrus, and anterior cingulate regions, which are known to be involved in impulse control (Aron, Robbins, & Poldrack, 2004; Brevet-Aeby, Brunelin, Iceta, Padovan, & Poulet, 2016; Fineberg et al., 2014; Muhlert & Lawrence, 2015; Robbins & Dalley, 2017). Sensation seeking, studied to a much lesser extent than impulsivity, was associated to differential activity in the insular and ventral and medial prefrontal cortex, as well as in subcortical regions, a set of brain areas that have been linked to emotion processing (Cservenka, Herting, Seghete, Hudson, & Nagel, 2013; Joseph, Liu, Jiang, Lynam, & Kelly, 2009).

Another personality trait-like characteristic, which has been more recently related to risk-taking, is dispositional mindfulness. It is generally defined as the capacity of a person to self-regulate attention to one’s experience in the present moment and acceptance (Bishop et al., 2006), though, similar to impulsivity and sensation seeking, different approaches include other facets, such as the ability to describe emotions and sensations (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Rau & Williams, 2016). Dispositional mindfulness was negatively associated to different risk-taking behaviours, including smoking, drinking, gambling, risky driving, and general health and security risk-taking (Black, Sussman, Johnson, & Milam, 2012; Koppel et al., 2018; Lakey, Campbell, Brown, & Goodie, 2007; Murphy & Matvienko-Sikar, 2019; Reynolds, Keough, & O'Connor, 2015; Shook et al., 2019; Young et al., 2019).

This trait was linked to higher activity in prefrontal areas, including these of cognitive control (Creswell, Way, Eisenberger, & Lieberman, 2007; Modinos, Ormel, & Aleman, 2010), and less cerebral reactivity to emotional laden stimuli (Brown, Goodman, & Inzlicht, 2013). However, as a new emerging field, more research is needed with higher sample sizes to provide more evidence of the association of dispositional and risk-taking, as well as its brain correlates.

In summary, impulsivity, sensation seeking, and dispositional mindfulness, are not only related to risky behaviours, but also seem to have similar brain correlates, sharing associations to areas related to cognitive control and emotion processing.

Behavioural modification techniques

Looking at the maintenance of risk-taking behaviours from a learning approach, these behaviours may be strengthens by operant conditioning processes. These models suggest that behaviour can be reinforced by positive, and downregulated by negative outcomes (Candido, 1996; Maldonado, 2015). For instance, the young driver accelerating and exceeding speed limits to get on time, may not get fined or have an accident, but probably is feeling positive emotions like excitement or thrill. These two facts together may cause repeating the behaviour, maintaining, or even increasing its frequency. In this way, not getting a negative consequence, and even being reinforced by positive emotions, can strengthen risk-taking and its frequency.

Therefore, from the behavioural model point of view, interventions to reduce these behaviours should give negative feedback or punish the person in a way that risk-taking is reduced to avoid negative consequences. Indeed, studies have shown that behavioural feedback with pictures inducing a negative emotion, result in less risk propensity and less risk-taking (Maldonado, Serra, Catena, Cándido, & Megías, 2016; Megías, Cortes, Maldonado, & Cándido, 2017), as well as loosing points when not deciding to brake in a risky traffic situations (Torres, Megías, Catena, Cándido, & Maldonado, 2017), enhancing electrophysiological indices of cognitive control (Megías, Torres, Catena, Cándido, & Maldonado, 2018).

Nonetheless, this approach has some limitations in risk-taking modification, as it seems to work best with little delay between risk behaviour and negative outcomes or feedback (Mangiapanello & Hemmes, 2015). This may be one of the big problems of the point based system in traffic rule regulation in Europe, as the way in which fines are processed they delay negative outcomes, payment and penalty. Furthermore, not all risk-taking is detected and fined, and respecting rules may not be enough rewarded. Considering the reasons of risky driving, there is a great amount different factors, including lack of concentration or stress, which triggers risky behaviour through negative emotional states.

Addressing the reduction of these promoting factors, instead of penalty of behaviours, gives rise to new intervention approaches. Between other intervention programs including relaxation and cognitive and behavioural therapies (Deffenbacher, 2016), a mindfulness-based training (Kabat-Zinn, 1990), which includes, apart from meditation exercises, elements of cognitive therapies, like training in emotion regulation strategies, has been proposed (Scholten et al., 2019).

As seen earlier, dispositional mindfulness was negatively related to risk-taking, indicating that people being more “mindful” engage in less risky behaviour. There is also research showing benefits of this type of trainings in reduction of risk-taking, such as drug use and psychological disorders linked to risky behaviours (Brewer et al., 2011; Cairncross & Miller, 2016; Cavicchioli, Movalli, & Maffei, 2018; Davis et al., 2014; Kass, VanWormer, Mikulas, Legan, & Bumgarner, 2011; Khoury et al., 2013; Koppel et al., 2019; Stephens, Koppel, Young, Chambers, & Hassed, 2018; Vidrine et al., 2016). The first studies even show changes in brain areas related to emotional processing and cognitive control (Fox et al., 2014; Tang, Hölzel, & Posner, 2015), confirming the first hypotheses and being a good start point for future research.

Taken together it seems that brain mechanisms of mindfulness-based trainings and meditation in general enhance the functioning of brain networks and areas risk-taking behaviour was linked to, as well as it reduces emotional states that triggers risky behaviours. However, these trainings have mostly been studied in clinical risk-taking, as drug abuse or suicidal behaviour (Cavicchioli et al., 2018; Khoury et al., 2013), but little research has explored the effect as a complementary training for sub-clinical risk-taking, such as intervention programs in everyday life risk-taking.

RATIONALE AND AIMS

Taking into account previous research, this doctoral thesis addresses external and internal factors of risk-taking behaviour and the underlying brain activity. As stated, there are still knowledge gaps in the way internal and external factors influence risk-taking and interact with each other, what are the brain areas and networks that support it, as well as in the effect and mechanism of intervention programs to modify risky behaviours.

Study 1 was aimed to uncover the effects of social context in risk-behaviour and its cerebral correlates (estimated using EEG recordings) in emerging adults in ecologically valid risk perception tasks. Both topics have been extensively studied, but important knowledge gaps remain on the effects of the type of dyad (same/different sex), the age, and the ecological validity of task. Moreover, we used a two stages design, with a primary risk perception task and a delayed secondary motorcycle simulation to determine whether brain areas involved in the primary task allow to predict risk behaviour in the delayed secondary one.

Study 2 was aimed at disentangling whether the association between impulsivity and sensation-seeking traits and brain connectivity (estimated using EEG recordings) depends on risk proneness. We used an a priori approach to first compute the connectivity between seven main brain networks (visual, somatosensorial, dorsal and ventral attention, limbic, fronto-parietal and default mode), and then determine whether the association between impulsivity/sensation-seeking and the between- and within-networks connectivity is modulated by the tendency to take risks (risk proneness).

Study 3 explores the effectiveness of a new emerging mindfulness-based intervention program to reduce risk-taking in applied settings. As indicated before, a number of findings reported in literature suggest that mindfulness training is able to strengthen the functioning of brain cognitive control areas. Moreover, the literature also suggests that failures in these control areas can account for heightened risk behaviours. Therefore, we used risk prone individuals in the traffic domain to uncover whether mindfulness-based training specifically oriented to driving is able to improve risky driving in every-day settings.

In all three studies traffic environments are used, as these are common to almost all people, ensuring a minimum of experiences and the possibility to generalize results, as well as it is not limited to a little range of age or only a proportion of the whole population. Also, it is a factor of high social impact, with a huge social, economic, and health consequences.

Thus, the general and specific aims for each study are as followed:

1. Test cerebral correlates of risk-taking triggered by social context
    a. Assess the effect of the presence of same-aged peers (same/different sex dyads) in emerging adults in a risk perception task and an ecological driving simulation.
    b. Explore brain areas related to social context effects.
    c. Predict risk behaviour from brain connectivity.

2. Evaluate whether the associations between personality traits (impulsivity and sensation seeking) and brain functional networks connectivity depends on the individual risk-proneness.
    a. Test risk perception differences in highly risk-prone and non-risk prone individuals.
    b. Determine whether personality traits (impulsivity and sensation-seeking) allow to classify individuals as risk or non-risk prone individuals.
    c. Compare the relation of the brain connectivity with impulsivity and sensation seeking in risk takers to non-risk takers.

3. Explore effects of a mindfulness-based training on risk-taking behaviour
    a. Contrast the effect of a mindfulness-based training on self-reported risky driving.
    b. Test for the influence of dispositional mindfulness at baseline on the effect of the training.

STUDY 1

Social and non-social brain areas in risk behaviour: The role of social context

Baltruschat, S., Megías, A., Cándido, A., Maldonado, A., & Catena, A. (Submitted). Social and non-social brain areas in risk behaviour: The role of social context. *Cerebral Cortex*

INTRODUCTION

Adolescence and emerging adulthood are characterized by maturation in cognitive, emotional and social abilities, along with a heightened propensity towards risk-taking behaviour, encouraged by the presence of peers (Albert et al., 2013; Crone & Dahl, 2012; Knoll, Leung, Foulkes, & Blakemore, 2017; Silva et al., 2016). In fact, risk-behaviour is the main causal factor of fatalities in youths, with road traffic accidents being the leading cause of death (World Health Organization, 2018), particularly when they are speeding with peers (Allen & Brown, 2008).

This enhanced tendency to take risks (Steinberg, 2008) has been interpreted as stemming from differences in the development of the brain network underlying the processing of affect, incentives and reward, and that of the network supporting cognitive control and behaviour regulation (Casey, 2015). Thus, a heightened sensitivity to reward and sensation seeking, and a weak impulse control system, that is not yet strong enough to regulate behaviour under highly emotional situations, could account for impulsive and risky behaviour (Romer, Reyna, & Satterthwaite, 2017; Shulman et al., 2016; Steinberg et al., 2018; Yoneda, Ames, & Leadbeater, 2019). Given that the behaviour of youths is highly influenced by the opinions of their peers (Gorrese & Ruggieri, 2013; Reiter, Suzuki, O'Doherty, Li, & Eppinger, 2019), the presence of peers is suggested to affect activity in areas involved in the processing of the reward, as the ventral striatum or the orbitofrontal cortex (Chein et al., 2011; Leung et al., 2014; Sherman et al., 2018, 2019; Telzer et al., 2015), which might foster risk-taking behaviours (Figner, Mackinlay, Wilkening, & Weber, 2009; Gardner & Steinberg, 2005). Support for this idea is provided by studies observing higher activity in the reward network (ventral striatum and orbitofrontal cortex (OFC)) during an urgent decision-making task, while adolescents are observed by peers (Chein et al., 2011).

However, findings related to differences in the cognitive control network in adults and youths as a function of the social context are not yet clear. This network, that support the regulation of actions and thoughts in accordance with current goals, embrace a large set of areas, including the frontoparietal, the cingulo-opercular networks, and some subcortical structures (Fan et al., 2014). Few studies have found effects of social context (peer influence) in the activation or connectivity of these areas, or even lack to find any differences (Breiner et al., 2018; Chein et al., 2011; Sherman et al., 2019; Smith et al., 2018). Using the go/no-go task, purported to recruit response inhibition, Smith et al. (2018) observed a null behavioural effect of the peer presence and a minimal one in the right posterior middle frontal gyrus, a region not commonly thought to support cognitive control. Neither Chein et al. (2011) found differential activity in cognitive control areas using the Stoplight task. However, using a social go/no-go task, Breiner et al. (2018) observed brain activation differences as a function of the peer presence/absence, but restricted to the 13-17 years old condition and using a non-corrected whole brain statistical approach. In stark contrast, Sherman et al. (2019) observed larger connectivity of the anterior insular cortex in the peer than in the alone condition with the stoplight task, but not with the go/no-go one. Moreover, behavioural peer effects were neither observed in the stoplight, nor in the go/no-go tasks.

These results suggest that the cognitive control network is scarcely affected by the peers' presence, what is unexpected from the maturational theoretical approach, and difficult to accommodate within this framework. Factors as age, behavioural task or ecological validity of the peer manipulation can be at the base of these mixed results.

The most common peer manipulation used are either virtual peers (simulated people not related in any way with the participant, (Breiner et al., 2018; Sherman et al., 2019), the sole presence of the peer (commonly observing from an adjacent room, (Chein et al., 2011; Smith, Steinberg, Strang, & Chein, 2015), or the mere knowledge about peers (Kwon, Vorobyev, Moe, Parkkola, & Hämäläinen, 2014; Vorobyev et al., 2015). It has been shown, that the mere presence of peers (friends) do not seem to influence risky choice (Somerville et al., 2019), and that believing the social interaction is taking place with another human versus a computer driven system activates different brain areas, especially in the prefrontal cortex (Pfeiffer et al., 2014). However, no research has considered ecological validity of social context manipulation, with the exception of Cascio et al. (2015), who used a confederate in their driving simulator session. They found that control cognitive network activation (basal ganglia and right inferior frontal gyrus) predicts safer driving in the presence of cautious passengers. It is worth noting, that Cascio et al. (2015) used a car simulator to assess the peer effect, which suggests that ecological validity of the social context can be a factor to consider when trying to account for the diversity of results on the cognitive control network and risk behaviour. It is also surprising, that no author has considered the gender of the peer, although some research has suggested that it could be a factor of variance in different types of risk-taking behaviours (Eisenberg, Golberstein, & Whitlock, 2014; Simons-Morton, Lerner, & Singer, 2005). Furthermore, using videos of interacting real peers, Ambrosia et al. (2018) have observed that activity in ventromedial prefrontal cortex moderate the association between reciprocal positive affect of peers and risky behaviour.

Our study is rooted in three pillars: actual *social context*, so that each participant was asked to do the task in close contact with a good friend (Ambrosia et al., 2018) , seated behind while also doing the task; the *type of dyad*, so that we defined three types: man-man, woman-woman and woman-man/man-woman; and *authentic potentially risky settings*: photographs of high-/low-risk traffic scenes to assess risk perception and simulator riding (Cascio et al., 2015) to quantify risky behaviour in medium-fidelity scenes. Within a brain-as-predictor scheme, we used brain sources estimated from high-density EEG recordings of the risk perception task as predictors of the driver's behaviour on the motorcycle simulator, from which we consider number of accidents and average speed as indicators of risky driving. To enhance ecological validity of our Social Context manipulation, the drivers performed the risk perception task seated in the motorcycle simulator.

METHOD

Participants

A total of 114 dyads took part in this study. The dyads were friends of similar age, and same/different gender. All participants had a driver’s license and were aged 18-28 years (*M* = 21.43, *SD* = 2.13). Sample size was calculated to 100 dyads with G-power (for a power of .8, α = .05, and a small effect size Cohen’s d = .25). We added 14 dyads to ensure a sufficient sample size in case of possible drop-out. Since the experiment was conducted in dyads, 114 of the participants were contacted and asked to bring a close friend of the same or the opposite gender (3 dyads were not included in the analyses because of EEG recording errors), resulting in two different dyad types, 78 same-sex (39 woman-woman) and 33 different-sex pairs (woman-man/man-woman). Each participant got paid for their participation in the study, and was informed about their rights according to the Helsinki declaration (World Medical Association, 2008). This study was approved by the Human Research Ethics Committee of the University of Granada (167/CEIH/2016) and all experiments were performed in accordance with relevant guidelines and regulations.

Procedure

The participants first gave written informed consent, and filled in a questionnaire to collect information on demographic variables. They performed the risk perception task with the dyad seated in the motorcycle simulator, one in the rider’s and the other in the passenger’s location (Peer condition, the "driver" and the "passenger"), and separated in different rooms (Alone condition), while brain activity was recorded with Electroencephalogram (EEG).

Risk perception task

We used the *SR Research Experiment Builder* (SR Research Ltd., Missessauga, Ontario, Canada) to present a set of 140 real traffic pictures taken from the driver´s perspective. The pictures were selected from a traffic risk scenes database (Baltruschat, Cándido, Megías, Maldonado, & Catena, 2020; Megías et al., 2015), with 70 of the pictures depicting a high-risk scenes (for instance, crossing pedestrians, animals on the road, or cars which are about to cross just in front), and the other 70 depicting a low level of risk. All stimuli were displayed with a refresh rate of 60 Hz at a distance of 185-200 cm on a screen (180 x 110 cm) projected on the wall in front of the participants. In the Peer condition, participants were not allowed to interact, but they were in close contact, as they both were seated on the seat of the motorcycle simulator. In the Alone condition, the driver performed the task in the same room, and the passenger completed the task in another room of the laboratory with stimuli displayed with a refresh rate of 100 Hz at distance of 100cm on 40 x 30 cm screen.

Each trial of the task began with a 750 ms fixation point in the centre of a white screen followed by an image of a traffic scene for 2000 ms. The task consisted of indicating whether or not the depicted traffic scene was risky, responding only when the participant perceived the scene as risky, and not responding at all if he/she perceived the scene as non-risky. After 2000 ms, a black screen was displayed for 750 ms (for examples and task description see supplementary Figure S1). The driver participant always responded with the motorcycle controls and the passenger clicking mouse buttons. Immediately after the risk perception task, the driver drove two circuits of the simulator, one with the peer sitting behind him in the Peer condition and alone in the Alone condition.

The proportions of hits (yes responses after a high-risk scene) and false alarms (yes responses after a low-risk scene) were computed for each subject, as well as signal detection theory discrimination (*d'*) and response bias indices.

Motorcycle Riding Simulation

The Honda Riding Trainer motorcycle simulator (HRT) consisted of a seat, handlebar, pedals, accelerator, brakes, turn indicators and a claxon (see Di Stasi et al. (2009), for a full description of the HRT simulator). The simulation was projected with the same dimensions as the stimuli of the risk perception. Participants rode through an urban road scenario that includes 8 risk situations (e.g. sudden opening of the doors of parked cars or pedestrians suddenly crossing the road). The number of accidents and the average speed were calculated for each participant and peer condition.

Brain sources estimated from EEG recordings

Electrical brain activity was recorded with a 62 active channel system (Brain Products, Inc.) with tin active electrodes mounted on an elastic cap arranged according to the extended 10-20 system. EEG recordings were referenced online to FCz, sampled at 1000 Hz and amplified using a 0.016-1000 Hz band-pass filter. During the recording, impedances were below 25 kΩ, which is the recommended value of the manufacturer of the system.

