Lista completă de lucrări

Tirla, L., Sârbescu, P., & Rusu, A. (2024). Assessing the effectiveness of psychoeducational interventions on driving behavior: A systematic review and meta-analysis. *Accident Analysis & Prevention, 199*, 107496. https://doi.org/10.1016/j.aap.2024.107496

Accident Analysis and Prevention 199 (2024) 107496

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Assessing the effectiveness of psychoeducational interventions on driving behavior: A systematic review and *meta*-analysis

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ARTICLE INFO

Keywords:
Driving behavior
Interventions
Systematic review
Meta-analysis

ABSTRACT

This review aimed to quantitatively summarize the evidence concerning the effectiveness of psychoeducational interventions on driving behavior. A final pool of 138 studies, totaling approximately 97,000 participants, was included in the analyses and covered all types of driving behavior targeted by the interventions. Using a random effects model, significant results were found for almost all driving outcomes, both post-intervention and long-term. The strongest effect was for reducing distracted driving at post-intervention ($d = 1.87$ [1.12, 2.60], $Z = 4.94$, $p < 0.001$). The only non-significant effects were for reducing errors in the long term ($d = 0.50$ [−0.87, 1.86], $Z = 0.71$, $p = 0.48$) and driving under the influence at post-intervention ($d = 0.35$ [0.00, 0.71], $Z = 1.96$, $p = 0.05$). Concerning which type of intervention was more effective, feedback, training and motivational ones appear to work best. Educational interventions show only weak effects, while awareness interventions seem mostly ineffective. Overall, our results show that most interventions can reduce different types of driving behaviors, but there are specific aspects to be considered based on the targeted behavior.

1. Introduction

Road accidents are one of the leading causes of worldwide mortality, a severe problem affecting the economy and proper functioning of many countries (Mohammed et al., 2019). According to the World Health Organization (WHO, 2018), 1.35 million people die yearly from road accidents. Research has consistently shown that driving behavior is the leading cause of road accidents (e.g., Ma, Zhao, et al., 2015). Thus, the need for interventions to reduce dangerous driving behaviors and improve safety has been quite stringent over the past decades (Elliott & Armitage, 2006; Shope & Bingham, 2008).

1.1. Driving behavior

Driving can be described by referring to two elements (Lajunen et al., 2022). The first element is driving behavior, which represents the style of drivers or the way they drive. It can include examples such as speed choices or if they choose to drive the car when they are tired or under the influence of intoxicating substances. The second element is driving performance, which is based on drivers' knowledge and skills. Therefore, driving behavior is what the driver chooses to do in traffic (e.g., to respect the rules or not), while the performance assumes his capabilities. When there are limitations in performance, they can lead to the occurrence of dangerous driving behaviors, such as errors (Lajunen et al., 2022).

Driving behavior is described in the literature from the perspective of many taxonomies. While a deep dive into all conceptualizations is beyond this paper's goal, we briefly describe the driving behaviors identified in the studies included in this *meta*-analysis. A somewhat "classic" conceptualization comes from Reason et al. (1990); the authors divide aberrant driving behavior into errors and violations. Errors represent the inability to achieve a goal, being considered unintentional (e.g., missing the signal, or hitting something with the back of the car when turning), while violations represent conscious deviations from traffic rules (e.g., crossing the red light). In this paper, the two aforementioned behaviors were analyzed separately.

A more recent conceptualization describes risky driving as consisting of deliberate risk-taking behaviors such as driving under the influence (alcohol or drugs), fatigued driving, speeding, not wearing a seatbelt, distraction or using a mobile phone while driving (Dula & Geller, 2003; Klauer et al., 2014; Shope & Bingham, 2008). Risky driving can occur without negative emotionality or the intention to cause injury to others (Dula & Geller, 2003). Taken its components separately, driving under the influence (DUI) is constantly a major public concern. Despite all

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https://doi.org/10.1016/j.aap.2024.107496
Received 9 August 2023; Received in revised form 10 January 2024; Accepted 2 February 2024
Available online 14 February 2024
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efforts to prevent this behavior, in the US, approximately 3.4 million college students (30 % of all college students) admit to driving after consuming alcoholic beverages, and alcohol-related traffic accidents are the leading cause of alcohol-related mortality among college students (Hingson et al., 2009). Fatigued driving and drowsiness are also related to the risk of causing road accidents because they affect the cognitive processes of the driver (Davies & Parasuraman, 1982).

