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"Regulating my anxiety worsens the safety of my driving": The synergistic influence of spatial anxiety and Self-regulation on driving behavior

Sergio Traficante [a,1], Luigi Tinella [a,b,*,2], Antonella Lopez [a,c,3], Sjaan Koppel [d,4], Elisabetta Ricciardi [a,5], Rosa Napoletano [a,6], Giuseppina Spano [a,7], Andrea Bosco [a,8], Alessandro Oronzo Caffò [a,9]

[a] Department of Educational Sciences, Psychology, Communication, University of Bari, 70121, Italy
[b] Department of Humanities, Philosophy and Education, University of Salerno, Italy
[c] Faculty of Law, Giustino Fortunato University, Benevento, Italy
[d] Monash University Accident Research Centre, Monash University, Australia

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ABSTRACT

Spatial Anxiety (SA) can be defined as the fear and apprehension experienced during tasks that require spatial thinking and may negatively impact the execution of daily actions. Although it has been explored in several research fields, limited research has explored the effects of SA on specific driving behaviours. In the current study, it was hypothesised that the severity of SA affects risky driving behaviours, and that this relationship is mediated by the driver's self-regulation abilities. Self-reported SA symptoms, driving self-regulation abilities, and risky driving behaviours (i.e., errors, violations, and lapses) were examined in 838 Italian drivers. Data were analysed through linear regressions and path analysis models, controlling for sociodemographic variables. The results showed the negative effects of SA on driving errors and lapses. As hypothesised, a driver's self-regulation abilities mediated the influence of SA on driving lapses, but not on errors nor violations. These findings suggest that the inclination to self-regulate the SA experienced while driving contribute to increase the occurrence of driving lapses. Showing specific pathways through which SA impacts risky driving, these results provide valuable insights for the development of 'driver-focused' road safety interventions.

1. Introduction

Spatial mental representation of the environment and spatial navigation play a crucial role for the execution of various daily activities (Lopez et al, 2020; Lopez et al., 2021). Spatial mental representation refers to the cognitive maps and mental models that individuals construct to understand and navigate their environment (McNamara, 1986; Tversky et al., 1993), whereas spatial navigation refers to the ability to move through physical space, to understand directions, and to reach specific destinations (Darken and Peterson, 2002; Epstein et al., 2017; Caffò et al., 2020). These abilities can influence the performance in spatial tasks, including the driving performance. Drivers create mental representations of familiar routes, including landmarks, intersections, and turns (Charlton and Starkey, 2017). These representations help them in anticipating upcoming actions and making informed decisions (e.g. Kunishige et al., 2020; Tinella et al., 2020). Moreover,

* Corresponding author at: Department of Educational Sciences, Psychology, Communication, University of Bari, 70121, Italy.
E-mail address: luigi.tinella@uniba.it (L. Tinella).
[1] 0009-0009-9163-4685.
[2] 0000-0003-4296-5233.
[3] 0000-0002-3717-1677.
[4] 0000-0003-3973-299X.
[5] 0000-0002-8127-5158.
[6] 0009-0007-0753-1487.
[7] 0000-0002-9565-460X.
[8] 0000-0002-9458-3993.
[9] 0000-0003-3973-8152.

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knowing where they are relative to their position or destination allows drivers to adjust their driving behavior, accordingly, moving through physical space, understanding directions, and reaching specific destinations. Furthermore, spatial mental representations aid memory recall, helping drivers remember critical details about their route (e.g. Taylor and Tversky, 1992; Von Stülpnagel and Steffens, 2012). Drivers mentally plan their routes by considering distances, turns, and landmarks. Effective spatial navigation ensures efficient and safe travel. For example, when faced with road closures, detours, or unexpected obstacles, spatial navigation skills allow drivers to find alternative routes. Drivers use spatial cues (such as road signs, buildings, and natural features) to stay oriented and avoid getting lost, maintaining their awareness of surroundings. Precise spatial awareness is crucial for parking, merging lanes, and navigating tight spaces. Drivers must constantly monitor the vehicle's position relative to the road, other vehicles, and surrounding obstacles, using both direct visual information and mental representations of space (Anstey et al., 2012; Meneghetti et al., 2021). Considering all of this, driving represents a complex spatial activity involving perception, attention, sensory and navigational abilities (Ranney, 1994; Tinella et al., 2021).

SA is a multi-faceted, domain-specific type of anxiety that influences navigation, and the performance of spatial tasks (e.g., navigation, wayfinding, mentally manipulating or rotating objects, perspective taking; Lawton, 1994; Ramirez et al., 2012). It is a form of fear or apprehension that an individual experiences while processing environmental information contained in one's geographical space (Lawton, 1994). Indeed, previous research has shown that spatial tasks can be challenging for individuals, causing uncomfortable internal sensations, and producing SA (Lawton, 1994; Lyons et al., 2018).