EEGLAB toolbox for MATLAB (Delorme & Makeig, 2004) (http://sccn.ucsd.edu/eeglab) was used for the offline preprocessing. EEG recordings were downsampled to 250 Hz, re-referenced offline to average reference, and FCz activity was recovered. Channels with flatline duration of more than 50 seconds or with excessive line noise relative to its signal (4 *SD*) were identified using the EEGLAB plugin clean_rawdata (freely available at https://sccn.ucsd.edu/wiki/EEGLAB_Extensions). Bad channels were interpolated with the spherical spline method included in EEGLAB software. Bad channels average was 3.5 (*SD* = 3.0). Recordings were then segmented from -200 to 1600 ms time-locked to the stimulus onset, and baseline corrected. Independent Component Analysis (ICA) was computed using the Second Order Blind Identification algorithm (SOBI, Tang, Sutherland, & McKinney (2005)), and ocular and muscle artifacts were removed using the EEGLAB plugin ADJUST (Mognon et al. (2011), http://www.unicog.org/pm/pmwiki.php/MEG/RemovingArtifactsWithADJUST), after visual inspection of ICA classification. An average of 30.6 ICAs (*SD* = 20.5) were discarded. EEG segments were averaged for each channel, risk condition, and subject.

Average ERPs for each participant and condition were used to estimate the brain sources of scalp potentials using the standardized low resolution brain electromagnetic tomography software (sLORETA; Pascual-Marqui (2002), that estimate the current source density in the sLORETA solution space based on the Montreal Neurological Institute (MNI) atlas.

Statistical analyses

Our statistical analysis develops in three stages according to a brain-as-predictor scheme. Firstly, behavioural data of the risk perception task were used to determine the effect of the Dyad Type (between groups: man-man (MM), woman-woman (WW), mixed: women-man (WM)/ man-woman (MW)), Social Context (repeated measures: Peer, Alone), and Picture Risk Level (repeated measures: high-risk, low-risk). Therefore, three repeated measures ANOVA were performed in each group (passengers and drivers). Taking proportions of risk responses, consisting in hits and false alarms (yes responses in high- and low-risk scenes, respectively as dependent variables, a 2 x 2 x 3 experimental design with Social Context (Peer and Alone) and Picture Risk Level (low- and high-risk) as within-subject factors, and Dyad Type (MM, WW, WM/MW) as between-group factor was used. For the discrimination index d' and response bias as dependent variable, a 2 x 2 experimental design with Social Context (Peer and Alone) as within-subject factor, and Dyad Type (MM, WW, WM/MW) as between-group factor was used. Age and sex do not covary with neither dependent nor independent variables, and therefore, were not further considered. Analyses of these data were done with IBM SPSS statistical software (Version 21.0., IBM Corp., Armonk, NY, 2012).

Second, estimations of brain activity were analyzed for the highest interaction observed in the behavioural analysis, comparing high- vs low-risk pictures in both, the Peer and Alone condition. This analysis was performed in sLORETA, and clusters were labelled using the Brainnetome atlas (Fan et al. (2016), http://atlas.brainnetome.org).

Our third goal was to predict behavioural performance of the motorcycle simulation (total number of traffic accidents and average speed) from functional connectivity, with a backward stepwise multivariate multiple regression analysis. The functional connectivity between the significant clusters observed in the Risk Perception Task was computed on the average of voxels within the cluster with the L1-regularized partial correlation FSLnets (fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSLNets). Tested lambda regularization values ranged from 0 to 100 in steps of size 10. The selected lambda value (= 30) was the one with the minimum sum of squared prediction errors. All the analyses for the brain activation and connectivity data were conducted on averages normalized by subject. Corrections for the multiple comparison problem were done using a permutation-based two-tailed paired max t-test.

RESULTS

Behavioural results

Risk perception task. The repeated measures ANOVA for the drivers' proportion of risk responses (hits and false alarms; yes responses in high- and low-risk scenes, respectively) yielded significant main effects of the Social Context, $F(1, 107) = 19.94$, $p < .001$, $\eta_p^2 = .157$, and the Picture Risk Level, $F(1,107) = 3448.67$, $p < .001$, $\eta_p^2 = .97$, as well as the interaction between these two factors, $F(1, 107) = 21.07$, $p < .001$, $\eta_p^2 = .16$. No other effects of the Dyad Type were significant (all p > .24). For the passengers, the results follow the same pattern: $F(1, 107) = 39.08$, $p < .001$, $\eta_p^2 = .27$, $F(1,107) = 2665.4$, $p < .001$, $\eta_p^2 = .96$, and $F(1,107) = 15.16$, $p < .001$, $\eta_p^2 = .12$, respectively for main effects of Social Context, Picture Risk Level and interaction of the two factors.

The analysis of the Social Context x Picture Risk Level interaction for the drivers showed that the proportion of hits were higher for the Alone (.83, *SD* = .16), than for the Peer (.79, *SD* = .16) condition, $p < .001$. Proportions of false alarms were, however, similar for both conditions ($p = .22$; Alone = .11, *SD* = .11; Peer = .10, *SD* = .09). Differences in the proportion of hits were also observed for passengers (.81 vs .75, Alone vs Peer), but there were also differences in the proportions of false alarms ($p < .001$; Alone = .13, *SD* = .12; Peer = .11, *SD* = .10).

Next, we used signal detection theory indexes to compute the ability to discriminate (*d'*) high- from low-risk pictures, as well as response bias. For both, drivers and passengers, we observed larger d' for the Alone (drivers = 2.61, *SD* = .05; passengers = 2.41, *SD* = .05), than for the Peer (drivers = 2.41, *SD* = .04; passengers = 2.19, *SD* = .05) condition (drivers: $p < .001$, $\eta_p^2 = .22$; passengers: $p < .001$, $\eta_p^2 = .25$). Similarly, for both, drivers and passengers, response bias was larger for the Peer (drivers = .27, *SD* = .05; passengers = .31, *SD* = .05), than for the Alone (drivers = .15, *SD* = .06; passengers = .13, *SD* = .06) condition ($p < .001$, drivers: $\eta_p^2 = .12$; passengers: $\eta_p^2 = .25$). Again, no effects of the Dyad Type, neither for drivers, nor for passengers, were observed (all $p > .48$).

Motorcycle simulation. The number of accidents was larger for the Peer (.57, *SD* = .06) than for the Alone (.40, *SD* = .06) condition ($p < .04$, $\eta_p^2 = .04$). The 49.5% of the drivers had at least one accident in the Peer condition, but only a 32.4% had one in the Alone condition. However, average speed was larger for the Alone (23.22 Km/h, *SD* = .47) than for the Peer (22.29 Km/h, *SD* = .45) condition ($p < .001$, $\eta_p^2 = .12$). No effects of the Dyad Type were observed (all $p > 0.43$).

Differential brain activity during the risk perception task

Differences between brain activity for high- and low-risk scenes were significant for both Social Context conditions (Table 1, Figure 1, Supplementary Table 1).

We observed clusters that showed this differential activity for both, the Peer and the Alone condition (Table 1: Peer & Alone rows, Figure 1: green areas), with t-peaks located at left area 13, with the cluster extending into the left medial OFC (l_mOFC (P&A)) (High < Low-Risk), right dorsal agranular insula , with the cluster extending into the right medial OFC (r_mOFC/AI) (High > Low-Risk), and right medial area 8 with the cluster extending into the bilateral cingulate gyrus (bil_CG (P&A)) (High > Low-Risk).

A second type of cluster showed differences only in the Peer condition (Table 1: Peer rows, Figure 1: orange and yellow areas), with t-peaks in left rostral area 45 with the cluster extending into the left ventrolateral prefrontal cortex (l_VLPFC (P)) (High < Low-Risk), right lateral area 11 with the cluster extending into the right medial OFC (r_mOFC (P)) (High < Low-Risk), and right caudal area 22 with the cluster extending into the right superior temporal gyrus (r_STG (P)) (High > Low-Risk).

Table 1. Clusters showing differences between high- and low-risk traffic scenes as a function of the Social Context. Peer: clusters showing differential activation exclusively when the task was performed with a peer. Alone: clusters activated exclusively when the driver performed the task without peer. Peer & Alone: clusters activated when drivers performed the risk perception task with and without the peer.

	Cluster			Peak					
Condition	Name	Location	k	H	*t*	X	Y	Z	Area
Peer	l _VLPFC (P)	Ventrolateral PFC	182	L	-5.53	-45	45	0	A45r
	r_mOFC (P)	Medial orbitfrontal C	6	R	-4.31	20	45	-20	A11l
	r_STG (P)	Superior temporal C	15	R	4.63	65	-30	10	A22c
Alone	bil_OFC (A)	Orbitofrontal C	161	L	-5.57	-10	25	-15	A13
	r_DMC (A)	Dorsomedial C	243	R	6.14	10	15	45	A8m
	l_DMC (A)	Dorsomedial C	14	L	5.12	-35	-30	45	A1/2/3
Peer & Alone	l_mOFC (P&A)	Medial orbitofrontal C	69	L	-5.50	-15	25	-15	A13
	r_mOFC/AI (P&A)	Medial orbitofronal C/ agranular insula	53	R	-5.68	30	25	5	dla
	bil_CG (P&A)	Cingulate C	63	R	6.19	5	15	40	A8m

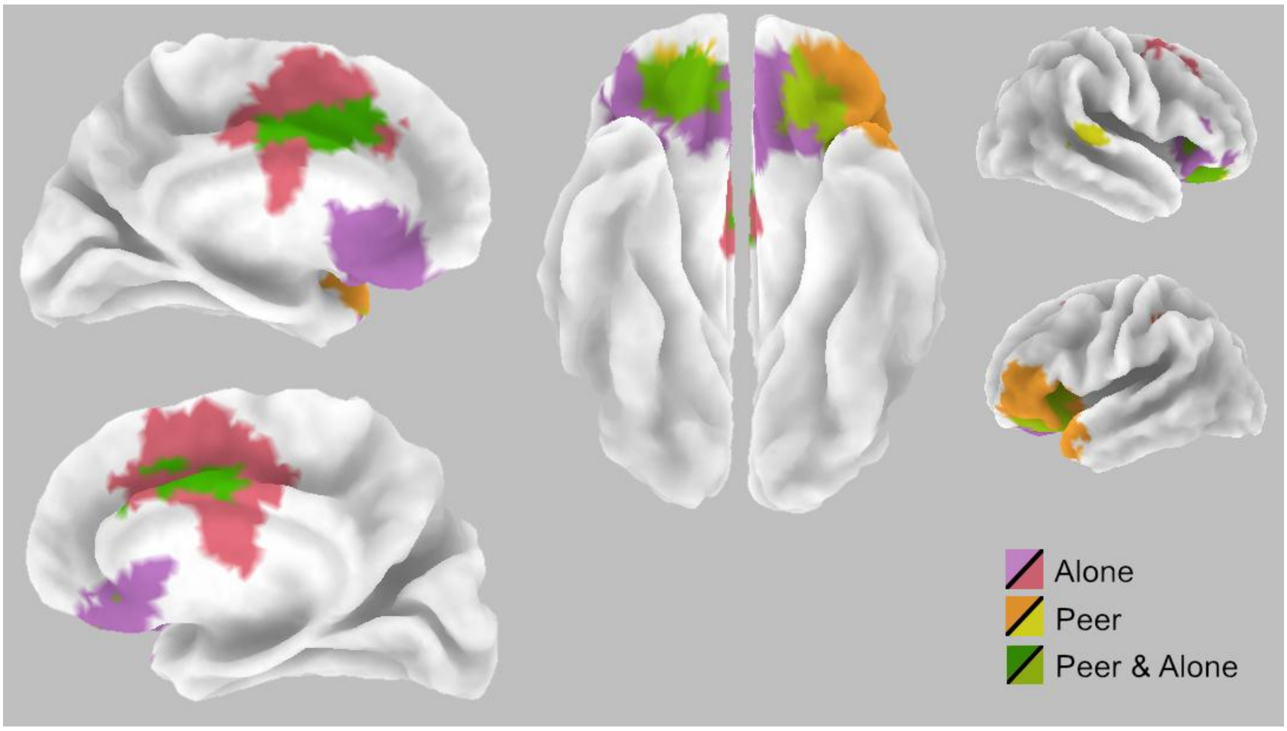
Note: H: Hemisphere; A: brain area; c, caudal; C, Cortex; G, gyrus; hf, head and face m, medial; op, opercular; r, rostral; v, ventral. X, Y, Z are in MNI space. k: number of voxels. Corrected p-values < .05.

The third type of cluster (Table 1: Alone rows, Figure 1: violet and pink areas) showed differences only in the Alone condition, with peaks in left area 13 with the cluster extending into the bilateral OFC (bil_OFC (A)) (High < Low-Risk), right medial area 8 with the cluster extending into the right cingulate gyrus and dorsomedial cortex (r_DMC (A)) (High >Low-Risk) and left area 1/2/3 with the cluster extending into the post-central, cingulate gyrus and dorsomedial cortex (l_DMC A)) (High > Low-Risk). No effects of the Dyad Type were observed (all $p > .11$).

Brain-as-predictor results

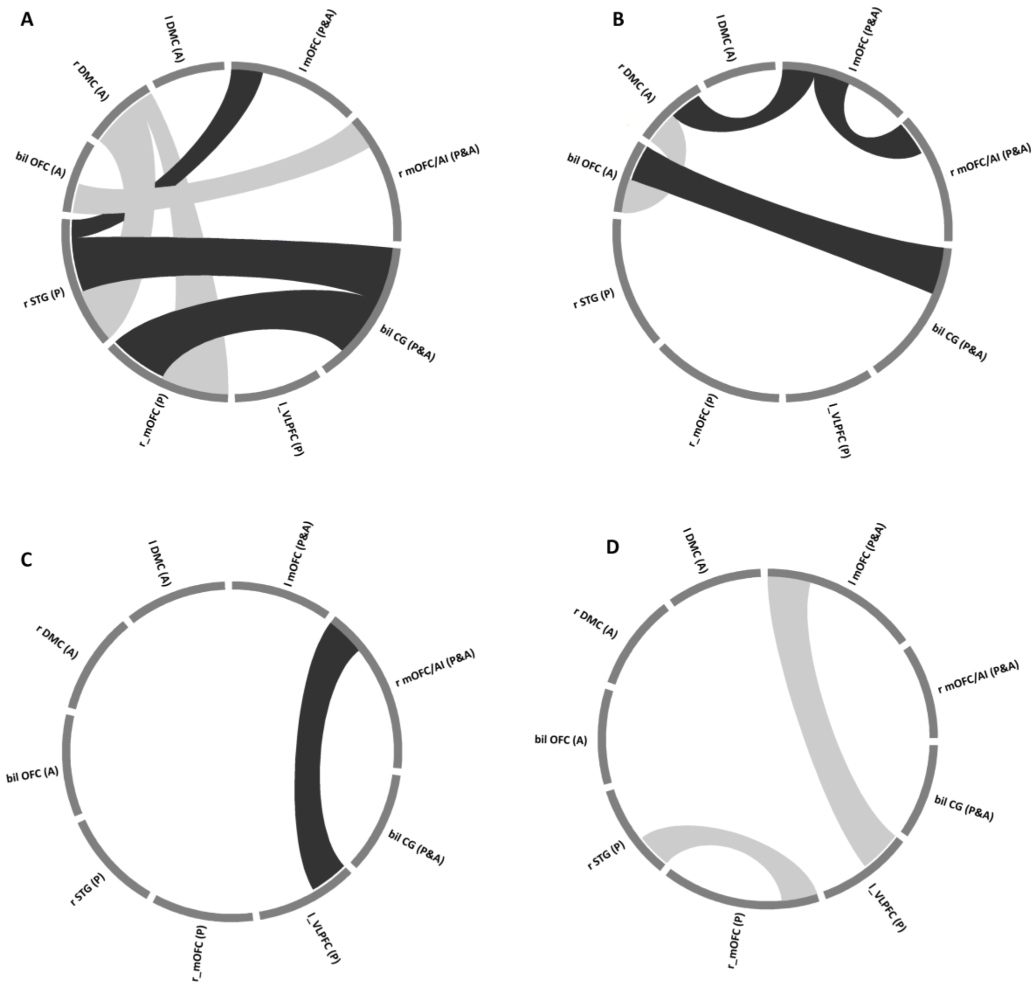
Functional connectivity for the Peer condition accounted for the 5.6% ($p < .007$) of the variability of the number of accidents and for the 12.7% of the variability of average speed ($p < .001$) during the Peer condition. Functional connectivity for the Alone condition accounted for the 27.3% of the variability of the number of accidents ($p < .001$) and for the 14.4% of the variability of average speed ($p < .001$) in the riding Alone condition. Figure 2 depicts the links that make a significant contribution to these predictions. Panels A and C indicate that more links are related to the number of accidents in the Alone (A) than in the Peer condition (C). In the Alone condition, the higher the connectivity of the bil_CG (P&A)) with the r_mOFC (P) and with the r_STG (P), the lower the expected number of accidents ($r = -.43$ and $r = -.39$, respectively). Moreover, the larger the connectivity of r_DMC (A) with r_mOFC (P) and with r_STG (P), the larger the expected number of accidents ($r = .48$ and $r = .38$, respectively). The connectivity of bil_OFC (A) with r_mOFC/AI (P&A) is also positively associated with the number of accidents. In stark contrast, in the Peer condition, only the connectivity of l_VLPFC (P) with r_mOFC/AI (P&A) is (negatively) associated with the number accidents when riding with the peer.

Figure 1.Color-coded clusters for the High/Low-Risk contrast as a function of the Social Context manipulation, medial, ventral, and lateral views. Alone: clusters showed differential activation exclusively when the driver performed the task without peer. Peer: clusters activated exclusively when the task was performed with a peer. Peer & Alone: clusters activated when drivers performed the risk perception task with and without the peer.



The links that accounted for the average speed when riding with the peer are depicted in panels B and D of Figure 2. The connectivity of the l_mOFC (P&A clusters) with r_mOFC/AI (P&A) and r_DMC (A), and that of this last area with bil_OFC (A) are negatively associated with speed during the Alone condition (r = -.25, -.23, and -33, respectively). However, the link between bil_OFC (A) and r_DMC (A) was positively related to average speed in this condition (r = .24). In the Peer condition, higher speed is expected when the connectivity between l_VLPFC (P) and l_mOFC (P&A), and that of r_STG (P) with r_mOFC (P) (r = .28, .23, respectively) is higher.