Speeding is often considered the "main killer" on the road (Panda et al., 2022) and represents any violation of speed limits (Molloy et al., 2018c). Excessive or inappropriate speed is a factor that aggravates the risk of road accidents (WHO, 2015). Not wearing a seat belt is also a risky behavior associated with higher severity of injury (Febres et al., 2020). Wearing a seat belt is an effective measure that could prevent accidents, and its use should be encouraged (Beck et al., 2019).

Risky behavior is also conceptualized in the literature as tailgating or repeatedly lane changes (Simons-Morton et al., 2006b), high-speed turns, running the red traffic lights or not stopping at a sign (Taubman-Ben-Ari & Lotan, 2011), driving through intersections during yellow lights (Zakrajsek et al., 2013), sudden starts or stops and turns (Fabiano et al., 2016), or reckless driving in general (Nirenberg et al., 2013). Not least, distracted driving is mainly caused by mobile phone use. The riskiest behavior in this category appears to be sending text messages (Dingus, 2014). However, distracted driving can also be represented by directing attention to an external factor (e.g., something on the road) that does not involve an intentional behavior of the driver (Merrikhpour, 2017), which is why (in this paper) distracted driving was analyzed as a separate outcome.

Regarding aggressive driving, it describes any action aimed at harming other people (Dula & Geller, 2003). It can include verbal manifestations of aggressiveness (e.g., yelling, swearing), physical expressions of hostility (e.g., hitting others), and use of the vehicle to express aggressiveness (e.g., to honk or put sudden brakes in front of other vehicles) (Deffenbacher, Lynch et al., 2002). Therefore, these aggressive behaviors together with risky driving form the core of dangerous driving. In addition, negative-emotional driving includes emotions associated with anger, frustration and irritation related to driving, being considered a somewhat secondary class of dangerous driving (Richer & Bergeron, 2012). Among these emotional manifestations is driving anger, which represents the degree to which drivers show anger when they find themselves in certain contexts in traffic, being different from the trait of anger that manifests in general (Deffenbacher et al., 1994). As driving anger and aggression are highly correlated (e.g., Deffenbacher, Filetti et al., 2002), they are quite often analyzed together (this is also the case in our review). These emotional manifestations, along with risky behaviors, determine a dangerous behavior that is frequently associated with road accidents (Lustman, 2011).

Lastly, studies often target a positive/constructive component of driving behavior. This can consist of a wide range of behaviors, from focusing on safety to ignoring traffic challenges and searching for alternative strategies to calm down and not express aggressiveness. We included here behaviors such as safe driving, which comprises adherence to road law or defensive driving (Anstey et al., 2018), or adaptive/constructive expression of anger (e.g., 'I turn on the radio or music to calm down, I tell myself it's not worth getting all mad about, and I try to think of positive things to do.'; Deffenbacher, Filetti et al., 2002).

From the same perspective, a concept that received some attention in previous research is driving skills. Spolander (1983) describes skills as being of two types: technical (primary) skills (that involve car control and efficient management of traffic situations) and secondary skills (that involve risk prevention and the ability to avoid accidents). Driving skills include visual scanning, anticipation, car control, and setting safety margins (Duncan et al., 1991). They can be measured objectively as well as subjectively. Objectively, they can be measured through the simulator, recording a series of parameters regarding behavior and vehicle response (Zhang et al., 2010). Sundström (2008) suggested that subjective driving skills are estimated by comparing driver's perception of his abilities with the abilities of other drivers or an average driver, by comparison with an internal criterion (e.g., a list with well-defined aspects regarding competence) or with an external criterion (e.g., with the actual skill).

1.2. Interventions on driving behavior

Different types of interventions have been examined in the literature for their effect on driving behaviors. These include cognitive-behavioral (e.g., Connors et al., 1986; Deffenbacher et al., 2000; Deffenbacher et al., 2002; Eensoo et al., 2011), educational (e.g., Af Wåhlberg, 2010; Alvaro et al., 2018; Berlin et al., 2021; Brown, 1980), feedback (e.g., Casutt et al., 2014; Creaser, 2015; Cuenen et al., 2019; Donmez et al., 2008), training (e.g., Albertsson & Sundström, 2011; Anstey et al., 2018; Bédard et al., 2008; Boele-Vos & De Craen, 2015), motivational, goal-setting, or coping interventions (e.g., Baird et al., 2013; Baird et al., 2017; Brewster et al., 2015; Correa-Fernández et al., 2017), awareness campaigns (e.g., Crew & Johnson, 2011; Delhomme et al., 2008; Elliott & Armitage, 2009; Megías et al., 2017), and mixed programs (e.g., Blom & Blokdijk, 2021; Curry et al., 2003; Fromme & Corbin, 2004; Grant, 1990). In this section, we briefly describe the interventions identified in the literature.