SA has been found to relate to problems with everyday activities, including driving behavior. SA creates a state of increased stress and arousal (e.g., Nori et al., 2023). This can impair a driver's ability to think clearly and make rational decisions. Attention becomes fixated on navigating complex situations, leading to a narrowed focus (Wickens, 2020). This can cause drivers to miss crucial information like traffic signals or pedestrians. Moreover, SA can influence decision making, leading to hesitation and indecisiveness. This indecisiveness can cause delayed reactions or impulsive maneuvers to avoid perceived threats (e.g. Bishop and Gagne, 2018). Furthermore, SA can increase risk taking such as speeding to get through intersections or challenging areas faster, making sudden lane changes without proper checks, disregarding traffic rules due to a desire to reach the destination quickly (e.g., Clapp et al., 2011; Nori et al., 2020; Gwyther & Holland, 2012). On one hand, all these behaviors can involve driving risks with dangerous consequences for the individual. On the other hand, SA can lead to avoidance behaviors especially on unfamiliar routes or during peak traffic hours (Stephens et al., 2020). In light of this, SA might lead to modifications in driving behavior to avoid challenging situations, as a form of driving self-regulation (Molnar et al., 2013a; Molnar et al., 2013b; Molnar et al., 2014). Individuals may exhibit self-regulatory behaviors to cope with their discomfort. In situations of anger, stress, sleepiness, and anxiety, drivers often need to use self-regulatory strategies to reduce the probability of engaging in risky driving behaviors and motor vehicle crashes (e.g. Watling et al., 2016; Love et al., 2023). Indeed, driving self-regulation is an important road safety strategy because drivers can recognize a possible danger, avoiding driving situations they find difficult (e.g., driving only in familiar environment, avoiding rush hours and night driving), reducing crash involvement (Baldock et al., 2006; Molnar et al., 2013a; Molnar et al., 2013b; Lazuras et al., 2022). While several studies have examined the relationship between anxiety and self-regulation (Gwyther & Holland, 2012), there is limited research that has focused on the potentially dangerous role that self-regulation can play in drivers with SA. In light of above, it was hypothesized that drivers who are anxious and lack confidence may be at a higher risk of self-regulation which could affect the driving behavior.

1.1. The present study

The focus of the present study was to investigate the relationships between SA, driving self-regulation, and risky driving behaviors. While previous research has examined SA in various contexts, there remains a gap in understanding its relationship to driving behaviors. We also consider the relationship between spatial anxiety and other variables relevant to driving behavior. While there is substantial literature examining the influence of spatial anxiety on spatial tasks and navigation performance (e.g. Hund & Minarik, 2006), research exploring its interaction with other factors, such as self-regulation and risky driving behaviors, remains limited. Previous studies have touched on these relationships, yet there is a lack of consensus regarding how spatial anxiety specifically affects driving errors, violations, and lapses, as well as the extent to which self-regulation mediates these effects.

Based on the previous literature, it was hypothesized that the severity of SA may influence risky driving behavior (i.e., violations, errors, and lapses), with the relationship mediated by a driver's self-regulation abilities. Based on previous literature and the gaps identified in the current research, the present study aims to investigate the relationships between Spatial Anxiety (SA), driving self-regulation, and risky driving behaviors (i.e., violations, errors, and lapses). The following hypotheses are proposed: (1) Drivers who experience higher levels of Spatial Anxiety (SA) will report more frequent risky driving behaviors, including violations, errors, and lapses. Research indicates that SA increases stress and arousal, impairing clear thinking and decision-making in drivers, leading to missed traffic signals, delayed reactions, and impulsive maneuvers. Elevated SA has been associated with higher rates of navigational and timing errors in spatial tasks (Hund & Minarik, 2006). (2) Driving self-regulation mediates the relationship between SA and driving lapses. SA may lead to avoidance behaviors as a form of self-regulation to cope with discomfort in driving situations. This maladaptive self-regulation could result in lapses due to over-regulation and cognitive interference from anxiety (Gwyther & Holland, 2012). (3) Driving self-regulation mediates the relationship between SA and driving errors. In this case, while high self-regulation levels generally improve road safety (Molnar and Eby, 2008; Auzoult et al., 2015), over-regulation due to anxiety could impair attentional control and decision-making, leading to errors (e.g. Derryberry & Reed, 2002). Finally, the last hypothesis tries to explore if the (4) driving self-regulation mediates the relationship between SA and driving violations. Although SA is linked to unintentional errors and lapses, its role in deliberate violations is less clear. Self-regulation strategies might influence the frequency of violations, especially in drivers with high SA.