Figure 2. Functional connectivity between significant clusters of the risk perception task, associated with the motorcycle simulation performance. A and C display the links that account for the number of accidents when riding alone (A) and with a peer (C). B and D display the links that account for the average speed when riding alone (B) and with a peer (D). Ribbon colour indicates negative (dark grey) or positive (light grey) correlation of the link with behavioural variables.



DISCUSSION

This study was aimed at uncovering the effects of the social context manipulation (Peer/Alone conditions) on brain activity and behaviour of late adolescents and emerging adults in risk perception (discriminating high- from low-risk traffic scenes) and risk behaviour (riding a motorcycle simulator). We also took into account the dyad type (same/different sex), which was in close touch while performing both tasks. Two main results emerged in our study: the effect of social context, and the prediction of risk behaviour on the motorcycle simulator from functional connectivity observed in the risk perception task.

Our social context manipulation showed that the presence of a peer (friend) decreased the ability to discriminate high- from low-risk scenes, and increased the tendency to judge the scenes as non-risky (response bias). We observed brain clusters uniquely involved in the Peer (superior temporal gyrus, orbitofrontal and ventrolateral prefrontal cortices) or the Alone (bilateral orbitofrontal, dorsomedial and postcentral cortices) condition, and areas involved in the risk perception task independently of the social context (orbitofrontal, bilateral cingulate gyrus and dorsomedial cortices). Being with a Peer, but not being Alone, engages some of the key component patches of the so-called social network: the posterior superior temporal, the ventrolateral prefrontal, and the orbitofrontal cortices, involved in motivational and attentional priority to other individuals (Azzi, Sirigu, & Duhamel, 2012; Watson & Platt, 2012), although no evidence was observed on the participation of other social network areas, as medial or dorsolateral prefrontal areas (Wang & Olson, 2018). The superior temporal cortex has been proposed as a hub of the brain social networks (Yang, Rosenblau, Keifer, & Pelphrey, 2015). It has also been involved in action selection in the processing of past outcomes (Paulus, Feinstein, Leland, & Simmons, 2005; Peake, Dishion, Stormshak, Moore, & Pfeifer, 2013), especially in the presence of peers (Blakemore & Mills, 2014), likely because of its importance in social sensitivity (van Hoorn, McCormick, & Telzer, 2018) and in the evaluation and adaptation of responses in social contexts (McCormick, Perino, & Telzer, 2018).

The risk perception task activated areas in the OFC that has been involved in the processing of rewards, value-based decision-making and maintenance of past successful response choices (Noonan, Kolling, Walton, & Rushworth, 2012; Stalnaker, Cooch, & Schoenbaum, 2015). We observed a medial-to-lateral pattern in left hemisphere OFC, in which more medial areas (area 14 and parts of area 13) were involved in the Alone condition, while lateral areas participated in the Peer condition (area 12, lateral area 13, lateral agranular insula, and parts of lateral area 11). Areas in the anterior and posterior orbital gyrus (medial area 13, lateral area 13, and parts of lateral area 11) activated independently of the social context. However, in right hemisphere, lateral areas (area 12) were involved rather in the Alone than in the Peer condition. These patterns are in agreement with the idea, that the ventral prefrontal surface is organized in different functional networks with areas belonging to the orbital or to the medial networks, and same areas belonging to both networks (Du et al., 2020; Price, 2007), although finer distinctions have been made (Kahnt, Chang, Park, Heinzle, & Haynes, 2012). We observed, that the peers' presence uniquely influence the activation of left lateral OFC, an area shown to respond to whatever reward (or error), independently of its positive or negative value (Noonan, Mars, & Rushworth, 2011), to social context (Domínguez D et al., 2018; Fujii, Hihara, Nagasaka, & Iriki, 2009), and to be predictive of involvement in risky behaviour, as alcohol and drugs (Wade et al., 2019).

Dorsomedial prefrontal and anterior cingulate cortices develop functions related to executive attention, motivation and emotion, and decision-making in social contexts

(Szczepanski & Knight, 2014), including belief updating based on the reliability of informants (De Martino, Bobadilla-Suarez, Nouguchi, Sharot, & Love, 2017). Two large subdivisions have been identified based on the social context influence on decision-making tasks: non-social (cingulate sulcus, activity independent of the presence/interaction with other people), and social (a mediodorsal/ area 24 cluster, whose activity appears to support social information) (Wittmann, Lockwood, & Rushworth, 2018). In our risk perception task we observed two regions, one corresponding to the non-social subdivision (mostly embracing parts of cingulate cortices, including medial area 9, pregenual area 32, and caudodorsal area 24), that activate independently of the presence/absence of the peer, and a roughly social cluster located above and below the non-social subdivision, (embracing, among others, parts of more dorsalmedial areas, as the supplementary motor area, medial area 6, medial area 8, caudal area 23 and area 24). Our social cluster, however, do activate in the absence, but not in the presence of the Peer. Thus, in fact, we do not observe a social region in the strict meaning, as we have no evidence favouring an effect of the presence of the peer in the cingulate cortex, although some research has also shown different neurons to activate more in social isolation than a social context (Demolliens, Isbaine, Takerkart, Huguet, & Boussaoud, 2017).

Our second important result concerns the prediction of risk behaviour, as it is measured by the number of accidents and the average speed in the motorcycle simulation, from functional connectivity of the nine clusters. The number of accidents was higher, being the speed slower, when riding with the Peer than Alone. In the Peer condition, the number of accidents was negatively associated with the strength of l_VLPFC (P) – r_mOFC/AI (P&A) connectivity. A larger number of links were necessary to account for this variable when riding Alone, so that the larger the strength of the connectivity of the Alone clusters (r_DMC (A) - r_mOFC(P), r_DMC (A) - r_STG (P), and bil_OFC (A) – r_mOFC/AI (P&A)), the larger the number of accidents, but the larger the connectivity of clusters active in both, Peer and Alone conditions (bil_CG (P&A) - r_mOFC (P), bil_CG (P&A) - r_STG (P), l_mOFC (P&A) - r_STG (P)), the lower the number of accidents.

Agranular insula has been linked to the valuation of rewards, the establishment of internal drives, and the regulation of affect (Wager, Barrett, & Feldman Barrett, 2004), and its connectivity with other prefrontal areas have been shown to be altered by the (lack of) premeditation impulsivity trait in risk prone individuals (Baltruschat et al., 2020). Moreover, the left area 45 (l_VLPFC (P)), a part of Broca's area, is involved in conflict resolution and the inhibition of prepotent responses (Hamilton & Martin, 2005; Samrani, Bäckman, & Persson, 2019). We believe that a reduction of this link may provide l_VLPFC incomplete information on the riskiness of the simulated traffic scenario, increasing the probability of erroneous decision-making. This is supported by the fact that a much more complex network is involved in the prediction of the number of accidents in the Alone than in Peer condition. In this network the right superior temporal and the social (dorsomedial cortex) and non-social (anterior cingulate) prefrontal cortex are the major contributors to the accidents, being the social part more associated with a rate increase and the non-social one to a rate decrease. The two prefrontal clusters have been thought as being involved in very different parts of decision-making tasks, with anterior cingulate cortex more involved in reward valuation, and the dorsomedial prefrontal cortex in the integration of task information (Liu, Hairston, Schrier, & Fan, 2011; Lorenz et al., 2014).

The strength of the functional connectivity of ventrolateral prefrontal (l_VLPFC (P)) and posterior superior temporal cortices (r_STG (P) with orbitofrontal cortex (l_mOFC (PA), r_mOFC (P)) was positively associated with the average speed when riding with a Peer. However, neither superior temporal, nor ventrolateral prefontal connectivity had a role in the prediction of average speed in the Alone condition, in which larger dorsomedial cortex – OFC connectivity (r_DMC (A)) – (bil_OFC (A)) was associated with higher speed, but larger connectivity of this OFC area with cingulate cortex (r_DMC (P&A)) was associated with lower average speed. Thus, it seems that the control of behaviour is accomplished by two different brain networks, one left lateral OFC - left ventrolateral prefrontal cortex -right temporal cortex that appear to be dominated by reward processing areas of the left OFC operating in the presence of peers, and the other medial orbitofrontal-mediodorsal-cingulate cortices, with rich links within the OFC that operated in the absence of peers. Notably, in this last condition all the within OFC links were negatively associated with average speed.

CONCLUSIONS

The social context, independently of the dyad type (same/different gender), reduce the ability to discriminate high-risk from low-risk scenes, and activate areas in the orbitofrontal, ventrolateral prefrontal, posterior superior temporal, cingulate and dorsomedial prefrontal cortices. The pattern of OFC and medial prefrontal activation suggests a social/non-social organization. Left OFC, left ventrolateral prefrontal cortex, and right posterior superior temporal cortices are uniquely activated in the presence of peers. Bilateral medial OFC and dorsomedial cortices are uniquely activated in the absence of peers. Bilateral medial OFC and portions of the cingulate gyrus activate independently of the social context. The functional connectivity between these areas predicted the performance in the riding motorcycle simulator, in a way that also depended on the peers' presence/absence, so that cingulate/dorsomedial cortex plays a role in the absence, but not in the presence of peers. These results are compatible with the idea that peers influence is caused by the downregulation of the cognitive control network, but we believe they rather indicate that social context serves as a selector of the brain networks that is recruited to perform the task.

APPENDIX

Supplementary Table 1. Brain areas included in each of the nine clusters showing differential brain activity during the risk perception task

Cluster name	H	Areas	Location	Voxel number (RH/LH)
l_VLPFC (P)	LH	MFG_L(R)_7_4	A9/46v, ventral area 9/46	22
	LH	MFG_L(R)_7_7	A10l, lateral area10	18
	LH	IFG_L(R)_6_2	IFS, inferior frontal sulcus	10
	LH	IFG_L(R)_6_3	A45c, caudal area 45	19
	LH	IFG_L(R)_6_4	A45r, rostral area 45	18
	LH	IFG_L(R)_6_5	A44op, opercular area 44	21
	LH	IFG_L(R)_6_6	A44v, ventral area 44	7
	LH	OrG_L(R)_6_2	A12/47o, orbital area 12/47	16
	LH	OrG_L(R)_6_3	A11l, lateral area 11	20
	LH	OrG_L(R)_6_6	A12/47l, lateral area 12/47	15
	LH	STG_L(R)_6_1	A38m, medial area 38	15
	LH	STG_L(R)_6_3	TE1.0 and TE1.2	12
	LH	STG_L(R)_6_5	A38l, lateral area 38	21
	LH	MTG_L(R)_4_2	A21r, rostral area 21	15
	LH	MTG_L(R)_4_4	aSTS, anterior superior temporal sulcus	8
	LH	INS_L(R)_6_2	vIa, ventral agranular insula	18
	LH	INS_L(R)_6_3	dIa, dorsal agranular insula	14
	LH	INS_L(R)_6_4	vId/vIg, ventral dysgranular and granular insula	11
	LH	INS_L(R)_6_6	dId, dorsal dysgranular insula	16
r_mOFC (P)	RH	OrG_L(R)_6_3	A11l, lateral area 11	19
	RH	OrG_L(R)_6_4	A11m, medial area 11	5
r_STG (P)	RH	STG_L(R)_6_2	A41/42, area 41/42	9
	RH	STG_L(R)_6_4	A22c, caudal area 22	10
	RH	pSTS_L(R)_2_1	rpSTS, rostroposterior superior temporal sulcus	5
bil_OFC (A)	RH	IFG_L(R)_6_2	IFS, inferior frontal sulcus	5
	RH	IFG_L(R)_6_3	A45c, caudal area 45	5
	RH	IFG_L(R)_6_4	A45r, rostral area 45	9

	RH	IFG_L(R)_6_5	A44op, opercular area 44	24
	RH/LH	OrG_L(R)_6_1	A14m, medial area 14	9/ 15
	RH	OrG_L(R)_6_2	A12/47o, orbital area 12/47	20
	RH/LH	OrG_L(R)_6_3	A11l, lateral area 11	16/ 11
	RH/LH	OrG_L(R)_6_4	A11m, medial area 11	8/ 9
	RH/LH	OrG_L(R)_6_5	A13, area 13	24/ 20
	RH	OrG_L(R)_6_6	A12/47l, lateral area 12/47	18
	LH	STG_L(R)_6_1	A38m, medial area 38	9
	RH	INS_L(R)_6_2	vIa, ventral agranular insula	13
	RH	INS_L(R)_6_3	dIa, dorsal agranular insula	15
	RH/LH	CG_L(R)_7_2	A24rv, rostroventral area 24	6/ 14
	RH/LH	CG_L(R)_7_7	A32sg, subgenual area 32	12/ 10
r_DMC (A)	RH/LH	SFG_L(R)_7_1	A8m, medial area 8	31/ 20
	RH/LH	SFG_L(R)_7_2	A8dl, dorsolateral area 8	32/ 5
	RH	SFG_L(R)_7_3	A9l, lateral area 9	6
	RH/LH	SFG_L(R)_7_4	A6dl, dorsolateral area 6	24/ 15
	RH/LH	SFG_L(R)_7_5	A6m, medial area 6	25/ 20
	RH/LH	SFG_L(R)_7_6	A9m,medial area 9	21/ 14
	RH	MFG_L(R)_7_5	A8vl, ventrolateral area 8	18
	RH	MFG_L(R)_7_6	A6vl, ventrolateral area 6	20
	RH	PrG_L(R)_6_1	A4hf, area 4(head and face region)	8
	RH	PrG_L(R)_6_2	A6cdl, caudal dorsolateral area 6	15
	LH	PCL_L(R)_2_1	A1/2/3ll, area1/2/3 (lower limb region)	9
	RH/LH	PCL_L(R)_2_2	A4ll, area 4, (lower limb region)	7/ 9
	RH	PoG_L(R)_4_1	A1/2/3ulhf, area 1/2/3(upper limb, head and face region)	5
	RH	CG_L(R)_7_2	A24rv, rostroventral area 24	5
	RH/LH	CG_L(R)_7_3	A32p, pregenual area 32	10/ 9
	RH/LH	CG_L(R)_7_5	A24cd, caudodorsal area 24	19/ 6
	RH/LH	CG_L(R)_7_6	A23c, caudal area 23	14/ 19
l_DMC (A)	LH	SFG_L(R)_7_6	A9m,medial area 9	5
	LH	PrG_L(R)_6_3	A4ul, area 4(upper limb region)	12
	LH	SPL_L(R)_5_3	A5l, lateral area 5	5
	LH	IPL_L(R)_6_3	A40rd, rostrodorsal area 40(PFt)	12
	LH	PoG_L(R)_4_1	A1/2/3ulhf, area 1/2/3(upper limb, head and face region)	14
	LH	PoG_L(R)_4_3	A2, area 2	15
	RH/LH	CG_L(R)_7_5	A24cd, caudodorsal area 24	5/ 5
	RH/LH	CG_L(R)_7_6	A23c, caudal area 23	5/ 5
l_mOFC (P&A)	LH	IFG_L(R)_6_5	A44op, opercular area 44	15
	LH	OrG_L(R)_6_2	A12/47o, orbital area 12/47	6

	LH	OrG_L(R)_6_3	A11l, lateral area 11	21
	LH	OrG_L(R)_6_5	A13, area 13	13
	LH	OrG_L(R)_6_6	A12/47l, lateral area 12/47	20
	LH	INS_L(R)_6_2	vIa, ventral agranular insula	19
	LH	INS_L(R)_6_3	dIa, dorsal agranular insula	19
r_mOFC/AI	RH	IFG_L(R)_6_5	A44op, opercular area 44	6
(P&A)	RH	OrG_L(R)_6_2	A12/47o, orbital area 12/47	10
	RH	OrG_L(R)_6_3	A11l, lateral area 11	22
	RH	OrG_L(R)_6_4	A11m, medial area 11	12
	RH	OrG_L(R)_6_5	A13, area 13	18
	RH	OrG_L(R)_6_6	A12/47l, lateral area 12/47	16
	RH	INS_L(R)_6_3	dIa, dorsal agranular insula	10
bil_CG (P&A)	RH/LH	SFG_L(R)_7_1	A8m, medial area 8	6/ 10
	RH/LH	SFG_L(R)_7_5	A6m, medial area 6	5/ 5
	RH/LH	SFG_L(R)_7_6	A9m,medial area 9	14/ 16
	RH/LH	CG_L(R)_7_3	A32p, pregenual area 32	5/ 16
	RH/LH	CG_L(R)_7_5	A24cd, caudodorsal area 24	15/ 15
	RH/LH	CG_L(R)_7_6	A23c, caudal area 23	8/ 10

Note: H, Hemisphere. CG, Cingulate Gyrus; IFG, Inferior Frontal Gyrus; INS, Insular Gyrus; IPL, Inferior Parietal Lobule; L, left; MFG, Middle Frontal Gyrus; MTG, Middle Temporal Gyrus; OrG, Orbital Gyrus; PCL, Paracentral Lobule; PoG, Postcentral Gyrus; PrG, Precentral Gyrus; pSTS, posterior Superior Temporal Sulcus; R, right; SFG, Superior Frontal Gyrus; SPL, Superior Parietal Lobule; STG, Superior Temporal Gyrus.

Only clusters with a voxel size > 4 voxels are listed.

STUDY 2

Risk proneness modulates the impact of impulsivity on brain functional connectivity

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INTRODUCTION

Taking risks in life is inherent to humans and animals. Almost every human activity (from foraging or finances to science or space exploration) can be regarded as an instance of a game in which the stakes are high. Unsurprisingly, certain personality traits such as impulsivity and sensation seeking, are inextricably linked to risk-taking (Zuckerman & Kuhlman, 2000), and share functional networks in the brain.