1.2.1. Cognitive-behavioral interventions

People experience some negative dysfunctional thoughts. When in traffic, for example, drivers may have thoughts such as "It's horrible." or "Other drivers are incompetent." These thoughts make them angry and contribute to distorted emotional responses. Cognitive interventions help reduce anger and risky behaviors. Specifically, individuals learn to process things in more realistic ways to help them find solutions. Cognitive interventions involve several steps: awareness of the cognitive processes and how they work, identification and exploration of cognitions, restructuring of negative cognitions, and identification of alternative strategies (Deffenbacher, 2016; Deffenbacher et al., 2000).

Studies usually focus on relaxation techniques (Connors et al., 1986; Deffenbacher et al., 2000), exploring antecedents and consequences of behaviors (Connors et al., 1986; Mills et al., 2008), finding pros and cons (Sommers et al., 2013), reevaluation of situations (Deffenbacher, Filetti et al., 2002; Feng et al., 2018; Gidron et al., 2015; Sommers et al., 2013), and developing skills to motivate behavioral change (Deffenbacher et al., 2000; Eensoo et al., 2011; Gidron et al., 2015; Griffin et al., 2004; Grossberg et al., 2004; Holden, 1983; Osilla et al., 2019; Sommers et al., 2015). Some techniques put more accents on emotions and thoughts (Taubman-Ben-Ari et al., 1999), while others explore emotional components and further develop specific behaviors (Eensoo et al., 2011). Behavioral stimulation is also used (Lange et al., 2006), and some experiencing strategies (e.g., VR simulation) can be provided (Jewell & Hupp, 2005; Vankov et al., 2021). Cognitive training (e.g., Go/No-Go task) is also used to refraining some cognitions (Osgood et al., 2020).

1.2.2. Educational interventions

Educational interventions are among the most used in road safety, but their effectiveness is still debated in the literature, the results being quite contradictory (Cutello et al., 2021). Educational interventions usually consist in presenting information to increase knowledge and awareness (Alvaro et al., 2018; Carcary, 2000; Ekeh et al., 2011; Hempel, 1992; Holden, 1983; Kayser et al., 1995; Raub et al., 1999; Reis & Davis, 1980; Shope et al., 2001). The content is sometimes deepened through discussions, working groups, or the exploration of skills and the search for solutions (Af Wåhlberg, 2010; Berlin et al., 2021; Brown, 1980; Buckley et al., 2018; Cutello et al., 2021; D'Amico & Fromme, 2002; Eensoo et al., 2018; Ekeh et al., 2008; Lenné et al., 2011; Luht et al., 2019; Paaver et al., 2013; Porter, 2013; Taubman-Ben-Ari & Lotan, 2011). Parents can contribute to road safety education; that is why some interventions are based on communication between them and teenagers to establish rules regarding driving (Simons-Morton et al.,

2006a; b; c; Zakrajsek et al., 2013).

1.2.3. Training interventions

Training interventions consist of providing content aimed at developing and practicing skills, in addition to educational content, as in educational interventions that focus on the informational component. It actively engages drivers in activities where they practice their skills and discover strategies for managing traffic situations. Beyond the educational content, this type of intervention also includes on-road driving (Anstey et al., 2018; Bédard et al., 2008; Boele-Vos & De Craen, 2015; Campbell et al., 2016; Fabiano et al., 2016; Horswill et al., 2021; Ishii et al., 2021; Marottoli et al., 2007; Sawula et al., 2017; Stock et al., 1983; Wang et al., 2010; Wilkins et al., 2013; Yuan et al., 2021), simulator training (Ebnali et al., 2019; Ekeh et al., 2013; Ivancic & Hesketh, 2000; McDonald et al., 2021), computer/ video-based training (Albertsson & Sundström, 2011; Anstey et al., 2018; Hatfield et al., 2018; McKenna et al., 2006; Muttart, 2013; Urlings et al., 2019), the experience of some traffic situations (Harrison et al., 2007), or PC training (Cuenen et al., 2016; Hamid, 2013; Nouchi et al., 2019). Hence, in addition to the received information, drivers also learn to put this information into practice and have the opportunity to experiment directly. In certain circumstances, the two (education and training) can be considered part of the same measure. However, studies showed that the educational content alone proved ineffective or gained weak effects, while the results were significantly improved when it also involved the experience of traffic situations or simulator training (Groeger, 2011). For this reason, in this review, we considered education and training as two different interventions.

