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Are subjective outcomes a “missing link” between driving stress and risky driving behaviors of commuters? Assessing the case of a LMIC

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ABSTRACT

Despite the efforts made by different stakeholders, most of Low and Middle-Income Countries (LMICs) continue to systematically report very negative road safety outcomes. In fact, in countries like Colombia, the rate of deaths from traffic crashes has increased in recent years. One of the most affected collectives in this regard -and at the same time one of the least addressed in specialized literature- are driving commuters, which are commonly exposed to several types of threats and stressors configuring an “everyday risk” potentially impairing their health and safety. This study aimed to assess whether there exists an indirect path -mediated by subjective outcomes- linking driving stress and risky driving behaviors among Colombian commuters. For this study, it was analyzed the data provided by a full sample of 941 driving commuters from different industries (18 % females, 82 % males) with a mean age of 37 years. The results of this research suggest that exposure to driving stressors is a risk factor for risky driving. Furthermore, these outcomes are consistent with previous evidence linking adverse subjective states such as fatigue and psychological strain with impaired driving performance. This statistical mediation exerted by subjective outcomes, which can be considered partial, suggests that interventions focused on managing driving stress and reducing road stressors can enhance both their psychological welfare and commuting safety outcomes.

1. Introduction

Among the road safety challenges presently faced by most LMICs, daily driving commuters’ safety and wellbeing stand out for three reasons: first, commuting accidents have increased in comparison with the national reports of annual occupational injuries (Almeida et al., 2014; Llamazares et al., 2019; Wang et al., 2019). Second, in most LMICs, commuting accidents are not legally considered as occupational safety events, which implies a high financial and health risk for workers (Vargas-Garrido et al., 2021). And third, the recent growth in the use of personal vehicles has been accompanied by an increased exposure to driving stressors, such as rush hour traffic, air pollution, persistent noise, poor road conditions, time pressure, and frequently negative interactions with other road users (Llamazares, Useche, Montoro & Alonso, 2019). Consequently, commuters from LMICs are considered highly vulnerable to negative commuting-related health and safety outcomes, such as stress, psychological strain, fatigue, and traffic accidents (Carriel, Lufin & Pérez-Trujillo, 2022; Heydari et al., 2019; Orozco-Fontalvo et al., 2019).

This study investigates the commuters’ health and safety outcomes from the perspective of driving stress. Commuting was defined as the daily-two-way travel from home to work (International Labour Organization, 2002; International Labour Organization, 2017) driving a personal vehicle (car or motorcycle). In the context of motor vehicle operation, the influence of driving stressors over both driving performance and road safety outcomes has been stated to take place via impaired cognitions (e.g., poor hazard detection and divided attention) and risk-taking behaviors (Matthews, 2002; Matthews, & Desmond, 2002) (Nævestad et al., 2015; Öz et al., 2013). Following the most common taxonomy used in literature, this research operationalizes the traffic accident preceding risk-behaviors as the frequency of *driving errors* (which are cognitive and/or psychomotor performance failures) and *traffic violations* (which are contextually motivated risky behaviors) (de Winter et al., 2015; Lijarcio et al., 2022; Reason et al., 1990; Useche

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et al., 2021a; af Wahlberg, A., Dorn, L., & Kline, T. , 2011).

In addition, chronic exposure to traffic stress produces psychophysiological outcomes such as hypothalamic–pituitary adrenal (HPA) axis overactivity (Zilioli et al., 2016), which in turn has been associated with heightened inflammatory states (Maes et al., 1998), immune dysfunction (Morey et al., 2015), cardiovascular diseases (Parati & Esler, 2012; Lovallo & Gerin, 2003), fatigue (Useche et al., 2017) and psychological strain, especially symptoms of anxiety and depression (Ströhle & Holsboer, 2003; Holsboer & Barden, 1996). These last two variables (psychological strain and fatigue) were used in this study to operationalize the commuters' stress-related subjective health outcomes.

1.1. Road safety and commuting in LMICs: The case of Colombia

Same as in other LMICs, the proportion of commuting accidents occurring in Colombia remains undetermined, due to their non-recognition as occupational safety events, added to a large number of underreported incidents and lack of academic research (*i.e.*, flawed statistics and biased police reports; García-Hermoso et al., 2018; Huertas et al., 2020; Montoro et al., 2018). The same occurs with potential commuting stressors, which to date have not been investigated in the country. Given this lack of empirical evidence, the Colombian context-specific commuting stressors is mostly inferred in the literature on the basis of national statistics on central issues in the driving stress literature such as trip impedance and the achievement of driving objectives related to safety and comfort (Gómez et al., 2018; Novaco et al., 1990).