2. Material and methods

2.1. Participants

A power analysis was conducted to estimate the sample size using G*Power 3.1 (Faul et al., 2009), with the following parameters: a p level of 0.05, a cautious low effect size (0.12), and a power of 0.80. Results indicated that a sample size of 113 participants was sufficient to warrant an 80 % chance of correctly rejecting the null hypothesis. Eight hundred and thirty-eight participants, 375 females (F) (age: M$\pm$SD=43,76 $\pm$ 17,03; Years of schooling: $M\pm$SD=13,40 $\pm$ 3,82) and 463 males (M) (age: $M\pm$SD=39,67 $\pm$ 19,59; Years of schooling: $M\pm$SD=13,06 $\pm$ 3,34) between 18 and 85 years of age, took part in the study. All participants were required to: (a) hold a valid current driver's license, provisional or above; (b) have normal or corrected to normal vision; (c) have driven more than one time within the last month; and not be or had been a professional driver (e.g., taxi driver, truck driver, transporter on delivery, etc.). Descriptive statistics for categorical variable (gender) and correlation matrix for continuous variable (age, years of schooling, driving behaviors; driving self-regulation and SA) are reported in Table 1. No correlation coefficient between age, years of schooling,

Table 1
Mean (M), standard deviation (SD) and correlation matrix for age, gender, years of schooling, driving lapses, driving errors, driving violations, driving self-regulation and spatial anxiety. $*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

	AGE		YSC		LAPSES		ERRORS		VIOL		DMQ		QAS	MALE		FEMALE	
														M	SD	M	SD
AGE	—													39.67	19.59	43.76	17.03
YSC	−0.474	***	—											13.06	3.34	13.40	3.82
LAPSES	−0.232	***	0.139	***	—									7.25	4.94	7.45	4.37
ERRORS	−0.134	***	0.063		0.571	***	—							4.11	3.60	3.37	3.33
VIOL	−0.202	***	0.032		0.372	***	0.557	***	—					12.15	8.06	9.28	7.50
DMQ	−0.055		0.130	***	0.173	***	0.079	*	−0.100	**	—			32.22	13.98	36.99	12.82
QAS	−0.097	**	0.041		0.320	***	0.168	***	−0.017		0.329	***	—	20.94	8.25	23.18	7.63
GEN	0.127	***	0.146	***	0.190	***	0.034		−0.075		−0.197	***	0.035	—	—	—	—

YSC=years of schooling; LAPSES=driving behavior questionnaire (lapses); ERRORS driving behavior questionnaire (errors); VIOL=driving behavior questionnaire (violation); DMQ-A=driving mobility questionnaire (total score); QAS=spatial anxiety questionnaire (total score); GEN=gender; p = p value.

gender and SA was higher than 0.75, suggesting that there were no issues of multicollinearity among the predictors. The participants, blind to the hypothesis of the study, were volunteers recruited with the support of a proxy informant, generally undergraduate and graduate students, and trainees. All participants signed their informed consent prior to the enrolment in the study. The Ethical Committee of the Department of Education, Psychology, and Communication approved the study protocol, and the whole study was performed following the Helsinki Declaration and its later amendments (Ethics reference code: ET-23-23).

2.2. Material and procedure

Participants had to be in a good general state of physical and psychological health. All participants were enrolled between October and December 2023. A brief interview was administered by supervised trainees in neuropsychological assessment to collect demographic information, to exclude neurodegenerative and vision/hearing disorders, and to gather information about participant's driving habits and years of license. After completing the interview, all participants completed a survey with the following self-report questionnaires.

2.2.1. Driving behavior questionnaire (DBQ)

The Italian 28-item version of Driver Behavior Questionnaire (DBQ), developed by Reason et al. (1990), and adapted to the Italian context by Lucidi et al. (2010), was used to measure self-reported aberrant driving behaviors. The instrument includes three subscales: (a) *errors*, misjudgments or failures of observation that could be hazardous to others (e.g., failure to check mirrors, not seeing a pedestrian crossing); (b) *lapses*, absent-minded behaviors which may be frustrating or have negative consequences for the driver responsible, but generally do not pose a threat to anyone's safety (e.g., taking the wrong exit); and (c) *violations*, deliberate contraventions of legally regulated or socially accepted behaviors associated with safe vehicle operation (e.g., speeding, poor lane discipline, close following of another vehicle). Each item in the questionnaire is rated on a six point-scale, ranging from 0 (Never) to 5 (Almost always). In this scale, higher score indicated a higher frequency of aberrant behaviors during driving activities. The questionnaire presented good psychometrics properties (Lucidi et al., 2010) (Cronbach's α violations = 0.78; Cronbach's α errors = 0.80; Cronbach's α lapses = 0.75; Cronbach's α overall scale = 0.77).

2.2.1.1. Driving mobility questionnaire (DMQ-A). The 21-item version of Driving Mobility Questionnaire (Extended DMQ-A) developed by Wong et al. (2015), and validated for Italian drivers (Spano et al., 2019), was used to measure the frequency with which drivers avoided driving (i.e., driving self-restriction) in certain conditions (i.e., at night, in the rain, or in foggy conditions). According to Spano et al. (2019), this questionnaire includes two factors: External Driving Environment (EDE) and Internal Driving Environment (IDE). Each item in the questionnaire is rated on five-point scale, ranging from 1 (Never avoid) to 5 (Always avoid). In this scale, higher scores indicate a higher level of self-restriction. The questionnaire presented good psychometrics properties (Spano et al., 2019) (Cronbach's α EDE=.84; Cronbach's IDE=.79; Cronbach's α overall scale = 0.73).