1.2.4. Feedback

Feedback interventions involve the delivery of information regarding the action undertaken by an individual, aiming to correct errors and improve behavior (Hatakka et al., 2002; Molloy et al., 2018a). Feedback can be considered a sub-category of training, considering that it can be delivered during the training sessions (Molloy et al., 2018a; Molloy et al., 2019). However, in our *meta*-analysis, the included studies that tested training interventions generally used driving simulators to develop skills and reinforce behavior, while feedback refers only to notifying drivers of their performance to avoid inappropriate behavior in the future. So, feedback can be a part of training, but within the context of this work, the feedback category included studies that focused more on the evaluation component and information on what drivers do or don't do well. On the other side, the training focused on the idea of learning by doing. For this reason, when we ran the analyses, we treated these categories as distinct. The studies included in this *meta*-analysis concerned feedback received from several sources, such as alarm/notification systems that are intended to warn drivers of various hazards (Creaser, 2015; Drucker, 2013; Ouimet et al., 2020; Pavlidis et al., 2018; Sieber et al., 2015; Sullman, 2019; Tian et al., 2021; Verwey & Zaidel, 1999; Yazdani & Rassafi, 2019), feedback provided by an instructor (Molloy et al., 2021), feedback provided by a researcher (Cuenen et al., 2019; Molloy et al., 2018b), performance reports (Giovanni et al., 2009; Howat et al., 1991; Merrikhpour, 2017; Merrikhpour & Donmez, 2017), video-based feedback (Lavallière et al., 2012), feedback given through a platform (Li et al., 2020) or combined feedback (Casutt et al., 2014; Donmez et al., 2008; Hickman, 2005; Molloy et al., 2018a;c; 2019; Mullen et al., 2015; Peek-Asa et al., 2019).

1.2.5. Motivational/goal-setting/coping interventions

Brief motivational interviewing (BMI) is used to modify behavior by identifying risk factors and strategies to avoid them. This intervention is delivered in an empathic manner, putting the client at the center of the process and includes (to some extent) a counseling component. The work plan is established collaboratively, assumes support, and gives the client autonomy (Baird et al., 2013; 2017; Correa-Fernández et al., 2017; Fernandez et al., 2008; Mello et al., 2016; Monti et al., 1999; Nirenberg et al., 2013; Ouimet et al., 2013; Schermer et al., 2006; Teeters, 2017; Walton et al., 2013).

However, motivation is not enough to change behavior. The implementation intention is also needed, which helps the individual to establish and pursue a goal (Gollwitzer, 1993). Implementation intentions interventions are also goal-setting strategies with a high potential for behavioral change. Making a concrete plan about what you will do and what behavior you will adopt in a particular context is much more likely to determine the achievement of the desired behavior (Brewster et al., 2015; Elliott et al., 2021; Elliott & Armitage, 2006). Setting goals by specifying explicit situations and identifying coping methods are strategies for behavioral change (Ludwig & Geller, 1997; Werch et al., 2010).

1.2.6. Awareness-campaign

The advertisements include short informative messages to raise awareness regarding risk factors among the population (Elliott & Armitage, 2009; Weinstein et al., 1986). These messages often contain positive or negative comments to see which influences behavior more (Megías et al., 2017; Plant et al., 2017). Other methods are to ask the participant to experience states through different techniques, such as those in which they have to imagine a death scenario (Taubman-Ben-Ari et al., 1999; Taubman-Ben-Ari et al., 2000) or those in which they listen to the experiences of other people who have suffered, for example, a road accident (Crew & Johnson, 2011). For instance, in a study by Delhomme et al. (2008) it was tested the blended impact of making a public commitment alongside an awareness of the importance of seat belt use.

1.2.7. Mixed interventions

Some studies also considered the use of combined interventions as educational, feedback, and motivational interventions (Curry et al., 2003; Sanna et al., 2015), cognitive, educational, motivational, and awareness interventions (Naveh & Katz-Navon, 2015; Woodall et al., 2007), cognitive, educational interventions, feedback, motivational, and awareness (Fromme & Corbin, 2004; Grant, 1990; Werch & Damron, 1985), cognitive, educational, and motivational interventions (Ma, Byrne, et al., 2015), or cognitive and educational content (Blom & Blokdijk, 2021). In general, using some combined strategies determines improved effects and increases road safety (Ma, Byrne, et al., 2015).