One recent influential model regards impulsivity as a construct that includes five dimensions (Cyders et al., 2007): Positive and Negative Urgency, (lack of) Premeditation, (lack of) Perseverance, and Sensation seeking (UPPS model). In neurobiological studies, UPPS impulsivity factors have been found to be associated with the functional connectivity of brain areas involved in emotional regulation, response suppression, and cognitive control. For instance, Golchert et al. (2017) found that connectivity of distinct regions of the anterior cingulate cortex (ACC) correlated with three UPPS dimensions. In particular, Positive urgency was negatively related to connectivity of subgenual ACC with the bilateral parietal cortex (embracing parts of the precuneus, retrosplenial cortex, and intracalcarine sulcus); (lack of) perseverance was positively related to the connectivity of supragenual ACC with the right middle fontal gyrus (MFG); and (lack of) premeditation was negatively related to the connectivity of supragenual ACC with the bilateral occipital cortex. Thus, it appears that an excessive coupling of prefrontal regions could underlie perseverance difficulties, and that (lack of) premeditation could be related to difficulties in the attentional modulation of information processing carried out by sensory regions of the brain (Golchert et al., 2017). Decoupling of subgenual ACC and parietal clusters, particularly retrosplenial, could form the neural basis of problems envisioning the future, which would provoke the impulsive actions that characterize positive urgency (Golchert et al., 2017).

Furthermore, urgency has been linked to connectivity within the default mode network (DMN). Using ALFF (amplitude of low frequency fluctuations), Zhao et al. (2017) observed activity in several brain areas of the DMN (such as subgenual ACC, medial frontal gyrus, right dorsolateral prefrontal cortex, left inferior frontal gyrus and MFG, and posterior cingulate/precuneus) is positively associated with mean urgency scores (positive and negative), which suggests that excessive activation of the nodes within the DMN could underpin the urgency trait (Chester et al., 2016).

There is also evidence that negative urgency is associated with brain structural abnormalities. For instance, Muhlert & Lawrence (2015) observed that gray matter volumes in the dorsomedial prefrontal cortex (DMPFC) and the right temporal pole — two areas involved in emotional processing and decision-making — are negatively related to negative urgency. Sensation seeking was also negatively associated with certain structural characteristics including cortical thickness (Holmes, Hollinshead, Roffman, Smoller, & Buckner, 2016) and grey matter volume (H. Wang, Wen, Cheng, & Li, 2017) of brain regions involved in cognitive control and self-regulation such as the ACC and MFG.

Nonetheless, other factors appear to modulate the differences in the relation between impulsivity and connectivity, such as, for instance, risk proneness. In a recent study, Barkley-Levenson et al. (2018), using a Stroop task, observed that in the congruent condition risky participants showed greater activation of the ACC, DMPFC, DLPFC, left frontal pole, and right insula in comparison with non-risky participants. Further analysis suggested that, in the congruent condition, the activation of several of these regions mediates the association between urgency and risk behavior (risky category), which could be interpreted as indirectly supporting the idea that differences in the functioning of the fronto-insular system is responsible for the observed differences in impulse control between risky and non-risky individuals. Comparing risky with non-risky adolescents, DeWitt, Aslan, & Filbey (2014) observed that the former group displayed increased connectivity between the amygdala and the right MFG, left cingulate gyrus, left precuneus, and right inferior parietal cortex, and between the nucleus accumbens and the right MFG. In a similar vein, Deza Araujo et al. (2018) demonstrated hyperconnectivity between the fronto-parietal network and the occipital cortex, and between the DMN and medial temporal and frontal regions in high risk seeking behavior in losses (observed in people that prefer delayed potential high losses rather than immediate but sure small losses).

However, to the best of our knowledge, no direct information is available on whether the associations between impulsivity or sensation seeking traits and brain functional connectivity are different in risk prone and non-risk prone individuals, or if, on the contrary, these personality traits are linked to connectivity independently of risk proneness. Our aim, therefore, was to test if the associations between functional coupling in large brain networks and impulsivity and sensation seeking traits are a function of risk proneness, as derived from the DOSPERT scale (Weber et al., 2002), in a normal young sample. For this purpose, we used the brain current source density (CSD, determined using sLORETA) estimated from a risk perception task, described in other studies (Megías et al., 2013; Megías et al., 2015). As an a priori approach, we depart from the influential work of Yeo et al. (2011) and estimate both the connectivity between the 7 networks described (Visual (VN), Somatomotor (SMN), Dorsal Attention (DAN), Ventral Attention (VAN), Limbic (LN), Fronto-parietal (FPN) and Default (DMN)), and between the nodes within these networks.

METHOD

Participants

The participants were selected from a pool of 1093 students of the University of Granada, who volunteered by responding to the Spanish online version of the *Domain-Specific Risk-Taking Scale 30* (DOSPERT-30, Lozano et al., 2017). Only individuals aged between 18 and 25 years and possessing a driver's license were chosen to take part in the study. The intentional risk-taking subscale was used to identify risk prone and non-risk prone individuals, using the 75th percentile as high cut-off and the 25th percentile as the low cut-off. Percentiles were computed separately for men and women, given that there are gender differences in the distribution of the scores. A total of 89 individuals (40 women; M = 21.64; SD= 1.99) participated in the study forming two groups according to their propensity to take risks: the risk prone (RP, N = 45, 21 women, age = 21.67 years), and the non-risk prone group (NRP, N = 44, 19 women, age = 21.61 years).

This study was approved by the Human Research Ethics Committee of the University of Granada (nº 204/CEIH/2016). All participants gave written consent, were informed about their rights according to the Declaration of Helsinki (World Medical Association, 2008), and were paid for their participation.

Questionnaires

First, demographic variables and information about driving experience and behavior (months since obtaining driver's license, km driven per year, number of accidents, and number of fines) were collected. Three questionnaires were administered to collect data regarding personality traits.

Domain-Specific Risk-Taking Scale 30 (DOSPERT-30). The risk-taking subscale of the Spanish version of the DOSPERT-30 scale (Lozano et al., 2017) was used to measure the participants' propensity to take risks. This subscale consists of 30 items with a seven-point Likert scale. To measure risk-taking propensity, the individual is asked to evaluate the likelihood that he/she would engage in different types of risk-taking behavior. The items refer to five domains of everyday life (ethical, financial, health/safety, social, and recreational risks). We used a 75% -25% cut-offs to categorize participants as either risk prone or non-risk prone.

Impulsive Behavior Scale (UPPS-P). The short version of the Spanish UPPS-P scale (Cándido, Orduña, Perales, Verdejo-García, & Billieux, 2012) measures five dimensions of the impulsivity trait (positive urgency, negative urgency, sensation seeking, lack of premeditation, and lack of perseveration). The scale consists of 20 items, with 4 items for every trait, measured with a four-point Likert scale.

Sensation Seeking Scale (SSS-V). The short Spanish version of the SSS (Pérez & Torrubia, 1986) consists of 40 dichotomic items (Yes/No), assessing the following 4 dimensions of the sensation seeking trait: thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility.

Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ-20). The SPSRQ-20 (Aluja & Blanch, 2011) measures the Behavioral Approach System (BAS) and the Behavioral Inhibition System (BIS), which are the two basic motivational systems according to Gray's psychobiological model of personality (Torrubia, Ávila, Moltó, & Caseras, 2001). This instrument consists of 20 dichotomic items (Yes/No) divided into two subscales, sensitivity to reward and punishment, which measure the BAS and BIS, respectively.

Motorcycle Riding Simulator

The Honda Riding Trainer motorcycle simulator (HRT) consists of a seat, handlebar, pedals, accelerator, brakes, turn indicators, and claxon (see Di Stasi et al., 2009; Megías, Cortes, Maldonado, & Cándido, 2017, for more details on the HRT simulator).The road scenarios were projected with a refresh rate of 30 Hz at a distance of 185 cm on the screen (110 x 180 cm, resolution: 1024 x 768 pixels) in front of the participant seated on the motorcycle simulator. Participants rode through an urban road scenario that includes 8 risk situations (e.g., opening doors of parked cars or pedestrians crossing the road). The driving simulation was approximately 5 minutes long depending on speed, crashes, and variability of the course taken by the participant. From the data measured by the HRT we computed the following riding indices of risk proneness: average speed (km/h), duration (s) of exceeded speed limits, and average exceeded speed limits (km/h).

Risk Perception Task

The *SR Research Experiment Builder* (SR Research Ltd., Mississauga, Ontario, Canada) was used to run the risk perception task, consisting of 140 real traffic pictures taken from the driver's perspective. The risk levels of the traffic situations were categorized into 70 high risk pictures and 70 low risk pictures (see Megías et al., 2015 for more details). All stimuli were projected on the screen using the same parameters as the HRT, with the participant seated on the motorcycle simulator in order to mimic a more realistic environment.

Every trial of the risk perception task began with a 750 ms fixation point that appeared in the center of a white screen followed by a 2000 ms traffic scene. The participants were required to indicate whether the traffic scene was risky or not, pulling the front brake only when they perceived risk, and not responding at all if they did not perceive the situation as risky. After 2000 ms, a black screen was displayed for 750 ms. The proportion of affirmative responses of risk perception and correct answers (according to the picture category) were computed for the two picture types (high-/low-risk) for each subject.

Procedure

As stated previously, DOSPERT-30 measures were taken online in the participant selection stage. In the experimental session all participants, after giving written informed consent, completed the risk perception task followed by the riding simulation. EEG recordings were taken during the risk perception task. At the end of the session participants responded to the remaining questionnaires.

EEG data recording and preprocessing

Brain electrical activity (EEG) was recorded during the risk perception task using a 64 active channel system (Brain Products, Inc.), mounted on an elastic cap and arranged according to the extended 10-20 system. Data were sampled at 1000 Hz, amplified using a 0.016-1000Hz band-pass filter, and referenced online to FCz. Electrode impedances were below 25kΩ, as recommended by the manufacturer.

Offline signal preprocessing was conducted using EEGLAB (Delorme & Makeig, 2004; freely available at http://sccn.ucsd.edu/eeglab). All EEG recordings were downsampled to 250 Hz, re-referenced offline to average reference, and FCz activity was recovered. Channels with a flatline duration of more than 50 seconds or with more line noise relative to its signal (4 *SD*) were interpolated using the spherical spline interpolation method, included in EEGLAB software. Recordings were then band pass filtered using a .1-30 Hz, 36dB/octave filter, segmented from -200 to 2.000 ms time-locked to the stimulus onset, and baseline corrected. Independent Component Analysis (ICA) was computed using the Second Order Blind Identification algorithm (SOBI; Tang, Sutherland, & McKinney, 2005), and ocular and electromyographic artifacts were removed using MARA's EEGLAB plug-in (Winkler et al., 2014; Winkler, Haufe, & Tangermann, 2011, freely available at https://irenne.github.io/artifacts). Averaged segments for each participant were submitted to standardized low resolution brain electromagnetic tomography software (sLORETA; Pascual-Marqui, 2002; freely available at http://www.uzh.ch/keyinst/loreta.htm) to determine activity for each voxel of the sLORETA brain template. sLORETA computed current source density using the MNI (Montreal Neurological Institue) template as the solution space.

Data analysis

1. DOSPERT prediction of risky driving behavior

To validate our categorization of DOSPERT based risk proneness, we analyzed between group differences on performance in the risk perception task, and the variables taken by the course driven on the HRT simulator, measuring risky driving behavior.

2. Personality traits and risk-taking (Questionnaire data)

To determine the personality trait profile of risk prone individuals we aimed to predict the DOSPERT based grouping using the scores of all other questionnaires (UPPS-P, SSS-V, and SPSRQ-20). We used a Partial Least Squares Discriminant Analysis, as implemented in the Classification Toolbox of the Milano Chemometrics and QSAR Research Group (http://michem.disat.unimib.it/chm/). Following a cross-validation approach, we used 75% of the sample, selected randomly, to estimate the model parameters (teaching sample) that were tested in the remaining 25% of the sample (test sample). The number of optimal components was estimated using venetian blind cross-validation. A single component produced the lowest classification error on the training sample. This model was fitted using variable autoscaling and Bayes assignation criterion.

3. Brain network of personality traits based on the risk level (EEG data)

We used the Brainnetome atlas coordinates (Fan et al., 2016, http://atlas.brainnetome.org) to compute functional connectivity between and within the 7 brain networks described in the work of Yeo et al. (2011). The atlas provides 210 cortical nodes, distributed for each network as follows: 34 for VN, 33 for SMN, 30 for DAN, 22 for VAN, 26 for LN, 26 for FPN, and 36 for DMN (see Fan et al., 2016, and supplementary Fig. 1 for more detail). Coordinates were translated to the sLORETA template, with each node embracing all the voxels located in a sphere of 10 mm radius, centered at the Brainnetome atlas node coordinates. The time series for each network, and each node in each network were spatially averaged using the first eigenvariate of the singular value decomposition (SVD) of the corresponding cluster of voxels. We used the FSLnets (https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSLNets) with default regularization parameter (lambda = 0.1) to compute between- and within-network functional connectivity, using ridge correlation coefficients with L2-norm regularization. We then computed, multivariate multiple stepwise linear regression, with group (risk prone and non-risk prone), personality traits, age and sex as the set of predictors. Afterwards, for each significant trait, partial correlations between functional coupling and this trait were performed separately for each group, while controlling for age and sex. Correlations were transformed to z-scores that were then used for the between group comparisons. Statistical decisions were made using the Bonferroni correction to hold the corrected *p* value below 0.05.

RESULTS

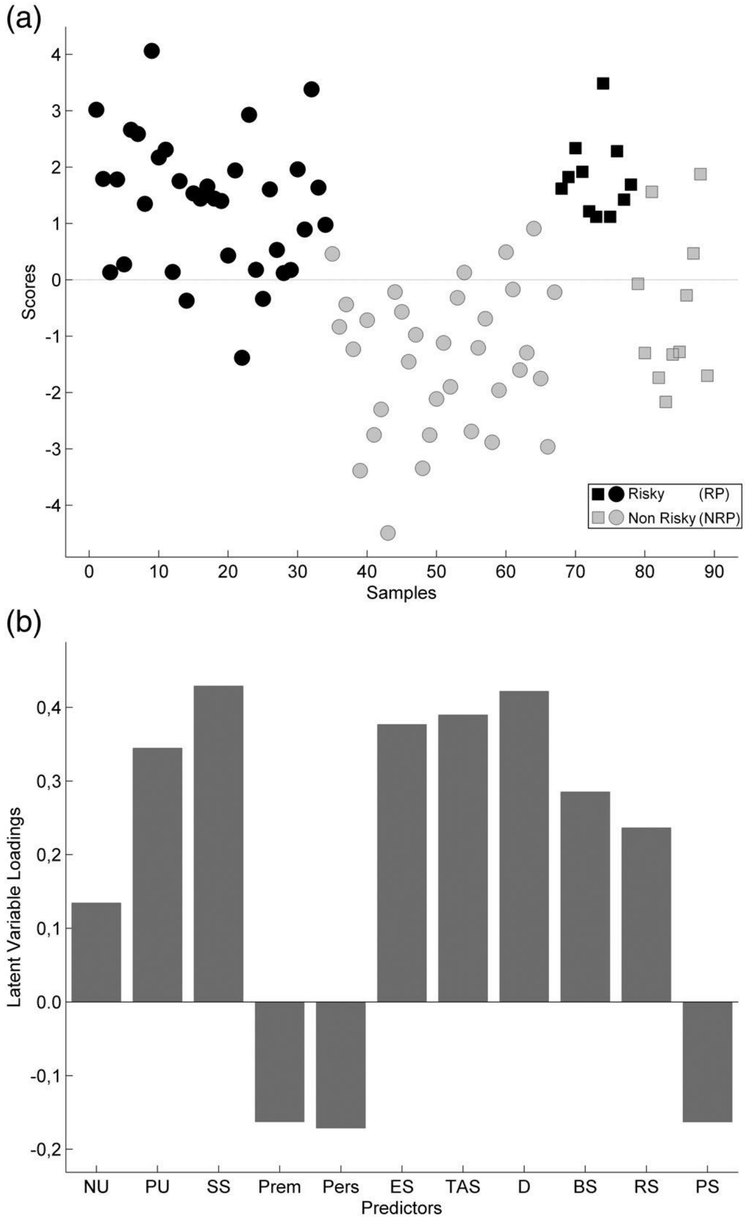
Prediction of risky driving behavior

Bonferroni-corrected comparisons indicated that risk prone individuals (measured by DOSPERT) perceived less risk in the depicted traffic scenes (42.89% vs. 51.23%, $t(87) = 3.54$, $p < 0.001$), drove at a higher average speed (30.64 Km/h vs. 27.28 Km/h, $t(87) = 3.97$, $p < 0.001$), exceeded speed limits for a longer time (44.22 sec. vs. 27.34 sec., $t(87) = 4.59$, $p < 0.001$), and by a greater amount (6.65 Km/h vs. 4.37 Km/h, $t(87) = 2.56$, $p = 0.012$) than non-risk prone individuals.

Personality traits and risky driving behavior

Analysis using the personality trait scores to predict our grouping of risk proneness showed that overall classification accuracy for the teaching sample was 89.53% (31/34 and 29/33 individuals of the training sample were correctly classified as risk prone and non-risk prone, respectively). For the test sample, overall classification accuracy was 86.36% (11/11 and 8/11 participants were correctly classified as risk prone and non-risk prone, respectively). Figure 1a displays scores on the latent variable for the participants in the teaching sample (circles) and in the test sample (squares). Figure 1b shows that loadings were negative for UPPS scores on (lack of) premeditation and (lack of) perseverance, and for SPSRQ scores on punishment sensitivity. Risk prone individuals scored higher than non-risk prone individuals with the exception of the three above-mentioned traits.

Figure. 1. Prediction of risk level by personality traits. Classification analysis revealed (a) Latent variable scores as a function of risk group (blue: risk prone; red: non-risk prone). Circles indicate the training sample and squares indicate the testing sample. (b) Loadings of the predictor variables.



Note: NU: Negative Urgency; PU: Positive Urgency; SS: Sensation Seeking; Prem: (Lack of) Premeditation; Pers: (Lack of) Perseverance, ES: Emotion Seeking; TAS: Thrill and Adventure Seeking; D: Desinhibition; BS: Boredom Susceptibility; RS: Reward Sensitivity; PS: Punishment Sensitivity.