2.2.1.2. Spatial anxiety questionnaire (QAS). The Spatial Anxiety Questionnaire (De Beni et al., 2014) measures the level of anxiety in environmental tasks. The questionnaire comprises8 items, and each item is rated on a six point-scale, ranging from 1 (Never) to 6 (Always). In this scale, higher scores indicated a higher level of SA in specific situations and environmental tasks. The questionnaire presented good psychometrics properties (De Beni et al., 2014) (Cronbach's α = 0.80).

3. Statistical analyses

Statistical Analysis were conducted using the software Jamovi, version 2.3.28 (The Jamovi Project, 2023). Independent samples t-tests were conducted to investigate differences in self-reported measures between gender groups. In order to assess theoretical mediation assumptions, three multiple regression analyses were performed considering demographic variables (i.e., age group, gender, and years of schooling), and SA (i.e., QAS) as predictors of different facets of aberrant driving behavior (i.e., DBQ errors, lapses, and violations), considered as outcomes. We have followed the theoretical assumptions of statistical mediation as highlighted by Baron and Kenny (1986) and by Gallucci et al. (2017). These assumptions indicate that predictors (QAS) should significantly affect the mediator (DMQ); predictors should have a significant effect on the outcome (DBQ); the outcome should be predicted by the mediator. If there is not the significant effect between predictor and dependent variable, the mediation assumption is not respected. In light of this, path models were tested, estimating the direct, indirect and total effects (through driving self-regulation, i.e. DMQ-A) of SA on driving errors and driving lapses.

4. Results

The independent samples *t*-test revealed significant gender differences across several variables. A significant gender difference in age was observed, with males being, on average, younger than females. Cohen's score indicates a small effect size (AGE: Welch's $t = -3.233$; $df = 832$; $p = 0.001$; Cohen's $d = -0.223$). Males reported a significantly higher number of driving violations compared to females. Cohen's score indicates a moderate effect size (DBQ_VIOL=Welch's $t = 5.329$; $df = 820$; $p < 0.001$; Cohen's $d = 0.368$). Additionally, males were found to have committed more driving errors than females. Cohen's score indicates a small effect size. (DBQ_ERRORS=Welch's $t = 3.087$; $df = 821$; $p = 0.002$ Cohen's $d = 0.213$). Female participants exhibited significantly higher levels of driving self-regulation than male participants. Cohen's score indicates a moderate effect size (DMQ_TOT=Welch's $t = -5.144$; $df = 823$; $p < 0.001$; Cohen's $d = -0.355$). Additionally, females exhibited higher levels of spatial anxiety compared to males. Cohen's score indicates a small effect size (QAS_TOT=Welch's $t = -4.067$; $df = 821$; $p < 0.001$; Cohen's $d = -0.281$). We chose to adopt the Welch's *t*-test because the Levine's test resulted significant ($p < 0.05$), assuming a violation of equal variances. Moreover, the multiple regression analyses as well as the path models performed for each driving outcome are summarized below.

4.1. Driving behaviors: multiple regression analyses

The first multiple regression analysis was performed on driving violations. Significant and non-significant effects are reported in Table 2. Explained variance (R^2) for the main effect model was equal to 0.0786 (adj. $R^2 = 0.0731$). Significant results were found for the effects of age group ($\beta = -0.099$; $p < 0.001$), gender ($\beta = 2.1425$; $p < 0.001$), years of schooling ($\beta = -0.191$; $p = 0.027$), and overall driving self-regulation ($\beta = -0.062$; $p < 0.001$). No significant differences were found for the effects of SA ($\beta = 0.0176$; $p = 0.616$).

The second multiple regression analysis was performed on driving lapses. Significant and non-significant effects are reported in Table 3. R^2 for the main effect model was equal to 0.150 (adj. $R^2 = 0.145$). The first-order effects model showed significant effects between driving lapses and age group, ($\beta = -0.0431$; $p < 0.001$), driving self-regulation ($\beta = 0.0286$; $p = 0.017$) and SA ($\beta = 0.161$; $p = < 0.001$). No significant differences were found for the effects of gender ($\beta = -0.149$; $p = 0.632$) and years of schooling ($\beta = 0.077$; $p = 0.115$). The third multiple regression analysis was performed on driving errors. Significant and non-significant effects are reported in Table 4. R^2 for the main effect model was equal to 0.0577 (adj. $R^2 = 0.0520$). Significant results were found for the effects of age group ($\beta = -0.016$; $p = 0.023$), gender ($\beta = -0.892$; $p < 0.001$) and SA ($\beta = 0.069p < 0.001$). No significant differences were found for the effects of driving self-regulation ($\beta = 0.0119$; $p = 0.207$) and education ($\beta = 0.0256$; $p = 0.507$).