1.2.8. The current review relative to the 3Es (or 4Es) framework for developing traffic safety interventions

Over the years, measures taken for road safety can be grouped around the 3 Es: Engineering, Enforcement, and Education (Groeger, 2011; Mwebesa, 2021). Engineering measures involve changes at the level of the vehicle (e.g., anti-locking braking system (ABS), airbags, warning systems) or infrastructure changes. Enforcement measures involve the imposition of laws or mandatory tests for substance use. Education measures are those that, through different lessons or informative materials, aim to inform traffic participants about the rules and the importance of respecting them. All these three types of measures have proven to some extent to be effective, especially the engineering ones, but research shows that it is better to use them together than separately to obtain stronger results (Mwebesa, 2021). In addition to these measures, research has added other Es, such as emergency response systems that aim to identify and prevent the occurrence of accidents (Groeger, 2011; Morimoto et al., 2022).

The present work includes the educational component of this framework along with other interventions described in the previous sections. The focus was particularly on those psychoeducational approaches that aim to change behavior using strategies and activities that directly involve drivers.

1.3. The aim of the present study

The effectiveness of interventions on driving behavior has not been extensively analyzed (so far) in the scientific literature, so we do not have a clear and comprehensive overview. Certain interventions demonstrate greater effectiveness than others, whereas others seem to lack efficacy. Furthermore, some interventions have proven effective in a few studies but ineffective in others. To the best of our knowledge, no previous work presents a bird's eye view of the effectiveness of such interventions using a *meta*-analytical approach. There are several systematic reviews and *meta*-analyses on traffic safety in the literature. Many of these reviews tested interventions on specific populations, such as young drivers (e.g., Curry et al., 2015) or older drivers (Castellucci et al., 2020; Fausto et al., 2021). More than that, Curry et al. (2015) focused only on interventions that included a parent component and showed that such interventions reduced risky behaviors. Thus, the question arises whether other types of interventions are also effective and on what categories of drivers.

Even when the reviews included several types of interventions, the focus was on a specific behavior, such as drugged driving (Razaghizad et al., 2021). This review showed that motivational interviews and sanctions could, to a certain extent, reduce driving under the influence of drugs, while prevention and educational programs showed low efficiency. Nazari et al. (2017) also reviewed several types of interventions (educational interventions, interventions that modify behavior and interventions that cause changes in the environment), but they did not estimate *meta*-analytic effects. They also focused on a specific type of behavior, namely driving while tired (Nazari et al., 2017). Some reviews included non-experimental studies and interventions aimed at outcomes such as intentions and attitudes and less at the behavior itself (e.g., Razaghizad et al., 2021). To summarize, previous reviews focused on specific populations, interventions, or behaviors, which narrows the comparability and generalizability of the findings.

This study aimed to review the interventions without restricting the search to a specific population or type of intervention in order to gain an overall perspective on what works better and for whom. Participants of all ages were included, thus having both young and older drivers. Also, the intention was not to focus on a single target behavior but to cover all driving behavior categories to obtain a comprehensive overview. Last but not least, only studies with an experimental/quasi-experimental design (i.e., with a control group) were included, to obtain accurate results regarding the effectiveness of the interventions.

Consequently, the aim was to conduct a systematic review and *meta*-analysis on the effectiveness of psychoeducational interventions on driving behaviors. Specifically, the purpose was to address the following research questions:

Research question 1: Are psychoeducational interventions effectively reducing errors and violations in post-intervention/long-term periods?

Research question 2: Are psychoeducational interventions effectively reducing risky driving (and its components) in post-intervention/long-term periods?

Research question 3: Are psychoeducational interventions effectively reducing distracted driving (overall and phone use behavior) in post-intervention/long-term periods?

Research question 4: Are psychoeducational interventions effectively reducing anger-aggression in post-intervention/long-term periods?

Research question 5: Are psychoeducational interventions effectively enhancing driving skills in post-intervention/long-term periods?

Research question 6: Are psychoeducational interventions effectively enhancing constructive driving in post-intervention/long-term periods?

2. Methods

The PRISMA framework for conducting and reporting the systematic review and *meta*-analytical procedures (Page et al., 2021) was followed.