In this regard, the state of affairs in the county remains, at best, challenging, as Colombia leads the ranking of road fatalities among the 33 member countries of the International Traffic Safety Data and Analysis Group – IRTAD (International Transport Forum, 2020). On average, Colombia reports about 200,000 traffic crashes per year, of which 50 % leave injured or deceased road users. According to the National Road Safety Agency (2019), 96 % of these accidents are caused by risky behavior behind the wheel. Specifically, 61 % of accidents are caused by traffic violations and 35 % by speeding. These figures corroborate previous self-report evidence suggesting that traffic errors and violations are highly prevalent in Colombia (Norza-Céspedes et al., 2014; Useche et al., 2017b,a).

The country has a fleet of 17.2 million vehicles (one vehicle for every-three inhabitants), 57 % of which are motorcycles. Further, half of the fleet is composed of vehicles older than 10 years, and 60 % of it remains concentrated in the 11 Colombian cities with more than 500,000 inhabitants (Ministry of Health, 2019).

Regarding commuting time and infrastructure, Colombia ranks 104/141 in road quality, as well as reports other worrying shortcomings, such as the usual traffic congestion at urban locations, in which Colombia ranks tenth in the world ranking, with an average commuting time of 47.8 min (World Economic Forum, 2019).

It is also worth mentioning that in LMICs there has been a much lower level of shift to teleworking than in high-income countries as a response to the COVID-19 pandemic, which explains why daily commuting remains a very common practice among the working population, and its associated risks could be even worsening because of pandemic stress-related issues (Andara et al., 2021; Arellana et al., 2020).

1.2. The transactional model of stress applied to the field of driving

According to the transactional framework for driver stress (Matthews, 2002; Matthews & Desmond, 2002), driving stress can be defined as a function of transactions between the driver and the road environment appraised as threats that surpass the individual coping resources (e.g., driving skills or individual social support), thus compromising relevant personal goals and values (e.g., personal safety, security and wellbeing). These transactions trigger psychophysiological reactions with a cumulative energetic cost, known as allostatic load (McEwen, 1998), which in situations of chronic exposure leads to two different consequences: negative subjective outcomes (see hypothesis 1 in Fig. 1), including stress-related emotional reactions and perceived disruptions in the physical and psychological functioning; and performance outcomes (hypothesis 2 in Fig. 1), such as impaired psychomotor control, poor hazard detection, increased risk-taking and emotion-related divided attention (Matthews, 2002; Matthews, & Desmond, 2002).

In addition to the transactional framework for driver stress, there are two widely used approaches to explain the association between driving experiences, driving risk behaviors and health outcomes: the impedance model of commuting stress (Novaco et al., 1990) and the stress-emotion-behavior models of risky driving (e.g., Deffenbacher et al., 2016). The impedance model of driving stress was discarded because it focuses exclusively on objective and perceived obstacles in commuting trips (e.g., traffic congestion and miscellaneous street constraints), without considering relevant predictors of well-being and driving performance such as negative interactions with other drivers and task difficulty.

On the other hand, the stress-emotion-behavior model, which defines driving stress as a situational trigger of emotion-related traffic errors and violations, was not used in this study because in the context of driving, the measurement of emotional reactions has focused mainly on anger predisposition (Deffenbacher et al., 2016) and expression (Deffenbacher et al., 2004), whose association with risky driving is sufficiently documented (Zhang & Chan, 2016), while its association with stress-related health outcomes has been little investigated.

Fig. 1 summarizes the core hypotheses of the transactional framework for driver stress (Matthews, 2002; Matthews, & Desmond, 2002). There is consistent evidence on the association between driving stress and impaired driving performance (Useche et al., 2021b; 2017; Matthews, & Desmond, 2001). Furthermore, in the field of transit psychology, driving stress constitutes the most documented predictor of both psychological strain (Ding et al., 2014; Taylor, 2011) and general fatigue (Matthews, 2002; Matthews, & Desmond, 2001, 2002), that can be understood for this study as negative subjective outcomes.

However, it is still not clear whether stress-related subjective outcomes (e.g. psychological strain and fatigue) are mediating mechanisms in the association between driving stress and performance outcomes such as risky driving behaviors (*i.e.*, errors and traffic violations) (see hypothesis 3 in Fig. 1). This gap in the scientific literature is theoretically relevant to the extent that the evidence on the psychological mechanisms which link driving stress with risky driving complements the original hypotheses of the transactional framework for driver stress (Matthews, 2002; Matthews, & Desmond, 2002), while it extends the knowledge on potentially modifiable psychological determinants of risky driving behaviors.