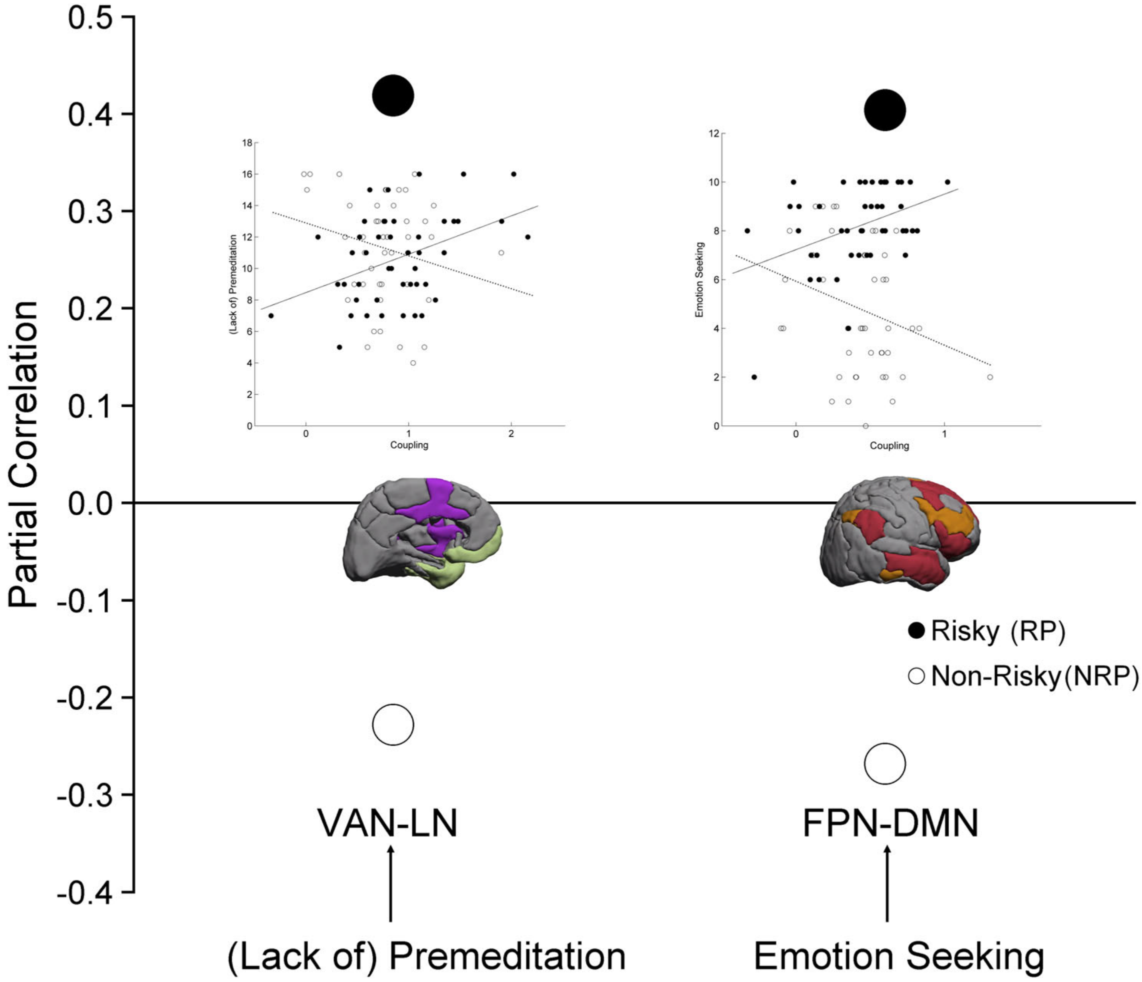
Personality traits related to brain network connectivity based on risk proneness

The multivariate multiple stepwise linear regression yielded significant effects of the set of predictors, $\Lambda = 0.52$, $p < 0.05$. Detailed analyses of this effect indicate that correlations between the functional connectivity of the networks and dimensions of personality traits vary as a function of risk proneness (Figure 2).

Independently of risk proneness, (lack of) premeditation modulated the coupling of the VAN with the DAN (r = -40, corrected $p < 0.05$), the FPN (r = -40, corrected $p < 0.05$), and the DMN ($r = 0.52$), plus that of VN and the LN ($r = 0.49$, corrected $p < 0.05$). The (lack of) perseverance modulated the VAN-DMN coupling ($r = 0.43$, corrected $p < 0.05$). Interestingly, the SSS scores for emotion seeking showed a stronger correlation with FPN-DMN coupling in risk prone ($r = 0.40$) than non-risk prone participants ($r = -0.27$) (corrected $p = 0.02$). Thus, FPN-DMN coupling appears to be modulated by emotion seeking, so that it tends to be enhanced in risk prone emotion seekers, but depleted in their non-risk prone counterparts. Moreover, a similar result was observed for the correlation between (lack of) premeditation and the VAN-LN coupling, being stronger for risk prone ($r = 0.42$) than for non-risk prone individuals ($r = -0.23$) (corrected $p = 0.02$).

Detailed analysis of these interactions at node level indicated that (lack of) premeditation differentially modulates the coupling of the right area 13 (LN) and left areas 1/2/3 (lower limb region) (VAN) ($r_{\text{Risk prone}} = 0.39$, $r_{\text{Non-risk prone}} = -0.45$, corrected $p = 0.013$). Emotion seeking differentially modulates, on the one hand, the coupling of the left area 11 (LN) and right dorsal dysgranular insula (VAN) ($r_{\text{Risk prone}} = -0.39$, $r_{\text{Non-risk prone}} = 0.39$, corrected $p = 0.05$), and on the other hand, that of the right medial area 10 (DMN) and right ventral area 9/46 (FPN) ($r_{\text{Risk prone}} = -0.33$, $r_{\text{Non-risk prone}} = 0.45$, corrected $p = 0.057$).

Figure 2. Influence of personality traits on functional coupling of the ventral attention network - limbic network (VAN-LN) and frontoparietal network-default mode network (FPN-DMN) as a function of risk-proneness. Colors in the schematic brains indicated the functional networks: Violet (VAN), green (LN), orange (FPN), red (DMN). The dots display the strength of the personality trait-brain coupling association for the risk and non-risk prone group. The insets display scatterplots of these correlations.



Personality traits also modulate the coupling between nodes within the same network as a function of risk proneness (Table 1), considering only the networks our previous analysis identified as affected by traits. The multivariate stepwise multiple regression on within networks node couplings yielded significant effects of personality traits on each of the (max $\Lambda = 0.03$, all $p < 0.05$). Detailed analysis of these effects indicated that (lack of) perseverance modulates coupling within the LN and the DMN, so that it enhanced coupling between certain nodes for the risk prone, but not for the non-risk prone group, whilst depleting the connectivity between areas 9 and 46 (FPN) in the risk prone group. In stark contrast, the coupling between medial area 9 and caudal area 45 (DMN) is enhanced in the non-risk prone, but not in the risk prone group. (Lack) of premeditation increased the coupling of rostral area 35/36 and the temporal agranular insula (LN) in the risk prone, but not in the non-risk prone group. Emotion seeking affects the FPN, so that it tends to deplete the coupling of ventral area 9/46 and lateral area 10 in the risk prone, but not in the non-risk prone group, whilst the reverse pattern is observed for the coupling of lateral area 10 and medial area 7.

Table 1. Significant paired within network couplings associated with personality traits for risk prone and non-risk prone individuals.

Questionnaire	Trait	Network	Nodes	*r* (RP)	*r* (NRP)	z	*p*
UPPS	(Lack of) Perseverance	LN	R A38m – L A35/36r	0.57	-0.23	4.03	0.01
	(Lack of) Perseverance	LN	R A20cv – R TI	0.67	-0.13	4.34	0.00
	(Lack of) Premeditation	LN	L A35/36r – R TI	0.59	-0.15	3.74	0.03
	(Lack of) Perseverance	FPN	L A46 – L A9/46v	-0.57	0.15	-3.67	0.04
	(Lack of) Perseverance	DMN	L A9m – L A45c	-0.25	0.55	-3.95	0.02
SSS	Emotion Seeking	FPN	R A9/46v – R A10l	-0.50	0.35	-4.16	0.01
	Emotion Seeking	FPN	R A10l – R A7m	0.18	-0.57	3.74	0.03

Note: The p column displays the Bonferroni corrected p-value. A: area; c: caudal; DMN: default mode network; FPN: fronto-parietal network; L: left hemisphere; l: lateral; LN: limbic network; m: medial; NRP: Non-risk prone group; R: right hemisphere; r: rostral; RP: Risk prone group; TI: temporal agranular insula; v: ventral.

DISCUSSION

Risk prone participants show greater impulsivity, sensation seeking, and reward sensitivity, but lower punishment sensitivity, in comparison with their non-risk prone counterparts. Moreover, the association between some of these personality traits and functional coupling between brain networks and between nodes within these networks is modulated by risk proneness. At the macroscopic level, the VAN-LN and the FPN-DMN couplings have greater positive correlations with (lack of) premeditation and emotion seeking, respectively, for risk prone individuals when compared with non-risk prone individuals. These between network results appear to be linked to the modulatory effect of these personality traits on the coupling of right area 13 with the left somatosensorial cortex (LN-VAN), the left medial area 11 with the right dorsal disgranular insula (LN-VAN), and right medial area 10 with right ventral area 9/46 (DMN-FPN). Moreover, the coupling between nodes within the same brain network is also differentially associated with personality traits in risk prone and non-risk prone individuals. In particular, the positive correlations between (lack of) perseverance and coupling between nodes in the LN (right medial area 38-left rostral area 35/36; right caudoventral area 20 - right temporal agranular insula) are higher for the risk prone than for the non-risk prone group. However, a higher negative correlation was found for the FPN (left area 46 - left ventral area 9/46) for this trait in the risk prone group in comparison with the non-risk prone group. (Lack of) perseverance was highly correlated with coupling of the DMN (left medial area 9 with left caudal area 45) in the non-risk prone group, and to a lesser extent in the risk prone group. Additionally, there are negative correlations between the emotion-seeking trait and the coupling of right ventral area 9/46 with right lateral area 10 (FPN) for risk prone individuals, and the coupling of right lateral area 10 and right medial area 7 for non-risk prone individuals.

The results of our personality profile analysis are consistent with previous findings relating risk-taking behavior to impulsivity and sensation seeking traits (Zuckerman & Kuhlman, 2000). Previous studies have found these traits to be positively associated with risk-taking behavior such as drug use, sexual risk behavior (Donohew, Zimmerman, Cupp, & Novak, 2000), financial risk-taking (Wong & Carducci, 1991), as well as imprudent driving behavior (Beanland et al., 2014). Additionally, lower sensitivity to punishment and greater sensitivity to reward were also associated with risk-taking behavior, including behavior observed in driving environments (Scott-parker, Watson, King, & Hyde, 2012). Here, we showed that these personality traits are highly predictive of risk proneness (Figure 1). Thus, a higher risk propensity is predicted by a more impulsive and emotion- seeking personality profile, being more sensitive to reward and less sensitive to punishment. This is worth taking into account when designing intervention programs for these youths, as they might not be responsive to punishments, and are instead reinforced by the emotions and sensations evoked by the risk behavior itself, with little control over their impulses.

Regarding the brain connectivity data, we observed that in the risk prone group, the emotion-seeking facet of the sensation seeking trait was positively related to the DMN-FPN coupling (Figure 2a), whilst the (lack of) premeditation facet of the impulsivity trait was positively related to the VAN-LN coupling (Figure 2b). In the non-risk prone group both relationships were weaker and negative.

The FPN has shown to be involved in cognitive flexibility and the control and adaptation to the changing behavioral goals or task demands (Cole et al., 2013; Woolgar, Afshar, Williams, & Rich, 2015). The DMN, on the other hand, has been linked with internal processes such as mind-wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). A reduction in DMN activity has been found to enhance performance in externally-driven cognitive tasks, whilst deficits in suppression of this network appear to underlie a number of mental illnesses (Anticevic et al., 2012). FPN-DMN coupling has been linked with the suppression of task irrelevant information by the reduction of DMN activity, and the enhancement of task-relevant features by increasing FPN activity (Chadick & Gazzaley, 2011). Whether this dynamic is caused by FPN action on DMN or by mutual inhibition is still a matter of debate (Anticevic et al., 2012), but we speculate that this causal mechanism is altered in risk-prone emotion-seekers, who will be looking for internal emotional signals rather than attending to the external stimuli of the task. Our results suggest that the coupling of FPN ventral area 9/46 and DMN medial area 10 could be responsible for this effect, and that medial area 10 could be necessary for reducing activation of the DMN. This idea is supported by our within networks data, which indicate that in risk prone individuals high emotion seeking appears to affect the coupling of prefrontal nodes (ventral area 9/46 and left area 10) of the FPN, but not that of the DMN.

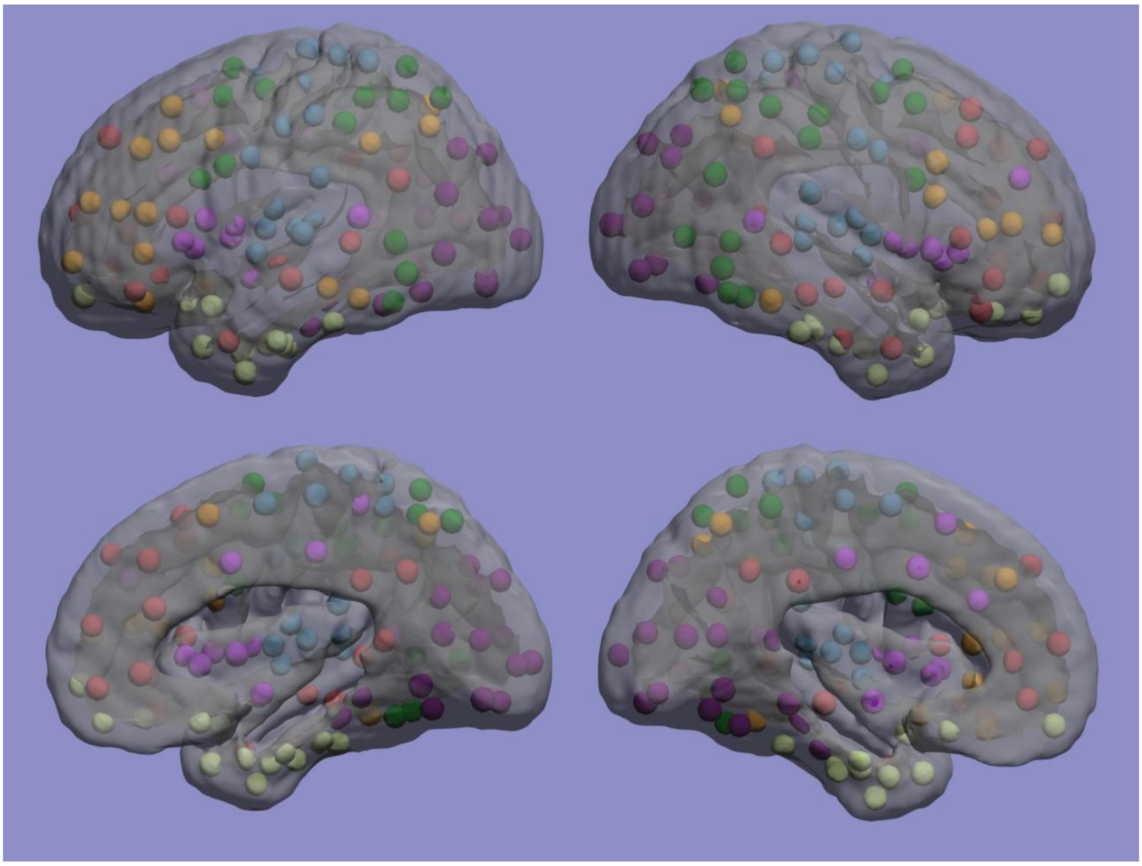
(Lack of) premeditation is associated with biased attentional modulation of information processing (Golchert et al., 2017). Our data show that this is positively correlated with the LN-VAN coupling, possibly by influencing the connectivity of orbitofrontal area 13 (LN) with the somatosensory areas of the VAN, and also that between the two LN nodes, the perirhinal cortex (Areas 35/36) and the temporal agranular insula, in risk prone, but not in non-risk prone individuals (in whom it tends to be negative). Given the role of the agranular insula in establishing internal drives and the valuation of rewards, and that it is the connection between this structure and the orbitofrontal cortex that influences the core affect (Wager et al., 2004), we believe that the (lack of) premeditation trait biases the way in which external stimuli are valued by risk prone individuals, accelerating the (most likely inappropriate) responses.

Our within networks data suggest that risk proneness also affects the association between (lack of) perseverance i.e. the tendency to give up under distress or boredom, and coupling of nodes in the LN, FPN, and the DMN networks. (Lack of) perseverance has been linked to abnormal gray matter volume and functionality of the medial prefrontal cortex (Wang et al., 2017). In risk prone — but not in non-risk prone individuals — we observed that the higher the (lack of) perseverance the lower the coupling between temporal areas of the LN (right temporal agranular insular cortex with the right caudoventral area 20; and the left rostral areas 35/36 with right medial area 38), but found the reverse pattern of results regarding the coupling of left area 46 with left ventral areas 9/46 in the FPN, and left medial area 9 with left caudal area 45 in the DMN in LN. These results suggest that (lack of) perseverance enhances the coupling of areas involved in the processing and valuation of the stimuli, and at the same time reduces the coupling of prefrontal areas involved in cognitive control, which will again promote the delivery of more rapid and inappropriate responses.

Taken together, our results indicate that risk proneness is not only related to a characteristic personality pattern, but also to different brain connectivity patterns associated with these personality traits. Risk prone individuals tend to score high on impulsivity and sensation seeking, showing a higher impact of personality traits on the connectivity of brain networks both at the macro- and the microscopic (node) levels. This suggests that 1) personality traits modulate the functional connectivity of brain networks and 2) the tendency to behave in a risk-prone manner influences how impulsivity-related personality traits are associated with the functionality of these brain networks.

APPENDIX

Supplementary Figure 1. Localization of the nodes used in the brain connectivity analyses. Node color represents the network they are forming part of.



Note: Purple: Visual network, Blue: Sematomotor network, Green: Dorsal attention network, Violet: Ventral attention network, Cream: Limbic network, Orange: Fronto-parietal network, Red: Default mode network

STUDY 3

Benefits of mindfulness-based training on risky driving and individual differences in dispositional mindfulness

INTRODUCTION

Risk-taking behaviour in various contexts of our life, like financial, health and security, or social contexts, has plenty of negative consequences, wherefore research has focused on psychological treatment and training programs to improve and reduce these behaviours. One of the everyday contexts of risk-taking behavior, affecting almost everyone, and therefore being of special priority, is the risky driving behavior. Even though legal restrictions and a penalty point system introduced in some European countries have shown some improvements in the number of serious injuries (Novoa et al., 2010), there were still 25.100 road fatalities in 2018 in the EU (European Comission, 2019). Worldwide, road traffic injuries are the eighth leading cause of death (World Health Organization, 2018).