2.1. Eligibility criteria

The PICOS approach was used to select the included studies (the acronym stands for: Population; Intervention; Comparison; Outcome; Study design). Therefore, to assess the effectiveness of interventions on driving behaviors, this review focused on studies that met the following four criteria: (P) participants must be drivers; (I) studies to test a psychoeducational intervention aimed at reducing negative driving behaviors/traffic anger or aimed at improving positive driving behaviors; (C) have a control group; (O) the study to include driving behaviors as outcomes; (S) have an experimental or quasi-experimental (between-groups) design. In addition, the studies had to be written in English. Participants had to be drivers, as the aim of the study was to review the effectiveness of interventions on driving behavior. Only psychoeducational interventions were included so that there is a manipulation at the level of the individual and behavior, an intervention that really motivates the drivers to change their behavior, not just an intervention that prevents them from carrying out the behavior. For example, Albert and Lotan (2019) tested an intervention based on an application that blocked notifications from the drivers' mobile phones while they were behind the wheel in order to reduce the behavior of texting while driving. The results showed that such interventions are effective when they are active, but after that, there are no changes in behavior because in the absence of those "blockers", individuals do not feel motivated to change something. Thus, only interventions that address a certain behavioral change were included. Furthermore, only experimental or quasi-experimental studies with a control group were included for maximized internal validity and to increase the possibility of drawing causal conclusions regarding the effectiveness of the interventions (ruling out alternative explanations for the obtained results) (Dauer et al., 2006).

2.2. Information sources

This work was based on a systematic search in online databases and screening of references from other reviews and *meta*-analyses regarding interventions on driving behaviors. The systematic search included the following databases: PsychINFO, Scopus, Web of Science, and Proquest Dissertations & Theses.

2.3. Literature search

The systematic search was carried out in May 2022. Therefore, the screening period was between May 2022 and December 2022. The months of January-July 2023 were intended for resolving any discrepancies, running statistical analyses, writing the results, and finalizing the manuscript. The Boolean search was as follows: (intervention OR training OR manipulation) AND (driv* OR traffic OR transportation) AND (anger OR errors OR violations OR lapses OR dangerous OR risky OR aggressive OR speed OR drunk OR distracted OR drug OR "seat belt" OR drowsy) AND (experiment OR "control group" OR random*). This strategy was used to search in titles, abstracts, and keywords.

2.4. Study selection

To select the eligible articles, first of all, the screening of the abstracts identified in the databases was carried out. The same process was followed for the articles identified in anterior reviews and *meta*-analyses. Further, two authors performed the full-text screening for the articles that passed the initial screening. Where there were differences between the two authors, a third author performed the screening until a consensus was reached.

2.5. Data items and data collection

The articles selected as eligible were coded by two authors to extract the following information: author and year of publication, information

about the sample (type of sample, average age, male percentage, etc.), interventions (type of intervention, if it is standardized or not, number of sessions, duration, the way it was delivered) and methodology (measurements). Means, standard deviations, and the number of participants were also extracted for each group separately to calculate the effect size. Where this information was not available, other types of information (e.g., percentages, frequencies, etc.) that allow calculating effect sizes were used. Every inconsistency between the coders was verified until a consensus was reached.

2.6. Statistical analyses

The Comprehensive Meta-Analysis 4.0 statistical package (Borenstein, 2022) was used to analyze statistical indicators. A *meta*-analysis of random effects was performed, and the magnitude of the effect size was expressed in Cohen's *d*. According to Cohen (1988) a *d* value of 0.20 indicates a small effect size, a value of 0.50 indicates a medium effect size, and a value of 0.80 indicates a large effect size. The following indicators were taken into account: *k* (number of studies included in the *meta*-analysis); the value of *d* (effect size); *z*-score (which indicates whether the observed result is robust); lower limit and upper limit (confidence interval of the mean with a probability of 95 %); *Q* statistic (a significant *Q* value indicates that probably the true effect size varies across studies); I^2 statistic (in order to estimate the proportion of the observed variance that is due to true variations in effect sizes. To investigate publication bias we first inspected the funnel plots (Egger et al., 1997), the Egger's regression intercept, and we also used the trim and fill procedure (Duval & Tweedie, 2000).

3. Results

3.1. Inclusion and description of studies

Fig. 1 illustrates the process of selection and inclusion of studies. Following the database search, 9363 unique records were found. Of these 9363 records, there were a total of 99 studies that met all the criteria and contained the necessary data to calculate the effect size. Additionally, 28 studies identified from other sources were added. Some studies included multiple studies or samples, resulting in 138 studies/samples.