Following the transactional framework for driver stress (Matthews, 2002), this study defines fatigue and psychological strain as driving stress-related subjective outcomes. Therefore, the aim of this research was to determine whether there exists an indirect path mediated by subjective outcomes that links driving stress and risky driving behaviors among Colombian driving commuters. There is abundant evidence supporting the assumption that signs of psychological strain such as anxiety (Fairclough et al., 2006; Shahar, 2009; Calvo et al., 1990) and depression (Hill et al., 2017; Bulmash et al., 2006) symptoms are negatively associated with driving performance. Likewise, fatigue is documented as one of the main determinants of impaired driving performance (Al-Mekhlafi et al., 2020; Lal & Craig, 2001).

Overall, the specialized literature agrees on defining driving as a physically and cognitively (simultaneously) demanding task, which involves complex processes of mental organization, decision making and complex searching (Bulmash et al., 2006). Therefore, and same as the exposure to further road stressors, the sole task of driving has been already associated with psychological strain or *distress* symptoms (Ding et al, 2014).

Moreover, psychological strain may negatively influence the drivers task performance (Useche et al., 2021b; Beck, Ali & Daughters, 2014;

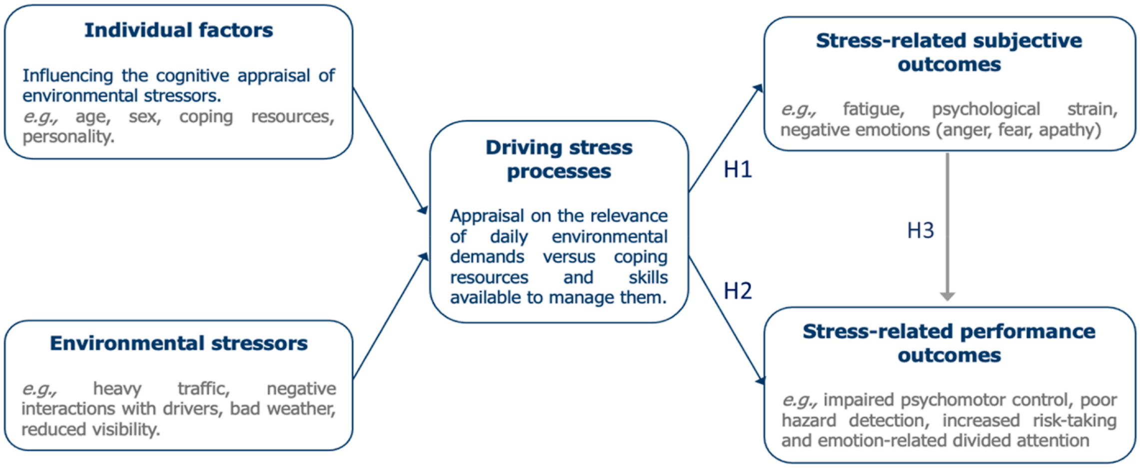

Fig. 1. Transactional framework for driver stress. *Notes for the figure:* Adapted from Matthews (2002). The gray line represents the path investigated in this study.

Scott-Parker, Watson & King, 2011; Martiniuk et al., 2010). Previous studies have shown how physical symptoms of anxiety, such as increased heart rate, blood pressure, and muscle strain, are known to impair performance in fine motor tasks (Calvo et al., 1990), such as driving motor vehicles (Fairclough et al., 2006; Shahar, 2009). Likewise, cognitive symptoms of anxiety, such as risk misjudgment, fear and worry, divide the attentional resources of drivers, distracting them from the environmental demands (Shahar, 2009). Furthermore, there is evidence that physical symptoms of depression such as retarded psychomotor reaction and visual-motor control (Sabbe et al., 1999); and cognitive symptoms such as impairments in mental flexibility and attentional set-shifting (Airaksinen et al., 2004), are associated with reduced driving performance (Bulmash et al., 2006), risky driving and traffic crashes (Hill et al., 2017).

Additionally, other recent studies have shown how another key issue to consider in work-related driving trips is fatigue (Useche et al., 2021b; Llamazares et al, 2019). Conceptually, fatigue constitutes a state of energy depletion, which implies difficulties in the maintenance of task-directed efforts and loss of vigilance (Brown, 1994). Generally, task-specific fatigue is reversible through rest. But chronic exposure to stress generates problems of general or prolonged fatigue, which compromises physical and mental health, and requires long periods of recovery or behavioral changes (Nieuwenhuijsen et al., 2016). Thus, stress-related fatigue implies a lack of metabolic energy or "fuel", which can negatively affect performance in high-effort and complex tasks (Matthews & Desmond, 2002). In the context of driving, fatigue leads to errors in task performance, especially delayed reactions to environmental stimuli and poor planning/execution of movements (Boksem et al., 2005).