4.2. Path model predicting driving lapses and driving errors

The path model testing the direct effect between SA and driving violations was not significant, and therefore was not tested. This choice is corroborated by Baron and Kenny (1986) and Gallucci et al. (2017). According to the authors, if there is not a significance effect between predictor (QAS) and dependent variables (DBQ_VIOL), the mediation assumption is violated. However, path models were tested between SA and two other driving outcomes, lapses and errors. The relationship between SA (QAS) and driving lapses was found to be significantly and totally mediated by driving self-regulation. The direct effect ($\beta = 0.295$; $p = <0.001$), indirect effect ($\beta = 0.0250$; $p = <0.05$) and total effect ($\beta = 0.320$; $p = <0.001$) were significant. In other words, SA significantly and positively affected driving self-regulation which in turn affected significantly and positively driving lapses.

Conversely, the second path model showed that driving self-regulation was not a significant mediator for the relationship between total SA (QAS) and driving errors. The path model found significant direct ($\beta = -0.170$; $p = <0.001$), indirect ($\beta = -0.012$; $p = 0.039$), and total ($\beta = -0.183$; $p = <0.001$) effects of age on driving lapses. Additionally, significant indirect effects of years of schooling ($\beta = -0.018$; $p = 0.026$) and gender ($\beta = 0.013$; $p = 0.031$) on driving lapses were found. Moreover, significant direct ($\beta = -0.089$; $p = 0.022$) and total effects ($\beta = -0.096$; $p = 0.013$) of age and gender ($\beta = -0.126$; $p = <0.001$; $\beta = -0.119$; $p = <0.001$) on driving errors were found. The findings on driving lapses and errors are described in Table 5, Fig. 1 and Fig. 2.

Table 2
Linear regressions of driving VIOLATIONS: standardized estimates (Estimate), standard errors (SE), t scores and p value for each outcome.

VIOLATIONS				
Predictor	**Estimate**	**SE**	**t**	**p**
Intercept	20.2056	1.9215	10.516	<.001
AGE	−0.0990	0.0166	−5.971	<.001
GEN	−2.1450	0.5515	−3.889	<.001
YSC	−0.1910	0.0865	−2.210	0.027
DMQ-A	−0.0620	0.0211	−2.937	0.003
QAS	0.0176	0.0351	0.502	0.616

Table 3
Linear regressions of driving LAPSES: standardized estimates (Estimate), standard errors (SE), t scores and p value for each outcome.

LAPSES				
Predictor	**Estimate**	**SE**	**t**	**p**
Intercept	3.6656	1.08970	3.364	<.001
AGE	−0.0431	0.00940	−4.581	<.001
GEN	−0.1498	0.31278	−0.479	0.632
YSC	0.0773	0.04903	1.576	0.115
DMQ-A	0.0286	0.01198	2.388	0.017
QAS	0.1608	0.01988	8.088	<.001

Table 4
Linear regressions of driving ERRORS: standardized estimates (Estimate), standard errors (SE), t scores and p value for each outcome.

ERRORS				
Predictor	**Estimate**	**SE**	**t**	**p**
Intercept	2.5973	0.85606	3.034	0.002
AGE	−0.0168	0.00739	−2.279	0.023
GEN	−0.8925	0.24572	−3.632	<.001
YSC	0.0256	0.03852	0.664	0.507
DMQ-A	0.0119	0.00941	1.264	0.207
QAS	0.0698	0.01562	4.468	<.001

VIOLATIONS=driving behavior violations; LAPSES=driving behavior lapses; ERRORS=driving behaviors errors; GEN=gender; YSC=years of schooling; DMQ-A=driving-mobility questionnaire (total score); QAS=spatial anxiety questionnaire (total score).

5. Discussion

The present study aimed to investigate the relationships between SA and aberrant driving behaviors by examining the mediation role of driving self-regulation in a sample of 838 active drivers. The results showed that: (1) SA negatively impacts on driving errors and lapses; (2) driving self-regulation mediates the relationship between SA and driving lapses; (3) driving self-regulation does not mediate the effect of SA on driving errors, and (4) There is no significant relationship between SA and driving violations.

The mediation models have demonstrated a significant impact of gender on driving lapses and errors. Research suggests that female drivers exhibit higher levels of driving self-regulation (Gwyther and

Table 5
Direct, indirect, and total effects of predictor and covariates on driving lapses and errors. * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

Effect	Direct Effect	Indirect effect	Total Effect	R squared
On Lapses				0.145
of QAS	0.276***	0.025*	0.301***	
of AGE	−0.170***	−0.012*	− 0.183***	
of YSC	0.058	−0.018*	0.040	
of GEN	−0.015	0.013*	−0.002	
On Errors				0.055
of QAS	0.160*	0.014	0.174***	
of AGE	−0.089*	−0.006	−0.096*	
of YSC	0.026	−0.010	0.015	
of GEN	−0.126***	0.007	−0.119***	

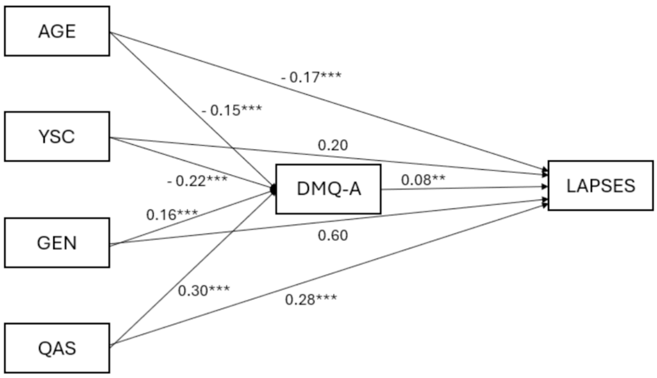

Fig. 1. Model tested on DBQ_LAPSES. Coefficients are reported for each regression path. * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