Regarding the studies' characteristics, the samples included 97,032 participants, with the average age between 16 and 80.31 years and gender distributions varying between 19.76 %–100 % male. Twenty-eight studies addressed drivers from the general population, four studies had learner drivers, 20 studies included offenders, 17 studies included elderly drivers, two studies included professional drivers, and 67 studies included young drivers. There were 129 experimental and nine quasi-experimental studies. Sixty-one studies had a no-intervention control group, eight had a placebo group, 32 had a control group that received a standard intervention, 31 had a usual care group, and six had a waitlist control group. Nineteen studies used a cognitive-behavioral intervention and 26 educational interventions. Twenty-seven used feedback, 29 used training, 16 used motivational, 11 used awareness, and 10 used mixed interventions. Seventy-nine studies used a standardized intervention (based on a manual or a theory), and 58 used a non-standardized intervention. The number of intervention sessions varied from 1 session to 120, and the period stretched from one day to two years. The intervention was delivered individually in 88 studies, collectively in 40, and combined in nine studies (see Appendix A and B for detailed information about the included studies, and Appendix C for

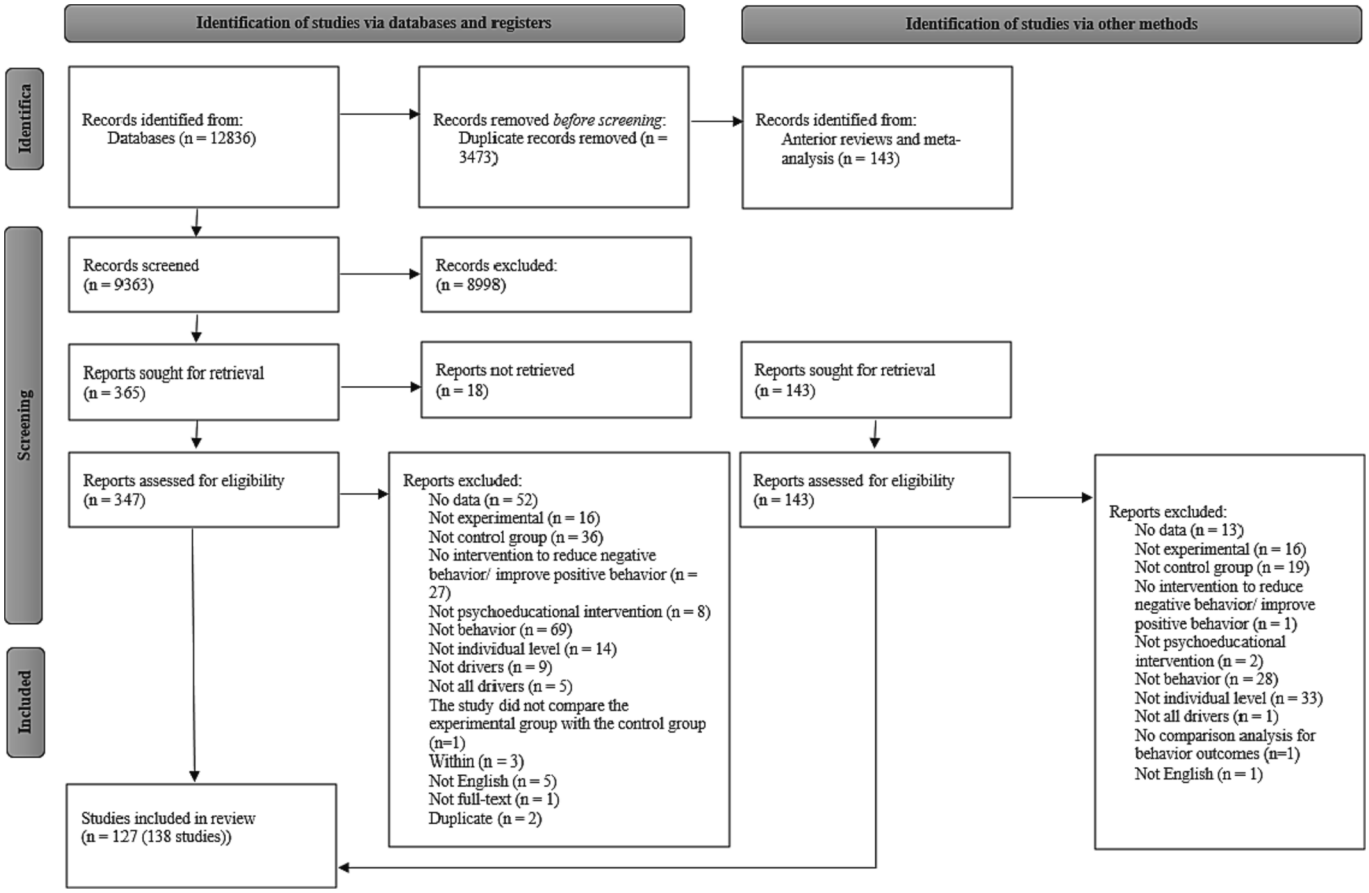

Fig. 1. Flow diagram of the systematic literature search.

a list of excluded studies).

3.2. Main effects

The effect sizes were computed using differences in means between experimental and control groups. Thus, the effects of interventions on errors and violations were *meta*-analyzed. The interventions' effect on risky driving as an overall outcome, but also on driving under the influence, fatigued driving, seat belt non-use and speeding as separate outcomes were also verified. Moreover, it was verified if interventions were effective on distracted driving (overall and phone use behaviors). Lastly, interventions' effects on anger-aggression, driving skills and constructive driving were verified.

The effects of interventions on outcomes mentioned above were tested on two time points (i.e., post-intervention and long-term/follow-up). The post-intervention effects included any outcome measured immediately after intervention and up to 14 days. The long-term effects included any outcome measured 30 days after the intervention and up to 2555 days (the longest period reported in the included studies). All effect size