1.3. The current study: Aim and hypothesis

As aforementioned, this study aimed to assess the indirect path mediated by subjective outcomes from driving stress to risky driving behaviors among Colombian commuters.

The prerequisite of this research objective is to test the transactional framework for driver stres' score hypotheses (Matthews, 2002; Nieuwenhuijsen et al., 2016):

H1. There is a positive association between driving stress and subjective outcomes such as fatigue and psychological strain; and.

H2. There is a positive association between driving stress and negative driving outcomes such as driving risk behaviors (See Fig. 1).

Additionally, beyond the associations proposed by the model (Matthews, 2002), it is hypothesized that:

H3. There is a significant indirect path mediated by negative subjective outcomes from driving stress to risky driving behaviors (See Fig. 1).

According to the transactional framework for driver stress, the study hypotheses were tested after controlling the effects of three individual confounders: commuters' age, sex and type of vehicle (car vs motorcycles).

2. Methods and materials

2.1. Participants

For this cross-sectional study, a total of 1,164 workers from three Colombian companies (a vehicle marketer: 53 %, a vehicle maintenance and repair company: 37 %, and a private security company: 20 %) were invited to participate through a convenience sampling method. These companies were involved in the study through the occupational safety and health research services offered by PRAX, a Colombian human resources consulting firm. After obtaining the corresponding permissions and ethical approval, drivers were directly invited from their human resources offices to participate in the study as part of their company's occupational health programs. The participation rate was 80.1 %.

The full study sample was made up of 941 workers (18 % women and 82 % men) driving their own vehicle (51 % car and 49 % motorcycle) from home to work on a daily basis, even though some slight routine dynamics (e.g., number of commuting days a week) could be affected by the COVID-19 pandemic. Precisely, 79 % of the study participants reported driving their vehicle at least 5 days a week, while 21 % of them were currently commonly commuting between 2 and 4 days a week. The average daily driving time was $M = 1.97$ h.

The companies participating in the study operate in different Colombian cities. Namely, 22 % of the participants work in the city of Bogota, 8 % in Cali, 7 % in Medellín, 5 % in Barranquilla, 5 % in Ibagué, and the remaining 53 % in Colombian cities with<500,000 inhabitants.

The average participants' age was 37.02 years (SD = 9.7, range: [18–67]). Regarding participants' educational level, 32 % of them had finished high school, 34 % are graduates of technical education, 21 % had a university degree and 13 % did not finish high school.

2.2. Description of the questionnaire

For this study, we used an electronic questionnaire composed of various instruments, aimed at assessing stress and driving behavior-related factors framed into the occupational field, that had been previously applied to commuting workers with a suitable reliability and discriminant capacity. The final version of the research form of four parts:

Driving stress was measured using an adapted version of the Driving

Stress Scale, developed by Ng, Barfield & Mannering (1995). This questionnaire describes stress scenarios that occur both on highways or primary roads and on low-traffic or secondary roads. Participants were asked to rate their stress levels on a 7-point Likert scale from 1 (very stressful) to 7 (not stressful at all). According to Hill & Boyle (2007), the scenarios of this scale are grouped into four factors: interaction with other drivers (*example item:* "Driving behind a vehicle that is moving slower than the speed limit"), weather (*example item:* "Driving in heavy rain"), driving tasks (*example item:* "Moving across lanes to exit") and visibility (*example item:* "Night Driving"). The items of the weather factor were modified, in order to reflect Colombian geographic conditions. In this study, the internal reliability coefficients of the scale factors were: F1 – Stress related to interaction with other drivers (3 items; range [3–21]) $\alpha = 0.818$; F2 – Stress related to weather (3 items; range [3–21]) $\alpha = 0.657$; F3 – Stress related to driving tasks (6 items; range [6–42]) $\alpha = 0.862$; and F4 – Stress related to visibility (3 items; range [3–21]) $\alpha = 0.859$. The score for each subscale was calculated by adding the corresponding items.

Fatigue was measured using the fatigue subscale of the Checklist Individual Strength (CIS) (Vercoulen et al., 1994), made up of 8 items, in which the participants reported the extent to which they experienced the symptoms described in the last two weeks (Item examples: "I feel tired", "I feel rested", "I get tired very quickly") on a 6-point scale where 1 = "No, it is not true" and 6 = "Yes, it is true". In this study, the reliability of the general fatigue scale was $\alpha = 0.837$. The general fatigue score was calculated by adding the 8 items of the scale. The CIS score range is 8–48.