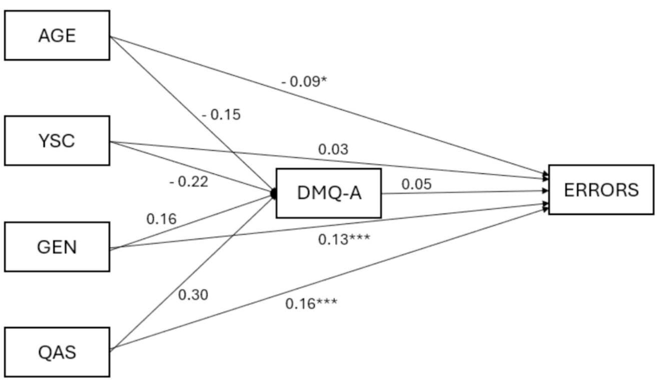

Fig. 2. Model tested on DBQ_ERRORS. Coefficients are reported for each regression path. * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

Holland, 2012; D'Ambrosio et al., 2008). In general, women report higher levels of SA, or anxiety about environmental navigation, than men (Geer, 2019; Geer et al., 2024; Lawton, 1994). This aspect is corroborated by literature indicating that women tend to use simple spatial navigation strategies more frequently than men. For example, different studies have highlighted as women were more likely use a route strategy (attending to instructions on how to get from place to place), whereas men were more likely to use an orientation strategy (maintaining a sense of their own position in relation to environmental reference points). The route spatial navigation strategy is associated with higher levels of SA (Lawton, 1994, Lawton, 1996).

On the other hand, in light of the mediation models results, age appears to influence susceptibility to SA, with older drivers make less driving errors and lapses compared to younger drivers. This finding is consistent with the current literature, which attributes the lower error rates of older drivers to their adoption of more effective driving coping strategies to compensate for age-related declines in reaction times (e.g. Charlton et al., 2006). Conversely, younger drivers tend to exhibit riskier driving behaviors and may underestimate potential risks (e.g., Hatfield and Fernandes, 2009). Moreover, older drivers are more inclined towards self-regulation in driving, as indicated by Bauer et al. (2003), who noted that as people get older, they are more likely to avoid driving at night, during peak hours, on long journeys, and when alone. This can be an explanation of the significant mediation role of the driving-self regulation on the relationship between age and driving lapses.

5.1. Spatial anxiety and driving behavior

The multiple regression models have shown that SA has an impact on driving behavior, specifically on lapses. Generally, drivers with elevated SA are more prone to commit driving errors, such as entering a side street without noticing pedestrians crossing, and driving lapses, such as starting in third gear from a traffic light. These findings are consistent with the existing literature (Hund & Minarik, 2006; Walkowiak et al., 2015), which associates SA with higher rates of navigational and timing errors in route selection. Research has found that drivers with higher levels of anxiety are worse at detecting specific signals among other distractors and may take longer to brake at crosswalks (Morton and White, 2013). Moreover, drivers with higher anxiety levels show evidence of visual tunneling (Briggs et al., 2011).

Nori et al. (2020) showed that individuals with a spatial cognitive style that favors surveying and have the ability to memorize landmarks, spatial relationships, and distances between landmarks and navigation targets are better equipped to develop an accurate mental representation that facilitates good driving skills with less errors and lapses. Drivers with poor visuospatial skills and elevated SA tend to explore less new environments and often drive on the same roads. This behavior limits their representation of the city to the places they usually visit. Environmental avoidance theory (Berman et al., 2010) suggests that drivers avoid new driving situations and routes due to the emotions and anxiety caused by the fear of getting lost. Therefore, avoiding these situations is associated with an increase of SA and a reduction in the opportunity to improve spatial skills. In this case, a cyclical response may occur in which poor spatial skills lead to increased SA, which leads to increased avoidance of driving situation, and which ultimately leads to minimized opportunities for improvement in spatial skills (Berman et al., 2010; Geer, 2019; Geer et al., 2024).

In light of this, the higher the spatial strategy that is used, the lower the number of lapses and errors in the driving process (Nori et al., 2020). Additionally, the literature shows that poor visuospatial orientation skills are associated with deliberate violations (Nori et al., 2020). However, the present study did not find a significant relationship between SA and driving violations. The results may be explained by the poor perception and confidence in drivers' spatial abilities. Indeed, driving violations refer to deliberate and intentional risky behaviors taken by drivers. In other words, driving behavior is influenced by attitudes, subjective norms, and perceived behavioral control. These factors shape an individual's intentions to engage in specific aberrant driving behaviors (Reason et al., 1990; Ajzen, 1991; Khanpour et al., 2023). On the other hand, lapses and errors are characterized by unintentional and inadvertent mistakes made while driving (Reason et al., 1990). For instance, ordinary violations may be more likely to occur due to overconfidence in spatial ability (Schlehofer et al., 2010). However, if the belief is not associated with actual ability, confident individuals with low spatial ability are more likely to commit violations than those who lack confidence and have low spatial ability (Nori & Piccardi, 2015; Nori et al., 2020). This behavior may be due to low confidence in their spatial abilities and high levels of SA. This can lead drivers to avoid potentially dangerous road situations, such as running stop signs or red lights.