Research on risk-taking reduction has progressed and individual differences in some personality traits (Baltruschat et al., 2020) may have given a hint to new, complementary behavioural modification techniques, such as dispositional mindfulness, which was negatively associated to risk-taking in different fields.

Dispositional mindfulness is referred to as the ability to be aware and pay attention to the moment-by-moment experiences (Bishop et al., 2006). While there is great consensus about the two main facets of this personality trait, which are the self-regulation of attention and the orientation to one's experience and acceptance (Bishop et al., 2006), more facets are considered in other models, for example non-judging of inner experiences, or being able to describe emotions and sensations (Baer et al., 2006; Rau & Williams, 2016).

Various studies observed negative association between dispositional mindfulness and gambling disorder severity (Lakey et al., 2007), smoking (Black et al., 2012) and drinking in adolescence and youths (Reynolds et al., 2015), as well as it accounts partially for differences in health and security risk-taking (Sala, Rochefort, Lui, & Baldwin, 2019; Shook et al., 2019).

Risky driving, concretely texting while driving, was also negatively related to dispositional mindfulness, particularly to the acting with awareness facet of the Five Facets Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006), measuring one of the main facets, automatic behavior and attention paid to one´s activities (Feldman, Greeson, Renna, & Robbins-Monteith, 2011; Moore & Brown, 2019; Panek, Bayer, Dal Cin, & Campbell, 2015). Scores of the Mindfulness Attention Awareness Scale (MAAS) (Rau & Williams, 2016), roughly measuring the same trait, have shown negative, moderate correlation with several measures of risky driving behavior. For instance, mindfulness was negatively related to intention to commit a driving violation (Bird, 2018), as well as to the frequency of engaging in distracting activities, such as mobile and technology use, being mind-wandering (e.g. daydreaming, not thinking about the actual driving task) the distraction with greatest negative correlation (Young et al., 2019). Aberrant driving behavior measured with the Driving Behaviour Questionnaire (DBQ) includes besides deliberate traffic rule violations, measures of lapses and aggressive driving behavior (Reason, Manstead, Stradling, Baxter, & Campell, 1990). Koppel et al. (2018) and Murphy & Matvienko-Sikar (2019) found that dispositional mindfulness was negatively related to all subscales of the DBQ, especially in these subscales measuring unintentional risk-taking occurring because of distraction or lack of attention (lapses and errors).

Using questionnaires to assess the relation of risky driving, dispositional mindfulness, and individual differences may be a good starting point, but should lead to research in application of this knowledge. Thus, based on previous discussed findings a logical consequence would be to contemplate teaching people with heightened risk-taking behaviour to be more mindful. Mindfulness-based programs, such as the Mindfulness-Based Stress Reduction (MSBR) program, usually include intensive meditation practice, as well as group discussions and instructions in cognitive and emotional regulation (Kabat-Zinn, 1990).

Research on mindfulness-based programs on reducing health risk-taking behaviour has been conducted in a variety of contexts. A meta-analysis in binge-eating showed that mindfulness-based training could improve binge eating, observing medium to large effect sizes, particularly in studies including participants with greater severity (Godfrey, Gallo, & Afari, 2015). Similarly, Mindfulness-based addiction treatments showed greater effects on smoking cessation and recovery of lapses compared to traditional therapies (Brewer et al., 2011; Davis et al., 2014; Vidrine et al., 2016). Furthermore, mindfulness-based treatments of psychological disorders (Goldberg et al., 2018), such as depression and anxiety, which often lead to risk-taking behaviour, showed reduction of symptoms with moderate effect size (Khoury et al., 2013), and even attention deficit/ hyperactivity disorder (ADHD) seems to show benefits (Cairncross & Miller, 2016).

In risky driving it seems even more indicated to use mindfulness-based trainings since, as previously mentioned, unintended lapses and errors in traffic environments are closely related to dispositional mindfulness (Young et al., 2019). Additionally, He, Becic, Lee, & McCarley (2011) observed less efficient eye movement patterns in mind-wandering states, which would be opposed to being mindful, having detrimental consequences for hazard detection. Accordingly, known benefits of mindfulness-based trainings, as self-regulation of attention and paying purposeful attention to the present moment, would be ideal to reduce risky behaviours caused by distraction and lack of concentration (Koppel et al., 2019). Even aggressive behaviour may be influenced by a mindfulness-based training promoting acceptance and non-judging of emotions helping to reduce anger and subsequent aggressive driving (Stephens et al., 2018). However, a lack of research in this field is making difficult to draw conclusions (Koppel et al., 2019).

In the present study we explored the effect of a mindfulness training program, adapted from the MSBR, on risk-taking in traffic environments in a sample of risky drivers. Criteria of participant selection take into account fines, rehabilitation courses, and a habit to exceed speed limits, which is one of the most frequent reasons for accidents and fatalities (Aarts & Van Schagen, 2006; Imprialou, Quddus, Pitfield, & Lord, 2016). To measure differences in risky driving in a baseline and post-training evaluation, we used the Spanish adaptation of the Driving Behaviour Questionnaire (SDBQ), as it includes all types of risky driving behaviour, deliberate traffic violations, as well as risk behaviour which occurs by error, distraction or anger against other road users. We also explored the relation of dispositional mindfulness, measured by the FFMQ scale, with risky driving behaviour in a sample of actual risky drivers. Finally, we explored the implication of initial dispositional mindfulness on training effects, as it might work as a facilitator.

METHOD

Participants

60 participants (17 women) aged between 19 and 63 (*M* = 35.3, *SD* = 14.58) took part in the study. Participants were recruited in an online survey from the University of Granada (students, teachers, and administration staff) and in a driving school during a rehabilitation course after being fined for traffic rule violation.

All of them hold a driving licence and meet at least one of the following real life driving behaviour indexes to ensure only risk prone individuals are selected: assistance to a drivers rehabilitation course at least once, loss of points in the Spanish fine system for traffic rule violations, being fined at least twice for risky driving behaviour (alcohol or drug use, not using seat belt or exceeding speed limits), or reporting to usually exceed speed limits for more than 20% of the permitted speed limit.

Participants were selected randomly to take part in a 5-weeks mindfulness meditation program. Twenty eight participants were part of the mindfulness groups (MG) (4 of them dropped out before the fourth sessions and were excluded from analysis) and 32 participants were part of the control group (CG).

Questionnaires

1. Risky driving behaviour

The Spanish adaptation of the Driving Behaviour Questionnaire (SDBQ, López-de-Cózar, Molina, Chisvert, & Sanmartín, 2005), originally of Reason et al. (1990), was used to measure risk behaviour. The 34-item scale comprises four subscales, which are not exclusive but share items, so that the sum of items of all subscale is not congruent with the total of items: *Aggression* measures violent driving because of anger against other drivers (11 items); *Violation* measures risk behaviours characterised by deliberate risky driving, e.g. exceeding speed limits (10 items); *Error* measures risk behaviours (7 items); and *Lapse* measures risk behaviour occurring by accident, paying little attention, or being distracted (16 items). Items are responded with an 11-point Likert scale from 0 (never) to 10 (always).

2. Mindfulness as personality trait

The Spanish version of the Five Facet Mindfulness Questionnaire (FFMQ, Baer et al., 2006; Cebolla et al., 2012) measures dispositional mindfulness with five facets. The 39-item questionnaire comprises five subscales, each with 8 items (except the last one), being rated on a 5-point Likert scale from 1 (never or very rarely true) to 5 (very often or always true): *Observing* measures the attention paid to sensations and perceptions of inner and exterior stimuli; *Describing* measures labelling experience and perceptions with words; *Acting with awareness* measures mechanical performance and the attention paid to one's activities; *Non-judging of inner experience* measures the evaluation of one's thoughts and feelings; and *Non-reactivity to inner experience* (only 7 items) measures the ability to let thoughts and feelings come and go without getting caught on them.

Mindfulness-based training

The mindfulness-based course was similar to the MBSR program, but adapted to reduced temporal disposition of the participants to a 5-week program with 3 hour weekly sessions. Sessions were prepared by an instructor with a large experience, and were taught by the instructor herself (MCVL) and another instructor (ECV) with experience in the MBSR program, neither of them involved in the baseline or post-intervention evaluation data collection. Sessions were oriented to enhance situation awareness and included meditation and yoga practice (attention to breath, body scan, yoga, guided meditation, and take a breath), group discussions, and explanations on emotion regulation, as well as the importance of focusing on what happens in the present moment, paying attention to both, internal and external experiences, to stop (take a breath), observe and select the appropriate response.

Procedure

Individuals interested in the study were selected depending on previous described real-life risky driving behaviour (see participant section), which was asked for in an online survey or during a rehabilitation course in a driving school. As part of a bigger project, participants came to the research centre in order to fill out the questionnaires. Mean time period between the two evaluations were approximately 4 months, but varied along the participants because of temporal availability, so that the number of days between evaluations was controlled for in the analyses.

Data analysis

All analyses were done with IBM SPSS statistical software (Version 21.0., IBM Corp., Armonk, NY, 2012).

Participants who did not drop out of the training were considered for analyses resulting in a total of 56 data sets, (see supplementary material for analysis with these 4 participants).

The Behaviour Shift Index (BSI, Li, Liu, Zhang, Liu, & Wei, 2018), defined as the rate between baseline and post-training evaluation $((Score_{baseline} - Score_{post\text{-}intervention}) / (Score_{baseline} + Score_{post\text{-}intervention}))$ for each of the four subscales of the SDBQ was computed. The BSI is a measure of the strength of the change between the two assessments, so that positive rates indicate a reduction of risky driving from baseline to post-training evaluation, and negative ones indicate increase of risky driving.

As sample size is moderate, results might be sensitive to outliers. Therefore, we used the BSI to detect extreme values, using the mean ± 2**SD* as range of normality. Two participants showing BSI scores outside these limits in two or more values of the four subscales were considered outliers and not included in the analyses (see supplementary material for analysis with outliers, as well as Figures S1 and S2). 54 participants remained for the data analyses, 31 in the CG and 23 in the MG.

Two independent samples t-test were used to asses between groups' (MG, GC) differences in socio-demographic variables and the baseline scores of SDBQ and FFMQ. There were no significant differences in age ($t(52) = 0.789$, $p = 0.433$; (average (±*SD*): M_{CG} = 35 (14.415); M_{MG} = 32 (12.933)), or education level ($t(52) = 0.032$, p = .975; M_{CG} = 3.43 (.59), M_{MG} = 3.55 (.64)), as well as initial levels of all subscales of SDBQ (all p > 0.27) and FFMQ (all $p > 0.26$). Non-parametric Mann-Whitney test yielded no significant differences in sex between the two groups ($U = 286$, $p = 0.11$).

Age was introduced as confounder in all following analyses, since SDBQ values are highly sensitive to this variable in our sample (SDBQ total score: $r = -0.421$, p = 0.001), and have also been reported in the literature to be negatively related to SDBQ and FFMQ scores (Koppel et al., 2018; Murphy & Matvienko-Sikar, 2019; Rau & Williams, 2016). As mentioned earlier number of days between both evaluations was also used as confounder to control for time variations.

The assumption of normal distribution was checked for with the Shapiro-Wilk test, not being significant for none of the dependent variables (all $p > 0.6$). Mauchly's sphericity test was used to test sphericity, and Greenhouse-Geisser correction for sphericity adjustments if necessary in both repeated measures ANCOVAs

Relationship between FFMQ and SDBQ subscales

For the analysis of the data, we first tested the relation of risky driving and dispositional mindfulness, performing partial correlations of the whole sample (using the same confounders), between subscales and total scores of both questionnaires (SDBQ and FFMQ).

Intervention effects on FFMQ and SDBQ scores

We explored main and interaction effects of time (baseline, post-intervention) and intervention (MG, CG) on both questionnaires. A 2 (intervention) x 4 (SDBG subscales) x 2 (time) repeated measures ANCOVA was performed with time (baseline and post-intervention evaluation) and SDBG subscales as within-subject factors, and intervention (MG and CG) as between-group factor, respectively. The same repeated measures ANCOVA was performed for the FFMQ scores, resulting in a 2 (intervention) x 5 (FFMQ subscales) x 2 (time) repeated measures design.

Relation of dispositional mindfulness at baseline and BSI scores

To test if changes in risky driving were predicted by initial dispositional mindfulness levels, we conducted a stratified multivariate analysis of covariance (MANCOVA). All FFMQ subscales and confounders were introduced to predict BSI scores of all SDBQ subscales, in each intervention group separately. Lastly, and based on the results of the MANCOVA, we performed another MANCOVA, introducing in addition to the previous predictors, the intervention factor and its interaction with the significant FFMQ subscale. To examine the relation of the significant factors we calculated partial correlations in each group.

RESULTS

Relationship between FFMQ and SDBQ subscales

Table 1 shows moderate partial correlations between the FFMQ and SDBQ baseline scores for the FFMQ Acting with awareness subscale with all SDBQ subscales, pointing to a strong effect of this facet on risky driving behaviors. The *Observing* subscale, though showing negative correlation coefficients, was the only facet not related to any of the SDBQ subscales. All correlations are negative showing higher dispositional mindfulness related to lower risky driving (see Table 1 for all results).

Tabla 1. Partial correlations between self-reported risky driving behavior (SDBQ) and dispositional mindfulness (FFMQ) at baseline in the whole sample

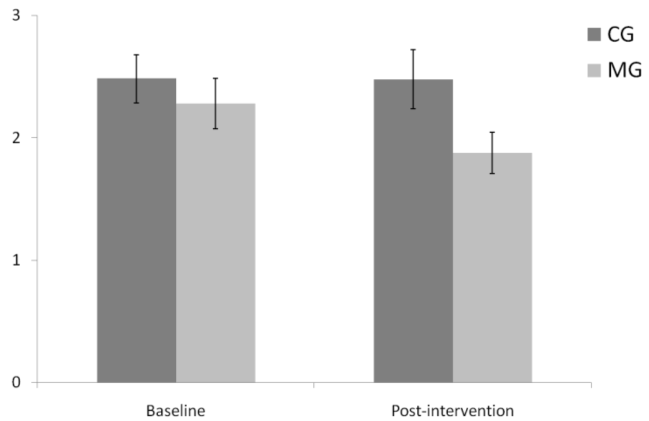
	FFMQ					
SDBQ	Acting with awareness	Describing	Non-judging of inner experience	Non-reactivity to inner experience	Observing	Total Mean
Aggression	-0.430**	-0.347*	-0.167	-0.239	-0.224	-0.412***
Error	-0.368**	-0.237	-0.316*	-0.313*	-0.22	-0.426***
Infraction	-0.322*	-0.148	-0.124	-0.178	-0.145	-0.268
Lapses	-0.579****	-0.316*	-0.349*	-0.361**	-0.145	-0.524****
Total mean	-0.508****	-0.307*	-0.281*	-0.323*	-0.216	-0.482****

Note: **** $p < 0.001$, *** $p < 0.005$, ** $p < 0.01$, * $p < 0.05$

Intervention effects on FFMQ and SDBQ scores

The repeated measures ANCOVA of the SDBQ yielded intervention x time interaction ($F(1, 50) = 4.887$, $p = 0.032$, $\eta_p^2 = 0.089$). Thus, the control and mindfulness group showed different total SDBQ scores in the baseline vs post-intervention comparison (Average (±Standard Error): Baseline: CG = 2.512 (0.183); MG = 2.239 (0.215); Post-intervention: CG = 2.535 (0.195); MG = 1.797 (0.229)), indicating that the MG reduced SDBQ total scores in the post-training evaluation, while the CG showed the same scores at both evaluations (Figure 1).

Figure 1. Interaction effect of time and intervention in self-reported risky driving behaviour



Note: CG, Control group; MG, Mindfulness group

The main effect of SDBQ subscales was also significant applying the Greenhouse-Geisser correction ($F(2.238, 111.91) = 9.209$, $p = 0.012$, $\eta_p^2 = 0.08$). All subscales were different from each other, except the error and lapses subscales. We also observed main effects of age (F(1, 50) = 10.938, p = 0.002, η_p^2 = 0.179) and the interaction of age with the SDBQ subscales and time (F(3, 150) = 3.987, p = 0.009, η_p^2 = 0.74).

The repeated measures ANCOVA of the FFMQ showed an interaction effect of time x interval between baseline and post-intervention evaluation (F(1, 50) = 6.563, p = 0.013, η_p^2 = 0.116), without showing a significant correlation between FFMQ and the interval between evaluations neither at baseline, nor at post-intervention evaluation (Baseline: r = 0.028, p = 0.843; Post-intervention: r = -0.243, p = 0.083). The time x FFMQ subscales interaction was also significant applying the Greenhouse-Geisser correction (F(3.226, 136.583) = 5.284, p = 0.001, η_p^2 = 0.096). These results show that also time subscales seem to change differently with time, no intervention effect was found.