Psychological strain (also referred as *psychological distress* in specialized literature; Useche et al., 2021b) was measured using the Goldberg General Health Questionnaire GHQ-12, validated in Colombia by Ruiz et al (2017). This scale consists of 12 items that assess the presence of anxiety/depression symptoms during the last weeks (item example:) using a 4-point Likert scale where 1 = "none at all" and 4 = "a lot more than usual". The scale items were grouped into a single factor, with a reliability of $\alpha = 0.84$. The psychological strain score was calculated by adding the 12 items of the GHQ. The range of the psychological strain scores is 12–48.

Finally, *risky driving behaviors* were measured using an adaptation of the 28-item version (Gras et.al., 2006) of the Driver Behavior Questionnaire (Reason et al., 1990). In this adaptation, used by Useche et al., (2011, 2017) and Gómez et al. (2018) in Colombian populations, the participants answer the DBQ-28 items using a 5-point Likert scale where: 1 = never and 5 = very often. The DBQ 28 has two factors: driving errors (16 items; *example item:* "Taking a wrong exit from a roundabout") and traffic violations (12 items; *example item:* "Showing hostility to other drivers"). In this study, the reliability of the error scale was $\alpha = 0.784$ and that of violations was $\alpha = 0.716$. The error and violation scores were calculated by adding the items of each subscale. The range of the subscale for driving errors is 16–80 and that of traffic violations 12–60.

The aforementioned psychometric scales are presented in appendix 1 (in Spanish), and the complete study questionnaire is available on the PRAX consulting firm website (https://www.prax.com.co/movilidad-segura).

2.3. Practical and ethical considerations

The data for this study was collected with the support of a human resources consultancy firm (PRAX) advising on occupational health and safety services. For this purpose, an online evaluation platform where organizations can access different standardized psychological tests for their employees was built up, and subsequently used for containing the electronic questionnaires used in this study. The evaluation platform is a fully online service and provides companies with automated computationally produced results. The use of the evaluation platform is in no way connected with the offer of other consulting services. Therefore, it was concluded that there are no conflicts of interest related to the study data collection. The employees of three organizations completed the above-mentioned questionnaires online as part of institutional occupational health programs between August and November 2020.

Data collection was anonymous, and all participants signed an informed consent authorizing the use of their responses in this research. The study protocol was reviewed and approved by the Ethics Committee of the Research Insitute on Traffic and Road Safety / University of Valencia, contact number: (+34) 963 39 38 80, IRB H1517828884105.

2.4. Statistical analysis

The associations between the study variables were investigated using path analysis based on structural equations, performed using IBM SPSS Statistics and IBM SPSS Amos, version 26.0. The variable risky driving behaviors (latent) was formed from the DBQ subscales of errors and violations. The variable driving stress (latent) was formed from the subscales of stress related to the task, interaction with road users, visibility and weather (observed); and the *subjective outcomes* latent variable (Matthews, 2002) was built up through the fatigue (CIS) and psychological strain (GHQ-12) scales (observed).

Bootstrap-based robust maximum likelihood estimation (10,000 bootstrap samples and 95 % confidence intervals) was used in order to handle multivariate non-normality. The models fit was evaluated by using Chi-square (χ^2), minimum discrepancy ratio (CMIN / df), Normed Fit Index (NFI), Tucker-Lewis Index (TLI), Incremental Fit Index (IFI) and Root Mean Square Error of Approximation (RMSEA). Estimators were calculated controlling for age, gender and vehicle (car vs motorcycle). A CFI / NFI / TLI / IFI higher than 0.90, a RMSEA lower than 0.08 and CMIN / df lower than 5.0 suggest an acceptable model fit to the data. When possible, the model fit was improved considering modification indexes. The indirect (or mediated) effects of the model, their confidence intervals (95 % CI) and significance were calculated following the bootstrap method (MacKinnon et al., 2004).

3. Results

3.1. Descriptive statistics

Table 1 shows the descriptive statistics of the study variables. The averages for driving stress, errors, violations, fatigue, and psychological strain were low. Traffic errors and violations were positively and significantly associated with all driving stress subscales, with fatigue and psychological distress, and significantly and negatively with age. Women reported significantly more driving stress, fatigue, and psychological strain than men. Likewise, car drivers reported significantly fewer driving errors, stress from interactions with road users, and psychological strain than motorcycle drivers.