5.2. The mediation role of the driving self-regulation

While existing literature suggests a relationship between SA and risky driving behaviors, the role of self-regulation as a mediator requires further empirical exploration and theoretical insight.

Results presented here showed that driving self-regulation was a significant mediator for the relationship between SA and driving lapses. Driving lapses refer to brief moments of inattention or unconsciousness that can occur while driving (e.g. Trick et al., 2004). They can occur due to various factors, including fatigue, distraction, stress, or cognitive overload. The significant direct effect suggests that higher levels of SA are associated with more frequent driving lapses, which aligns with expectations (e.g. Nori et al., 2020). Moreover, the significant indirect effect indicates that driving self-regulation partially accounts for the relationship between SA and driving lapses. In other words, individuals with higher SA may have poorer driving self-regulation skills, which in turn contribute to an increased likelihood of driving lapses. Together, these findings suggest that while SA directly influences driving lapses, a portion of this influence is also mediated by the individual's level of driving self-regulation.

This result might appear initially counterintuitive given that several studies highlighted that high driving self-regulation levels improve road safety by reducing the occurrence of aberrant behaviors (Oviedo-Trespalacios et al., 2017; Ang et al., 2019). Several studies have highlighted that successful self-regulation depends on executive functions such as inhibiting impulsive behavior, shifting attention between tasks, and updating working memory (Hofmann et al., 2012; Dohle et al., 2018). Despite the above, the literature also has shown that over-regulation behind the wheel may be dangerous for driving tasks. Gwyther and Holland (2012) indicate that anxious drivers may be more prone to over-regulation. The over-regulation could be considered a maladaptive response related to driving anxiety, namely the unnecessary avoidance of certain behaviors. These findings indicate that drivers with high scores for self-regulation and SA cope with the worries and stressors of driving by disconnecting from the driving task.

Another possible explanation of the result could be due to the cognitive interference of SA, that could impair an individual's ability to concentrate and make effective decisions while driving (e.g. Barnard and Chapman, 2016; Nori et al., 2020). This interference can disrupt the cognitive processes involved in self-regulation, such as attentional control, impulse regulation, and decision-making (e.g. Taubman-Ben-Ari et al., 2004; Gugliotta et al., 2017; Shi et al., 2019). As a result, individuals with higher SA may struggle to regulate their driving behavior effectively, increasing the likelihood of lapses such as missing traffic signs or failing to check blind spots.

Finally, driving self-regulation does not mediate the relationship between SA and driving errors. This means that the level of driving self-regulation (the ability to control one's driving behavior) does not act as an intermediary factor in such a relationship. In other words, even if someone has good driving self-regulation skills, it doesn't necessarily mean that their SA won't affect their likelihood of making driving errors. So, regardless of how well someone can regulate their driving behavior, if they experience SA, it may still directly contribute to an increase in driving errors without being mitigated or influenced by their level of driving self-regulation (Lazuras et al., 2019; Meng & Siren, 2012).

This concept is important in understanding the complex interplay between psychological factors (like anxiety) and driving performance, highlighting that simply having good self-regulation skills may not be enough to counteract the negative effects of SA on driving behavior. Probably other factors that we should have taken into consideration might explain the lack of the effect, including driving inexperience. It might undermine the effectiveness of driving self-regulation as a mediator between SA and driving errors by limiting the development of self-regulation skills, increasing vulnerability to anxiety, impeding the adoption of coping mechanisms, and reducing confidence on the road safety (e.g. Gotardi et al., 2019; Bowen et al., 2020; Sheykhfard et al., 2022). Moreover, novice drivers typically experience higher cognitive loads while driving as they must simultaneously process a wide array of information, such as traffic signals, road signs, and the actions of other drivers (Mourant and Rockwell, 1972; Paxion et al., 2015). This cognitive load may interfere with their ability to effectively regulate their driving behavior, making it difficult to mitigate the impact of SA on their performance (e.g. Matthews et al., 1996). Furthermore, inexperienced drivers may lack the coping strategies necessary to manage SA effectively (e.g. Kontogiannis, 2006). While self-regulation theoretically involves the ability to adapt one's behavior in response to internal and external factors (e.g. Molnar et al., 2013a; Molnar et al., 2013b), novice drivers may not yet have developed the repertoire of strategies needed to mitigate the effects of anxiety on their driving performance (Xiang et al., 2024). Finally, individual differences in neurobiological factors, such as stress response mechanisms, may also play a role in shaping the relationship between SA, driving self-regulation, and the occurrence of driving errors in inexperienced drivers. Some individuals may be more predisposed to experiencing heightened anxiety in spatially demanding situations, which could further exacerbate their susceptibility to making errors behind the wheel (e.g. Taylor et al., 2007; Taubman-Ben-Ari and Yehiel, 2012).