Relation of dispositional mindfulness at baseline and BSI scores

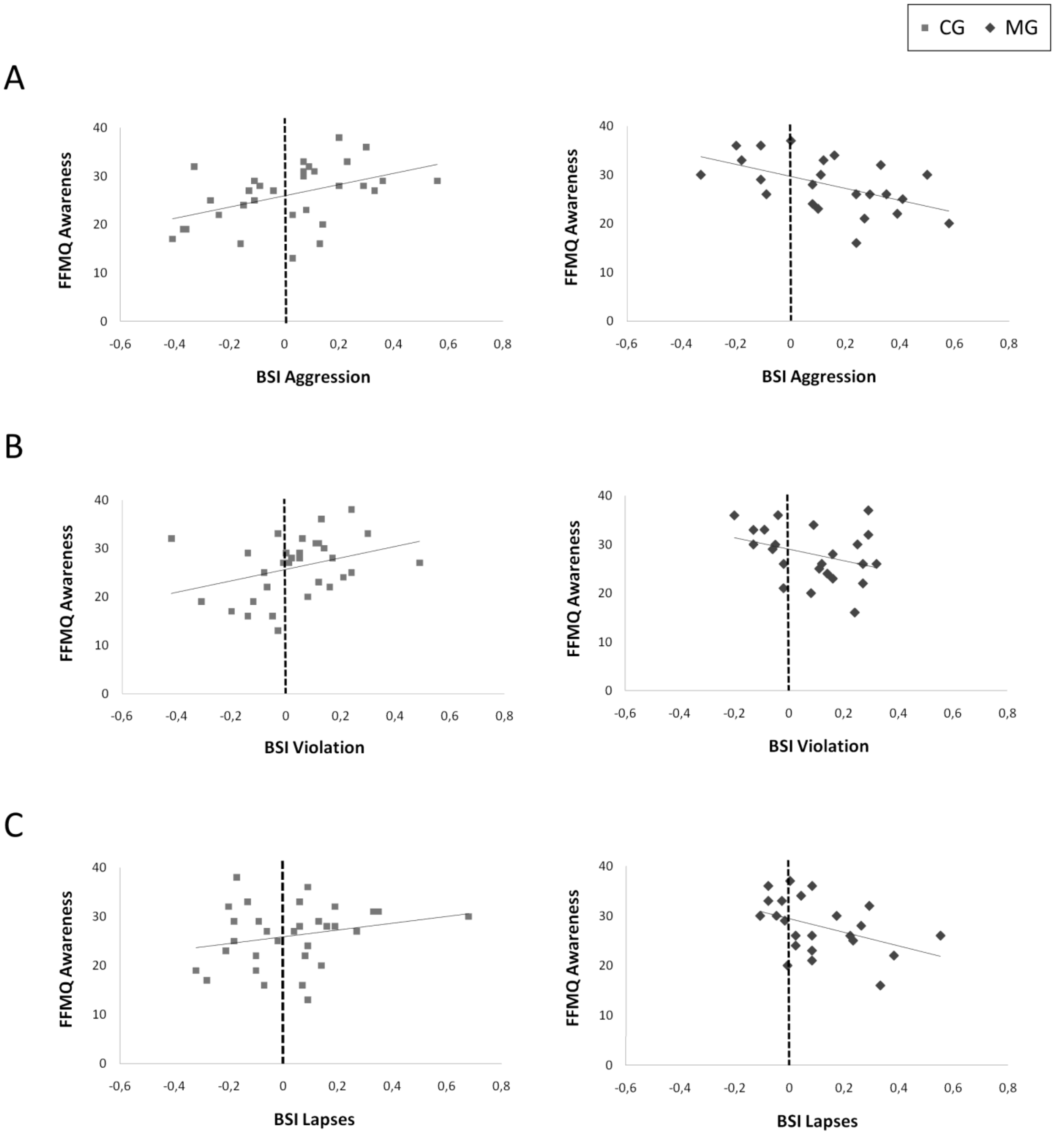
Stratified MANCOVA analysis on SDBQ scores yielded only a significant effect of age in the CG (F(4, 20) = 4.578, p = 0.009, η_p^2 = 0.478), and a significant effect of the FFMQ acting of awareness subscale (F(4, 12) = 3.315, p = 0.011, η_p^2 = 0.639) in the MG. Concretely, while age is associated with the SDBQ lapses subscale (F(4, 23) = 5.864, p = 0.024, η_p^2 = 0.203) in the CG, the FFMQ acting of awareness subscale predicts the BSI of the SDBQ aggression subscale (F(1, 15) = 5.472, p = 0.034, η_p^2 = 0.267), and marginally the SDBQ lapses subscale (F(1, 15) = 4.463, p = 0.052, η_p^2 = 0.229) in the MG. Figure 3 shows correlations between the significant variables in the MG.

The second MANCOVA, indicated that FFMQ acting of awareness subscale yielded significant main effects of age (F(4, 41) = 4.21, p = 0.006, η_p^2 = 0.291) and intervention (*F*(4, 41) = 6.941, $p < 0.001$, $\eta_p^2 = 0.404$), and the interaction between intervention by the FFMQ acting of awareness subscale (*F*(4, 41) = 5.835, $p < 0.001$, $\eta_p^2 = 0.363$). Concretely, age predicts significantly the BSI of the SDBQ lapses subscale (*F*(1, 44) = 4.626, $p = 0.037$, $\eta_p^2 = 0.095$); the intervention factor predicts SDBQ aggression (*F*(1, 44) = 13.514, $p = 0.001$, $\eta_p^2 = 0.235$), SDBQ violations (*F*(1, 44) = 7.42, $p = 0.009$, $\eta_p^2 = 0.144$), and SDBQ lapses (*F*(1, 44) = 7.993, $p = 0.007$, $\eta_p^2 = 0.154$) subscales; and the interaction between intervention x the acting of awareness subscale predicts also SDBQ aggression (*F*(1, 44) = 10.888, $p = 0.002$, $\eta_p^2 = 0.198$), SDBQ violations (*F*(1, 44) = 6.435, $p = 0.015$, $\eta_p^2 = 0.128$), and SDBQ lapses (*F*(1, 44) = 6.390, $p = 0.015$, $\eta_p^2 = 0.127$) subscales.

Differences between groups in BSI scores of all SDBQ subscales are displayed in supplementary Figure S1 (b). Partial correlations between the FFMQ acting with awareness subscale and SDBQ BSI are significant for the SDBQ aggression (*r*(19) = -0.49, $p = 0.024$), SDBQ violations (*r*(19) = -0.439, $p = 0.047$), and SDBQ lapses (*r*(19) = -0.498, $p = 0.022$), subscales in the MG group. For the CG, partial correlations were significant for the SDBQ aggression (*r*(27) = 0.387, $p = 0.038$) and SDBQ error (*r*(27) = 0.385, $p = 0.039$) subscales.

Both groups show relation between these variables but in different directions, being negative in the MG and positive in the CG (Figure 2). In the MG the lower the acting with awareness score, the higher is the reduction of self-reported risky driving behaviour, concretely aggressive behaviour, violations, and attentional lapses. While in the CG, individuals with the lower dispositional mindfulness get riskier in time, the least mindful individuals of the mindfulness group reduce risk-taking in time.

Figure 2. Relation between significant BSI scores of SDBQ subscales and the FFMQ acting with awareness subscale



Note: CG, Control group; MG, Mindfulness group

DISCUSSION

In the present study we measured the effects of a mindfulness-based meditation training in a sample of risky drivers. All participants had risky driving habits and were evaluated in risky driving behavior with the SDBQ, and in dispositional mindfulness with the FFMQ, before and after the training. Participants who were trained in mindfulness meditation show a reduction of self-reported risky driving behavior after the mindfulness-based intervention compared to the control group, while neither of them shows changes in dispositional mindfulness. Moderate negative associations between both measures are found in the whole sample, indicating that greater risk-taking is related to lower dispositional mindfulness. Furthermore, the acting with awareness facet of dispositional mindfulness partially accounts for the BSI in risky driving only in the MG, showing that the lower the acting with awareness score at baseline the greater is the reduction of aggressive driving, infraction, and lapses. Importantly, the mindfulness training shows effects on the same types of risky driving.

Relation of dispositional mindfulness and self-reported risky driving

A huge amount of research has associated dispositional mindfulness to lower risk-taking behavior in different contexts (Black et al., 2012; Lakey et al., 2007; Reynolds et al., 2015; Shook et al., 2019), including risky driving (Feldman et al., 2011; Koppel et al., 2018; Moore & Brown, 2019; Murphy & Matvienko-Sikar, 2019; Panek et al., 2015; Young et al., 2019). This is in line with our baseline results, where we found moderate, negative correlations in the whole sample, as well as in both intervention groups separately. Our findings are also consistent with the importance of the acting with awareness facet in reckless driving (Koppel et al., 2018; Murphy & Matvienko-Sikar, 2019; Panek et al., 2015; Young et al., 2019).

It is worth noting that our sample yielded correlations of larger magnitude than former research, even taking into account age, an important factor for risky driving and dispositional mindfulness (Koppel et al., 2018; Shook et al., 2019). The selection of drivers with actual risky driving habits might have increased these relationships, since previous studies were done in general population samples.

Effects of mindfulness-based training on self-reported risky driving

The benefits of the mindfulness-based training we have are in line with studies showing reduced risk-taking in other contexts. For instance, mindfulness-based therapies showing beneficial effects on nicotine addiction, (Brewer et al., 2011; Davis et al., 2014), and binge-eating (Godfrey et al., 2015). However, as stated by Koppel et al. (2019), there is very few research about the effect of mindfulness-based training on risky driving. Just one study explored the effect of a Buddhist psychology course on behavior in a driving simulation, comparing these participants with controls in a single test session at the end of the course. Observed differences in risk behavior and attention were in favor of the Buddhist psychology course group, but did not reach significant level (Kass et al., 2011). Nonetheless, the study has some methodological issues, as the scarce sample size (8 participants in each group), and the lack of baseline measurements.

Another study with a quasi-experimental design, showed that dispositional mindfulness was negatively related to errors and violations measured with the DBQ in individuals practicing mindfulness compared to non-practicing ones, and that they were also less likely to have been involved in a car crash (Koppel et al., 2018). However, given that individuals were not assigned to the training, but searched for it themselves, similar to study of Kass et al. (2011), other variables and individual differences may have influenced the group differences.

Our study overcomes some of the methodological issues, as the sample size, consisting only of individuals with risky driving habits to prevent a floor effect. Moreover, more than 70% of our sample were men, being a sample more representative of risky drivers, as men are more likely to show reckless driving behavior (Watson, Watson, Siskind, Fleiter, & Soole, 2015). Previous research was mostly made in women, using samples consisting of between 70 to 100% females (e.g. Feldman et al., 2011; Koppel et al., 2018; Moore & Brown, 2019; Young et al., 2019). Thus, our results provide solid evidence of risk-taking reduction of a mindfulness-based training in road users with greatest risk propensity.

Effects of mindfulness-based training on dispositional mindfulness

Despite the improvements in risky driving behavior, no differences were observed in none of the dispositional mindfulness facets. Although research found greater mindfulness after mindfulness-based trainings (Rau & Williams, 2016), other authors also lacked to find differences in individuals practicing mindfulness compared to a non-practicing group (Koppel et al., 2018). Thus, the changes in behaviors related to dispositional mindfulness might be better indicators of the effects of mindfulness-based training. In this vein, it has already been questioned if instruments measuring dispositional mindfulness are affected by mindfulness training, since they are thought as measuring a personality trait (Rau & Williams, 2016). Our results provide more evidence for dispositional mindfulness measurements to be a stable trait and that they might not be susceptible to changes of short mindfulness training, while measurements of risk-taking behavior are far more sensitive.

Prediction of changes in self-reported risky driving with dispositional mindfulness

Analyses showed that only in the mindfulness group BSI of self-reported risky driving were predicted by dispositional mindfulness. Greater changes in aggressive driving, violations, and lapses are related to lower scores in the acting with awareness facet. This might be due to the fact, that the relation between dispositional mindfulness and risky driving is negative at baseline, so that individuals with higher mindfulness trait are already low in risky driving, and changes in risky driving are greater in individuals with lower mindfulness reducing their risk behavior. At the same time, it also shows that individuals with lower levels of the acting with awareness facet benefit most from the training. In contrast, the control group showed an opposed, although non-significant, relation with most reduction of risky driving in individuals showing high dispositional mindfulness.

These results provide insights into the influence of individual differences of dispositional mindfulness at baseline on training effects. Dispositional mindfulness seems to be protective for risk-taking in general, as well as for risky driving specifically (Feldman et al., 2011; Koppel et al., 2018; Moore & Brown, 2019; Murphy & Matvienko-Sikar, 2019; Panek et al., 2015; Young et al., 2019). In the current study, in the mindfulness group we observe a greater reduction of reckless driving in individuals with lower dispositional mindfulness, indirectly confirming earlier research, adding evidence that these programs might be most useful for most vulnerable road users. Moore & Brown (2019) already found differences in the moderation effect of dispositional mindfulness in risky driving only in individuals with low and moderate dispositional mindfulness. Likewise, Godfrey et al., (2015) found greater effects of mindfulness meditation training in studies using samples with higher severity binge-eating. Altogether, it seems to be essential to take into account the individual differences in dispositional mindfulness at baseline in future research.

Exploring the differences in self-reported risk-taking behaviour we find effects on aggressive driving, violations, and lapses. As hypothesized by Koppel et al. (2019), prediction of the acting with awareness facet accounted for lapses in driving, being these two facets, in earlier studies, the most related ones of both variables (dispositional mindfulness, FFMQ, and risky driving behavior, DBQ) (Koppel et al., 2018; Murphy & Matvienko-Sikar, 2019). Although the prediction of lapses by acting with awareness is reasonable, as lapses occur exactly because of a lack of attention to the current activity, it may seem confusing to find acting with awareness to be closely related to aggressive driving and traffic rule violations. In the latter score, a group of meditators already showed an advantage over non-meditators (Koppel et al., 2018), so that our results confirm the relation of a lower level of self-reported traffic rule violations in individuals practicing mindfulness-based meditation. However, the strongest effect with highest BSI is generated in aggressive driving, being also the type of risky driving which is best predicted by the acting with awareness facet.

Intuitively, aggression seems to be more related to non-judging or non-reactivity to inner experience, as these facets might be more related to emotion regulation, which give the impression to be deficient in highly aggressive individual. However, some studies also reported relations between a measure of attention to the present moment and aggression (Heppner et al., 2008), and even to aggressive driving (Stephens et al., 2018). In addition, aggressive behavior was already correlated to acting with awareness in studies exploring relation between other personality traits and dispositional mindfulness, finding moderate to high correlations with neuroticism (Baer et al., 2006), which includes angry hostility, being acting with awareness one of the subscales that is most related to this trait (Rau & Williams, 2016). Actually, acting with awareness is measuring what is meant to be one of the two most characteristic abilities (presence and acceptance) of dispositional mindfulness (Rau & Williams, 2016), and may be influencing basic attention processes necessary for more complex abilities, such as emotion regulation, and in this way being related to aggression.

Examining aggression reduction programs, we found that, traditionally, aggressive driving behavior has been addressed with a couple of different intervention types (for a review see Deffenbacher, 2016). Since it is strongly associated to the driver's anger, which is an emotion or mental state, cognitive therapy groups have been suggested to change maladaptive cognitive patterns and improve emotion regulation. Other interventions targeted the heightened emotional and physiological arousal of aggressive drivers that is thought to trigger before mentioned maladaptive cognitive patterns. Through relaxation therapies, angry drivers are supposed to acquire skills to control arousal and, thus, after it's down regulation, use more adaptive cognitive patterns. Some behavioral interventions are also used, although often combined with one of the previous techniques to cognitive-behavioral therapies, focusing on habit changes through detecting and avoiding sources of anger, or performing incompatible behaviors. Generally, these interventions achieved, alone or in combination, a reduction of anger and aggressive driving even after one year follow-up, although no consistent differences between therapy types were found (Deffenbacher, 2016).

A new approach for aggressive behavior reduction in general, actually, has been to use mindfulness-based training, encouraging meta-awareness of the present moment and acceptance, but including elements of cognitive therapies, such as emotion regulation strategies, and relaxation techniques, such as meditation. These programs have shown some evidence in favor of aggressive behavior reduction (Fix & Fix, 2013).

Therefore, our findings of reduced aggressive driving are not surprising, although we found only one study that addressed the effectiveness of a mindfulness-based program in a driving context. Kazemeini, Ghanbari-e-Hashem-Abadi, & Safarzadeh (2013) observed mindfulness training to decrease aggressive driving more compared to a cognitive therapy. However, again, lack of research has not allowed deducing effectiveness of mindfulness-based training on aggressive driving. Consequently, and confirming the findings of research in dispositional mindfulness and effectiveness of mindfulness-based trainings in other contexts of aggressive behavior, our results provide more evidence that theses intervention programs are effective, demonstrating greatest effects in risky drivers with low dispositional mindfulness.

Future research

Further research is needed to explore the long-term effects and the impact on real life risk-taking in traffic environments. Effects have been reported after a 5-week program, but these effects might be bigger in size in a longer program and it would be important to compare different program types and length, as the heterogeneity of the mindfulness-based trainings in the different studies makes it difficult to compare effects across different fields.

CONCLUSIONS

Various studies observed benefits of being mindful on risky driving behavior, but very little is known about the effectiveness of mindfulness-based training on aberrant driving behavior. The present study indicates that a 5-week training program is enough to reduce risk-taking, though it does not increase dispositional mindfulness. We also found that the training is especially effective in reducing aggressive driving, as well as unintended risk-behavior, as lapses, both through greater awareness to current activities, in risky drivers with lower dispositional mindfulness. Altogether, the present findings point to great benefits of mindfulness-based trainings for traffic rule offenders.

APPENDIX

Supplementary analysis

1. ANOCOVA on SDBQ scores with participants who dropped out

Participants who dropped outs included in the MG (CG: N = 32, MG: N = 28):

Intervention x time interaction was not significant ($F(1, 56) = 2.586$, $p = 0.113$, $\eta_p^2 = .044$).