3.2. Structural equation modeling

The path model for predicting risky driving behaviors through driving stress and subjective outcomes had an acceptable fit to the data ($\chi^2 = 124.271$, $p < 0.001$; df = 31; CMIN / df = 4.009; NFI = 0.965; TLI = 0.952; IFI = 0.973; RMSEA = 0.057). Fig. 2 and Table 2 summarize the standardized path coefficients of the model.

As expected, driving stress is significantly and positively associated with both subjective outcomes (hypothesis 1) and driving risk behaviors (hypothesis 2). Indeed, all the examined paths were significant ($p < 0.05$), except for the effects of vehicle type on driving stress, subjective outcomes and risky driving behaviors. The effects of age on driving stress and risky driving behaviors were also not significant. The model explained 3 % of the variance of driving stress, 12 % of the variance of subjective outcomes, and 33 % of the variance of risky driving behaviors.

Regarding the mediation hypothesis of the study (hypothesis 3), a significant indirect path mediated by hazardous subjective outcomes

Table 1
Descriptive statistics and bivariate correlations between study variables.

Study Variable	M	SD	2	3	4	5	6	7	8	9	10	11
Sociodemographic factors												
1. Age	36.94	9.75	-0.099**	-0.306**	-0.021	-0.111**	0.007	0.002	-0.016	0.098**	-0.047	-0.022
2. Gender (male) [a]	82 %	–	–	0.195**	-0.063	0.044	-0.131**	-0.161**	-0.110**	-0.173**	-0.104**	-0.119**
3. Vehicle (car) [b]	51 %	–		–	-0.064*	-0.061	-0.028	-0.078*	-0.009	-0.058	-0.063	-0.065*
Risky road behaviors												
4. Errors	19.87	4.12			–	0.684**	0.378**	0.366**	0.335**	0.320**	0.288**	0.297**
5. Violations	15.26	3.31				–	0.276**	0.365**	0.275**	0.226**	0.260**	0.232**
Driving stress-related factors												
6. Task-related stress[a]	5.99	3.10					–	0.661**	0.672**	0.725**	0.170**	0.225**
7. Road interactions-related stress	7.02	3.65						–	0.585**	0.575**	0.202**	0.245**
8. Weather-related stress	5.09	2.86							–	0.643**	0.160**	0.242**
9. Visibility-related stress	6.43	3.92								–	0.152**	0.180**
Subjective (negative) outcomes												
10. Fatigue	14.74	7.31									–	0.554**
11. Psychological strain	18.75	5.54										–

Notes for the table: [a] Dummy variable: Success = Being a male driver; [b] Dummy variable: Success = Driving a car; ** Correlation is significant at the 0.001 level (2-tailed); * Correlation is significant at the 0.050 level (2-tailed). [a]A correction factor was applied to the task-related stress subscale to compensate for the difference in the number of items with the other driving stress subscales..