6. Study limitations

Some limitations of the present study should be noted. Firstly, the study used only self-report questionnaires, which, although validated and widely used, may not provide the most accurate objective representation of driving behavior. Indeed, they can be influenced by different limitation such as self-deception, recall bias, subjective interpretation, and the emotional state of respondents. Despite these issues, they are valuable in cross-sectional studies for providing preliminary evidence on variable relationships. Combining these with objective measures, like physiological assessments and biofeedback and neurofeedback, can improve data quality and reliability, offering a more comprehensive understanding of SA levels and driving self-regulation behaviors. In addition, the study's measure of self-regulation was limited to avoidance behaviors, which is consistent with previous literature in the field (e.g. Sullivan et al., 2011; Molnar et al., 2013a; Molnar et al., 2013b).

Furthermore, other factors should be taken into account such as individual differences, coping capacities, or the level of familiarity with the driving performance. Future studies should replicate these findings using objective measures, such as a driving simulator, which can provide a more ecologically valid assessment of risky scenarios. Another important aspect to consider is the driving frequency and its potential impact on SA and self-regulatory behaviors. Unfortunately, we had not information available on this varaiable as well as on numbers of motor vehicle crashes. Moreover, no state or trait anxiety scores was examined. This could be considered a limitation of our study. Nevertheless, the literature has shown that general anxiety doesn't affect spatial navigation (Thoresen et al., 2016). Indeed, people with high trait and state anxiety scores do not necessarily have high SA scores (Walkowiak et al., 2015).

Finally, employ a Structural Equation Model (SEM) would have allowed the inclusion of heterogeneity effects within the model through the Multi-Group Analysis (MG). Anyway, the size of our sample did not allow for testing structural equation models. Indeed, the number of observed variables/variables is slightly greater than 13 (838/60 = 13,9) but is more less to 20, as defined by Kline (2023). For this reason, we didn't employ SEM. Future research should adopt a sample size more representative to provide a more comprehensive point of view.

7. Conclusion

This study has highlighted that SA is related to risky driving behaviors, and that driving self-regulation mediates this relationship. Considering our findings, SA is associated with higher rates of navigational and timing errors in route selection (Hund and Minarik, 2006; Lawton, 1996). In general, drivers with elevated SA had higher levels of self-reported driving errors and lapses. The more interesting result is related to the mediating role of driving self-regulation between SA and driving lapses. This suggests that anxious and less confident drivers may be at greater risk of over-regulation, as an anxious driving style and a negative affective attitude were significant predictors of self-regulation. Moreover, the findings indicate that drivers with high scores of self-regulation and SA cope with the worries and stressors of driving by disconnecting from the driving task (Gwyther and Holland, 2012).

The results of this study suggest the potential benefits of developing tailored training programs to reduce SA. One promising avenue of exploration is the integration of mindfulness-based anxiety reduction techniques. By incorporating mindfulness practices into training programs, individuals may develop a more awareness of their thoughts and emotions associated with SA. This increased awareness may enable them to effectively manage anxious situations while navigating through space during the driving task (Koppel et al., 2019). In addition, drivers with poorer spatial navigation strategies could be trained to improve their spatial skills using virtual reality programs or game-based learning interventions (Rupp, 2012). Game-based interventions can reduce SA symptoms behind the wheel by providing gamified tasks with realistic simulations of traffic situations, immediate feedback on driver performance as well as on their arousal while driving (e.g. Dunwell et al., 2014; Hulme et al., 2021). These interventions can help drivers to develop stress management and spatial navigation strategies in a controlled and safe environment. (e.g. Xie et al., 2016; Khan et al., 2021; Chen et al., 2023)

In addition, the study of these aspects can be considered keys area for future research. It is of great importance to investigate detailed planning through driving simulators and virtual reality, to integrate advanced driver assistance systems (ADAS), and to develop personalized interventions that consider individual differences in spatial anxiety. Longitudinal studies are recommended to assess the long-term effectiveness of the proposed interventions. Furthermore, research should be expanded to encompass a wider range of populations to gain a deeper understanding of and more effective means of managing SA. Policy makers and road safety authorities should consider these findings to develop policies and campaigns promoting traffic safety and mindful driving to mitigate SA.

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Sergio Traficante: Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Luigi Tinella:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonella Lopez:** Writing – review & editing, Validation, Supervision. **Sjaan Koppel:** Writing – review & editing, Validation, Supervision. **Elisabetta Ricciardi:** Writing – review & editing, Visualization. **Rosa Napoletano:** Writing – review & editing, Visualization. **Giuseppina Spano:** Writing – review & editing, Validation. **Andrea Bosco:** Writing – review & editing, Validation, Supervision, Project administration, Methodology. **Alessandro Oronzo Caffò:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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