Participants who dropped outs included in the CG (CG: N = 36, MG: N = 24):

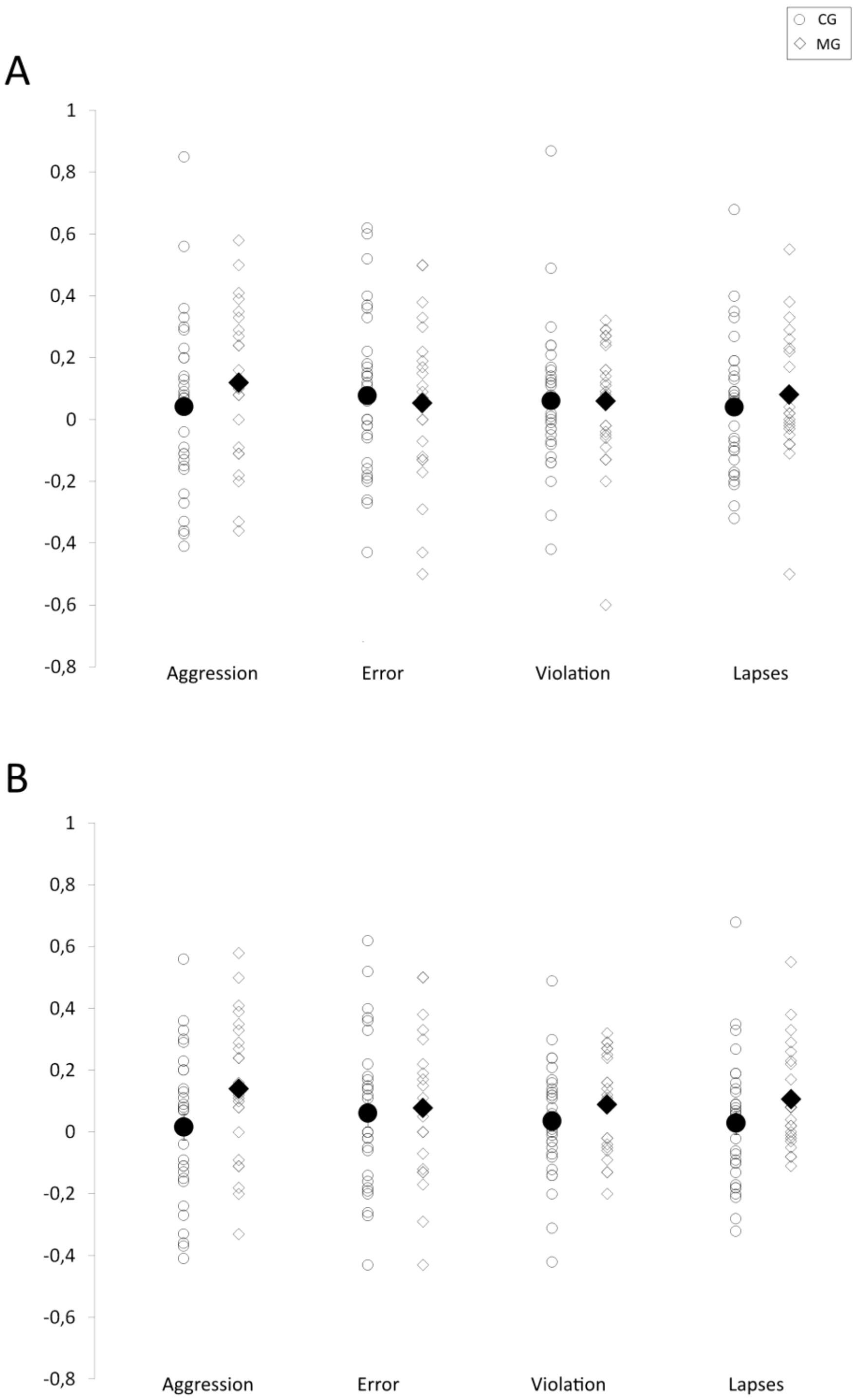
Intervention x time interaction was not significant ($F(1, 56) = 3.572$, $p = 0.064$, $\eta_p^2 = .06$).

All together it seems that drop-out participants are more similar to the CG than to the MG, and are therefore excluded from analyses. In this way, neither MG results are influenced, nor does training experience of the first sessions influence the results.

2. ANOCOVA on SDBQ with Outliers (without participants who dropped out)

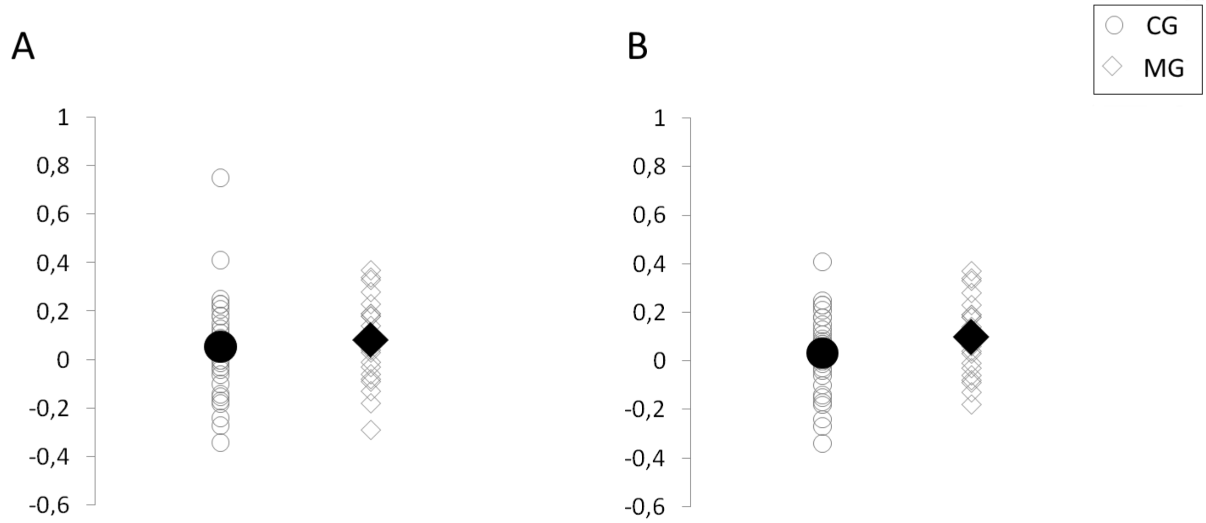
Taking into account all participants without the ones who dropped out (CG: N = 32, MG: N = 24), the intervention x time interaction was not significant ($F(1, 52) = 3.071$, $p = .086$, $\eta_p^2 = .056$), indicating sensitivity to outliers.

Supplementary Figure S1. BSI scores of all subscales of the SDBQ in both groups used to detect outliers (one of each group showed two or more scores out of normal range), with outliers (A) and without outliers (B)



Note: CG, Control group; MG, Mindfulness group

Supplementary Figure S2. BSI scores of both groups in the total score of the SDBQ with outliers (A) and without outliers (B)



Note: CG, Control group; MG, Mindfulness group

GENERAL DISCUSSION

Risk-taking behaviour arises from a decision-making process being widely accepted as the result of the interaction of two competitive brain systems: intuitive and analytic. The intuitive system is mostly influenced by emotions and experience, while the analytic system evaluates different options more objectively (Evans, 2008; Frankish, 2010; Kahneman & Frederick, 2002; Loewenstein et al., 2001; Reyna, 2004; Slovic et al., 2004). In this way, risk-taking behaviour may result mostly out of emotional situations, which are highest for adolescents when being with peers (Chein et al., 2011; Shulman et al., 2016; Steinberg, 2008). In study 1 we hypothesized that this effect may be similar in emerging adults as brain development in cognitive control areas involved in decision-making do not complete until late twenties (Casey et al., 2019; Giedd, 2004), although previous studies have found effects in mostly emotional and reward processing areas and not in cognitive control areas. However, our findings point to the activation of different brain networks in different social contexts. A number of areas showing differential activity during risk discrimination are activated by the task, being activated in both social contexts (bilateral orbitofrontal (OFC), cingulate cortices), while others were dependent on the social context, being activated only when the youth was alone (right lateral OFC and agranular insula, bilateral medial OFC and dorsomedial cortices) or with a peer (left lateral OFC and ventrolateral prefrontal cortex, right posterior superior temporal gyrus). When predicting accidents and average speed in a driving simulation the connectivity of dorsomedial and cingulate areas does not seem to play a role when a peer is present, being in line with the dual system predicting lower involvement of cognitive control areas and circuits. In this way, our results suggest an alternative approach for research of the peer-effect congruent with current theoretical models.

Furthermore, personality traits, such as impulsivity and sensation seeking, have been related to risk-taking (Beanland et al., 2014; Cservenka et al., 2013; Donohew et al., 2000; Joseph et al., 2009; Wong & Carducci, 1991; Zuckerman & Kuhlman, 2000) and brain correlates associated to these personality traits (Aron et al., 2004; Brevet-Aeby et al., 2016; Fineberg et al., 2014; Muhlert & Lawrence, 2015; Robbins & Dalley, 2017), overlap with those of risk propensity (Blankenstein et al., 2018; Canessa et al., 2017; Coutlee et al., 2016; Hsu et al., 2005; Morriss et al., 2019; Pletzer & Ortner, 2016; Tom et al., 2007), although the interrelations of these individual differences were not studied at brain functional level. In study 2 we had the aim to fill this knowledge gap studying individual differences and its brain correlates in relation to risk propensity. We found that impulsivity and sensation seeking facets are not only related to, but predicted risk propensity. We also observed that the relation between brain connectivity during risk discrimination and several impulsivity related traits was opposite in risk vs non-risk prone individuals, showing generally stronger relations in the risk prone group. The facets of lack of perseverance and premeditation, as well as emotion seeking, showed different relation with between – and within network connectivity in brain circuits usually associated to cognitive control and emotional and reward-processing (limbic, ventral attention, fronto-parietal and default mode networks). These findings provide evidence that personality traits are linked to functional connectivity and that these links depend on risk propensity. Hereby, we shed light on the interaction between individual differences and functional brain connectivity, being a good starting point for future research in this field of study.

Lastly, most research on the links between mindfulness and risky driving depend on research measuring individual differences in dispositional mindfulness (Feldman et al., 2011; Koppel et al., 2018; Moore & Brown, 2019; Murphy & Matvienko-Sikar, 2019; Panek et al., 2015; Young et al., 2019). Together with findings showing reduction of risk-taking after mindfulness-based training in other, mostly clinical, contexts (Brewer et al., 2011; Cairncross & Miller, 2016; Cavicchioli et al., 2018; Davis et al., 2014; Kass et al., 2011; Khoury et al., 2013; Koppel et al., 2019; Stephens et al., 2018; Vidrine et al., 2016), we hypothesized that this kind of training might also lower risky driving. In fact, we found a reduction of self-reported risky driving behaviour after training in mindfulness, while dispositional mindfulness remaining constant before and after the intervention. Although we did not find differences between diverse types of risky driving, the mindfulness intervention showed the greatest benefits in individuals with low dispositional mindfulness mostly on aggressive driving, and in a lower degree on traffic rule violations and lapses. These findings indicate the importance of the interaction of individual differences and mindfulness-based training that should be taken into account when using this kind of interventions. Furthermore, our results prove the effectiveness of mindfulness-based training not only for clinical risk-taking behaviour, but also for risky driving, an everyday activity concerning almost everyone.

The studies of the current doctoral thesis, besides focusing on different elements of risk propensity, combined together offer valuable clues to the research in risk propensity. Firstly, in study 1 and 2, we found the limbic, fronto-parietal, and ventral attention networks to be involved in risk discrimination (study 2), as well as the activation of brain areas of these networks (study 1). Thus, findings of both studies are in line with the dual system model showing that regions and networks related to processing of emotions and reward, as well as to cognitive control are involved in the processing and decision about risk. This can be observed by the fact, that higher connectivity between networks and within the limbic network indicated higher impulsivity in risk prone individuals (study 2), and also that connectivity of cognitive control and attention areas does not seem to predict risky driving behaviour in a highly emotional situation (study 1).

Moreover, and based on the links mentioned, effects of social context and mindfulness training was related to similar brain regions and networks in the literature in a reverse way. The presence of peers in youths has been related to higher activity of emotional related brain regions (Albert et al., 2013; Chein et al., 2011; Leung et al., 2014; Sherman et al., 2018, 2019; Telzer et al., 2015), while mindfulness-based training has been associated with an enhancement of cognitive control and a reduction of activation in emotional related brain areas (Fox et al., 2014; Tang et al., 2015). Research on mindfulness-based interventions report effects of emotion regulation skills (Tang et al., 2015), which seem to be deficient in youths in highly emotional situations (Albert et al., 2013; Casey, 2015). Thus, our findings are consistent with previous research; study 1 confirms the implication of brain regions and networks in the effect of social contexts which have shown altered activation after mindfulness-based training, at the same time as study 3 indicates that this kind of training reduces risk-taking. Together with studies showing improved social-emotional skills (Schonert-Reichl et al., 2015; Semple, Lee, Rosa, & Miller, 2010; Zelazo & Lyons, 2012), our findings give rise to the hypothesis that mindfulness-based training may have a positive impact on peer influence in youths. In future work, it would be interesting taking into account the resistance of peer influence in research with adolescents and emerging adults.

Finally, it is worth noting that along with emotional- and reward- processing, cognitive control, and attention related networks also areas of the default mode network were involved in risk discrimination (study 1), as well as they showed differences in the links to impulsivity in risk and non-risk prone individuals (study 2). This network is not considered in neuroscience models of risk-taking, as it is more associated to internal processing and tends to show reduced activity during external stimuli-driven tasks (Anticevic et al., 2012; Christoff et al., 2009). Nonetheless, this network is extensively related to mindfulness practice, showing alterations after a mindfulness-based training (Berkovich-Ohana, Glicksohn, & Goldstein, 2014; Creswell et al., 2016; Doll, Hölzel, Boucard, Wohlschläger, & Sorg, 2015; King et al., 2016). Together with the finding of reduced risky driving in study 3, this network may be involved in the cerebral mechanism of this kind of intervention. In future research it would be interesting to test the relation of risky driving reduction and changes in the default mode network, besides of changes in networks and areas linked to cognitive control and emotional processing.

As all research, the studies included in the current doctoral thesis present several strengths and limitations. One of the strengths is the high number of participants tested with EEG in study 1 and 2. Even study 3 has a high number of participants compared to the few studies performing mindfulness –based training to enhance cognitive control or reduce risky behaviour. Another strength is the intervention program in a subclinical sample with heightened risky driving behaviour, since most research is based on individual differences in dispositional mindfulness and not on the effect of training. Furthermore, we used a translation of brain activation and functional connectivity during risk discrimination together with an ecological valid task, the driving simulation. However, it would also be interesting to explore brain correlates during the driving simulation, which might be a limitation addressed in future research. Another limitation is that the two first studies were performed with young samples, wherefore future research will concentrate in older samples to study the brain correlates of social context and interrelation of brain connectivity and individual differences in impulsivity and risk propensity, since age is an important factor closely related to risk-taking. Lastly, we used self-reported risk-taking to measure the impact of the mindfulness-based intervention program, which may differ from actual behaviour. Studies with behavioural measurements are needed to verify the effectiveness of this program on real-life activities.

CONCLUSIONS

The different studies composing the present doctoral thesis result in the following conclusions:

1. In emerging adults, the presence of a peer results in reduced ability to discriminate high- from low-risk traffic scenes independently of the dyad type (only women, only men, or mixed dyads). Differential brain activity during risk evaluation is observed in social and non-social networks, including mainly ventral prefrontal and orbitofrontal, as well as dorsomedial and cingulate cortices. Some of these areas are active when a peer is present or absent (social), and others seem to depend on the task, independently of the social context (non-social).
2. Connectivity between ventral prefrontal, orbitofrontal, dorsomedial, and cingulate cortices predicted accident rates and average speed for the driving simulation when peers were alone, but only prefrontal areas were involved when peers were present. This finding provides more evidence that the social context triggers different brain networks for risk processing.
3. Individual differences in impulsivity and sensation seeking are not only related but predictive for risk-taking propensity and they are associated with different functional brain connectivity patterns.
4. Risk propensity modulates the association of impulsivity-related personality facets with between- and within-network connectivity related to cognitive control and reward- and emotion processing (Limbic, ventral attention, and fronto-parietal networks), as well as to internal processes as mind-wandering(default mode network).
5. A Mindfulness-based intervention program reduced self-reported risky driving behaviour in a sample of risk prone drivers, without enhancing dispositional mindfulness, pointing to behavioural changes without changes in dispositional mindfulness, which is congruent with the idea of this facet as a personality trait.
6. Risk prone drivers with low dispositional mindfulness showed the greatest enhancements of self-reported risky driving behaviour after a mindfulness-based

training, indicating that benefits of this intervention might depend on individual differences.

FUTURE PERSPECTIVES

Derived from the studies of the doctoral thesis the following general aims are proposed for future studies:

- Brain correlates of the effect of social context and risk propensity should be tested in older samples and in non-driving risky scenarios.
- The interrelation of risk propensity and individual differences in other personality traits should be studied at brain level, combining neuroimaging techniques and behavioural ecological valid, everyday tasks, such as a driving simulation.
- The effectiveness of mindfulness-based training programs should be tested with behavioural measurements and follow-up studies.
- The brain mechanisms of mindfulness-based intervention changes in risk-taking will be studied with neuroimaging techniques.
- The relation between individual differences and behavioural changes after mindfulness-based training should be examined to identify the individuals who benefit most.

CONCLUSIONES (in Spanish)

De la presente tesis doctoral se derivan las siguientes conclusiones:

1. En jóvenes adultos la presencia de un igual reduce la capacidad de discriminar escenas de tráfico que conllevan mucho y poco riesgo independientemente del tipo de la pareja de iguales (solos hombres, solo mujeres o parejas mixtas). En la actividad cerebral diferencial de las escenas de tráfico de mucho y poco riesgo observamos redes cerebrales sociales y no-sociales incluyendo la corteza prefrontal ventral y orbitofrontal como la corteza cingulada y dorsomedial. Algunas de estas áreas están activadas tanto en presencia como en ausencia del igual (áreas sociales) y otras dependen de la tarea y están activadas independientemente de la presencia o ausencia de iguales.
2. La conectividad entre la corteza prefrontal ventral, orbitofrontal, dorsomedial y cingulada predice el número de accidentes y la velocidad media en una tarea de conducción simulada cuando el joven está solo, pero solo las zonas prefrontales están involucradas cuando el igual está presente, lo que indica que el contexto social activa redes cerebrales diferentes.
3. Diferencias individuales en impulsividad y búsqueda de sensaciones no están solo relacionadas con la propensión al riesgo, sino que la predicen, además de estar asociadas a diferentes patrones de conectividad funcional del cerebro.
4. La propensión al riesgo modula la asociación entre rasgos de personalidad relacionados con la impulsividad y la conectividad cerebral entre los nodos de la misma red, y entre redes, asociados con el control cognitivo y el procesamiento de recompensa y emociones (redes límbica, de atención ventral y fronto-parietal), como también con procesos internos como el mind-wandering (red por defecto).
5. Un programa basado en mindfulness reduce la conducción arriesgada autoinformada en una muestra de conductores arriesgados, sin mejorar el mindfulness disposicional, lo que indica que pueden producirse cambios en la conducta de riesgo sin que se observen cambios en el rasgo de mindulness disposicional.

6. Los conductores arriesgados que mostraban una baja tendencia a actuar mindful mostraron los cambios más pronunciados en la conducción arriesgada autoinformada, indicando que a efectividad de este tipo de programas puede depender de diferencias individuales.

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