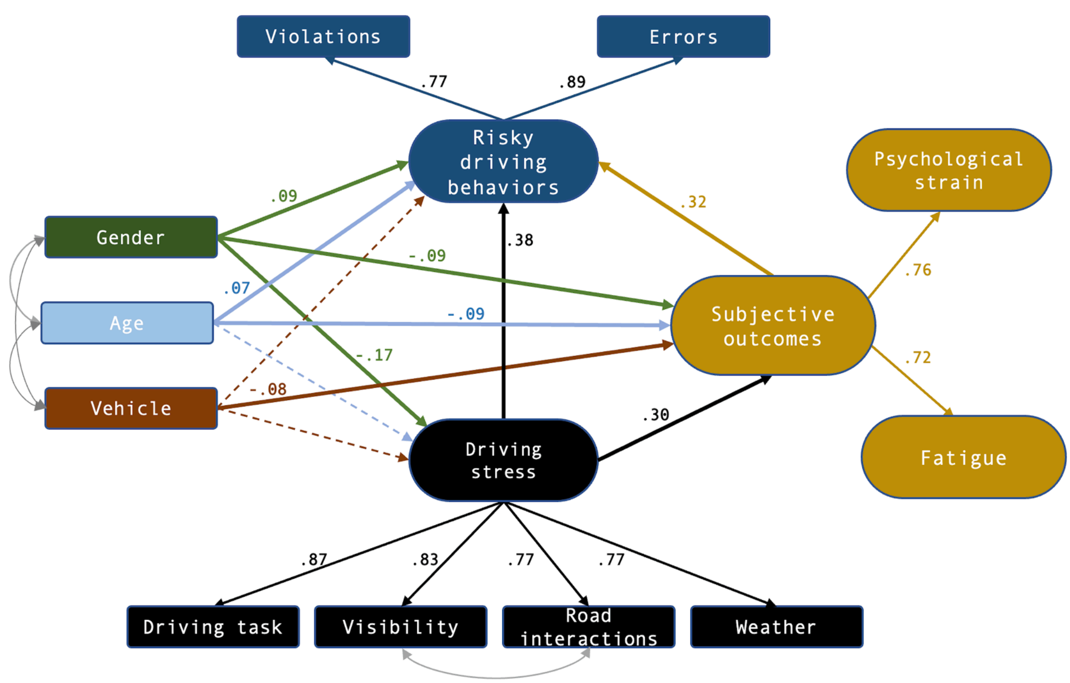

Fig. 2. Path model to predict risky driving behaviors through driving stress and subjective outcomes. Note: standardized regression coefficients appear on solid straight lines. Dashed lines represent non-significant paths. Model covariances (curved lines) were included according to modification indexes.

were found from driving stress to risky driving behaviors (SPC = 0.109, 95 % CI = 0.067–0.168, $p < 0.001$). As the direct association of driving stress with risky driving behaviors is significant, this mediation of subjective outcomes is considered partial.

4. Discussion

This study investigated whether driving stress-related subjective outcomes (*i.e.*, psychological strain and fatigue) mediate the association between stress and risky driving behaviors (*i.e.*, driving errors and traffic violations) in a sample of Colombian commuters. Overall, the descriptive outcomes of the study suggest that commuters perceive greater stress due to aversive interactions with specific road users than due to environmental situations of bad weather and low visibility, or due to task demands such as driving in heavy traffic, roads in poor condition or performing complex maneuvers. Probably, negative interactions on the road stand out as commuting stressors due to the high national levels of traffic errors, violations and aversive driving styles (Norza-Céspedes et al., 2014).

Furthermore, as expected, SEM-based path analysis revealed a significant indirect path mediated by negative subjective outcomes from driving stress to risky driving behaviors. This mediation effect was partial, insofar as the direct association between driving stress and risky driving behaviors was also statistically significant.

Consistently with the transactional framework for driver stress (Matthews, 2002; Matthews and Desmond, 2002; Rowden et al., 2011), the results of this study suggest that exposure to driving stressors is a risk factor for risky driving. Furthermore, the study results are consistent with the existing previous empirical evidence linking adverse subjective states, such as fatigue and psychological strain, with impaired driving performance (Hill et al., 2017; Bulmash et al., 2006; Boksem et al., 2005). However, the reported findings extend the previous literature by providing evidence that part of the effect of driving stress on driving performance is mediated by drivers' fatigue and psychological strain

Table 2
SEM path model estimates, confidence intervals and p-values.

Path			SPC[1]	S.E.[2]	C.R.[3]	95 % CI[4]		P[5]
						Lower	Upper	
Gender (male)	→	Risky driving behavior	0.088	0.039	2.685	0.012	0.165	*
Age (years)	→	Risky driving behavior	-0.068	0.035	−2.059	-0.135	0.003	0.066
Vehicle (car)	→	Risky driving behavior	-0.064	0.036	−1.903	-0.131	0.008	0.081
Gender (male)	→	Driving stress	-0.174	0.037	−5.015	-0.247	-0.104	***
Age (years)	→	Driving stress	0.012	0.038	,347	-0.06	0.086	0.741
Vehicle (car)	→	Driving stress	-0.016	0.034	-0.454	-0.089	0.05	0.581
Driving stress	→	Stress (weather)	0.771	0.021	25.526	0.729	0.811	***
Driving stress	→	Stress (visibility)	0.831	0.018	25.526	0.796	0.867	***
Driving stress	→	Stress (task demands)	0.867	0.017	28.11	0.829	0.898	***
Driving stress	→	Stress (interactions)	0.77	0.020	24.107	0.729	0.807	***
Driving stress	→	Subjective outcomes	0.305	0.042	7.034	0.225	0.393	***
Driving stress	→	Risky driving behavior	0.385	0.038	10.117	0.306	0.457	***
Gender (male)	→	Subjective outcomes	-0.089	0.042	−2.307	-0.169	-0.007	**
Age (years)	→	Subjective outcomes	-0.088	0.038	−5.015	-0.159	-0.013	*
Vehicle (car)	→	Subjective outcomes	-0.079	0.034	−1.996	-0.153	0.001	0.057
Subjective outcomes	→	Fatigue	0.724	0.040	10.823	0.642	0.802	***
Subjective outcomes	→	Psychological strain	0.765	0.042	10.823	0.684	0.848	***
Subjective outcomes	→	Risky driving behavior	0.319	0.044	7.277	0.227	0.401	***
Risky driving behavior	→	Errors	0.885	0.037	1.682	0.815	0.963	***
Risky driving behavior	→	Violations	0.772	0.036	16.682	0.694	0.835	***

Notes for the table: [1]SPC = Standardized Path Coefficients (can be interpreted as linear regression weights); [2]SE = Standard Error; [3]CR = Critical Ratio [4]95 % CI = Confidence Interval at the level 95 %; [5]*p*-value: *significant at the level $p < 0.05$; **significant at the level $p < 0.01$; ***significant at the level $p < 0.001$.

(Gulian et al., 1989; Kontogiannis, 2006).

4.1. On the (key?) role of subjective outcomes over road safety

The findings of this study on the "missing link" between stress-related subjective and driving performance outcomes also allow us to conceptually integrate previous literature that has evaluated driving stress, fatigue, and psychological strain as separate predictors of safety outcomes (Cunningham & Regan, 2016; Kontogiannis, 2006; Kwon et al., 2019; Montoro et al., 2018; Useche et al., 2017). This implies a considerable extension of the predictive scope of the transactional model of driving stress.

In practical terms, this statistical mediation exerted by subjective outcomes (as defined by Matthews, 2002) is important because it suggests, firstly, that interventions focused on managing driving stress and reducing road stressors can improve not only safety outcomes, but also commuting drivers' psychological well-being (Matthews et al., 1998). However, secondly, the results of this study suggest that psychosocial interventions focused exclusively on the management of driving-related fatigue and psychological strain may not be sufficient to reduce risky driving behaviors. This is because while part of the effect of driving stress is mediated by negative subjective outcomes, another part directly affects driving performance.

It can be considered as reasonable to suggest that interventions focused on managing driving-related fatigue should focus not only on issues such as education on fatigue awareness (Alvaro et al., 2018), but also on work environmental interventions aimed at reducing commuters' environmental and behavioral stressors. For instance, studies such as the developed by Huertas et al. (2020), Avila-Palencia et al. (2017), Hansson et al. (2011) and Evans & Wener (2006) have shown how commuting-related stress rates tend to decrease when (*i*) commuting distances and trip length are shorter, but also when (*ii*) environmental improvements, including the use of non-motorized means for daily transport, are implemented.

Likewise, there is evidence that interventions based on environmental changes such as improvements in road infrastructure (e.g. pavement repair, traffic signaling, speed bumps) or vehicle safety technology (e.g. anti-drowsiness detection, warning and stimulation devices, and lane departure warning systems) are effective in reducing the risk of fatigue-related negative safety outcomes (Huertas et al., 2020; Nazari et al., 2017; Staton et al., 2016), allowing us to suggest approaching fatigue management from both sides: the commuting environment –that, although more difficult to be intervened in LMICs (Elshahat et al., 2020; Koyanagi et al., 2017), can get benefitted from certain changes, such as transport patterns– and the workers themselves, level in which chances for safety improvements are even more plausible.

4.2. Limitations of the study and further research

Finally, it worth mentioning that this study has limitations related to its cross-sectional design, which prevents attributions of causality in the associations between variables; the arbitrary selection of participants and the overrepresentation of male workers (something that is also predominant in low and middle-income countries), which prevents the generalization of results; and its exclusive use of self-report measurements, which impede to know whether the scores for driving stress, fatigue, psychological strain and risky driving behaviors represent objective data or the participants' perceptions. In this study, selection and self-report biases are attenuated, respectively, by the conformation of a relatively large sample and the use of reliable standardized instruments for data collection, as suggested by previous studies (Pina et al., 2022). Anyway, future research may extend the reported findings using more robust methodological designs (e.g., longitudinal, experimental designs or naturalistic observations based on objective indicators of driving stress and performance), which allow to capture the emergence of driving stress and the psychophysiological outcomes that link it with driving performance.

5. Conclusion

The findings of this study support the assumption that subjective outcomes (psychological strain and fatigue) mediate the association between stress and risky driving behaviors of commuters, implying a potentially significant extension of the predictive scope of the transactional model of stress on commuting safety.

In practical terms, and as most of the few existing interventions have come to imply, subjective outcomes might constitute a key factor to consider in occupational health and road safety-related research and practice dealing with commuting crashes.

Finally, it should not be forgotten that the data of this research come from the study of a LMIC, whose specificities and shortcomings, despite entailing great value for improving the state of affairs in commuting safety, must be considered when interpreting these findings.

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CRediT authorship contribution statement

Boris Cendales: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francisco J. Llamazares:** Writing – original draft, Validation, Supervision, Resources, Funding acquisition. **Sergio A. Useche:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, 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.

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