estimates (both post-intervention and long-term) were based on between-groups (not intra-group) comparisons. However, regarding fatigued driving at both time points, seat belt use at post-intervention, phone use at post-intervention, and constructive driving at post-intervention, there were fewer than three studies on each outcome (too few to *meta*-analyze the results). All results can be found in Table 1 (heterogeneity analysis results are briefly discussed at the end of section 3.2.).

Interventions had a strong effect on errors at post-intervention (d = 0.94, 95 %CI [0.08, 1.80], p = 0.03; k = 5) and a non-significant one in the long term (d = 0.50, 95 %CI [−0.87, 1.86], p = 0.48; k = 4). Concerning violations, interventions had a low to medium effect at post-intervention (d = 0.45, 95 %CI [0.12, 0.78], p < 0.01; k = 11) and a low long-term effect (d = 0.23, 95 %CI [0.12, 0.35], p < 0.001; k = 28).

A significant medium effect of interventions on overall risky driving was obtained at post-intervention (d = 0.53, 95 %CI [0.35, 0.71], p < 0.001; k = 49) and a small one in the long term (d = 0.34, 95 %CI [0.25, 0.43], p < 0.001, k = 60). Concerning DUI, a partially significant effect was identified at post-intervention (d = 0.35, 95 %CI [0.00, 0.71], Z = 1.96, p = 0.05; k = 8), while a small but significant one was obtained in the long term (d = 0.22, 95 %CI [0.10, 0.35, p < 0.001; k = 33). Interventions also had a low to moderate long-term effect on seat belt use (d = 0.41, 95 %CI [0.21, 0.60], p < 0.001; k = 9).

Concerning speeding, interventions had medium effects at both post-intervention (d = 0.59, 95 %CI [0.35, 0.84], p < 0.001; k = 35) and long-term (d = 0.67, 95 %CI [0.40, 0.94], p < 0.001; k = 18). A very strong effect was obtained on distracted driving overall at post-intervention (d = 1.87, 95 %CI [1.12, 2.60], p < 0.001; k = 7) and a medium one in the long term (d = 0.65, 95 %CI [0.15, 1.16], p = 0.01; k = 6). It was also identified a strong long-term effect on phone use (d = 0.80, 95 %CI [0.11, 1.49], p = 0.03; k = 4).

Interventions had an almost strong effect on anger-aggression at post-intervention (d = 0.78, 95 %CI [0.34, 1.22], Z = 3.46, p < 0.01; k = 6) and a similar long-term one (d = 0.74, 95 %CI [0.62, 0.85], p < 0.001; k = 5). Concerning driving skills, interventions had a medium effect at post-intervention (d = 0.52, 95 %CI [0.24, 0.79], p < 0.001; k = 20) and only a very small but significant effect in the long term (d = 0.11, 95 %CI [0.05, 0.17], Z = 3.47, p = 0.001; k = 5). There was also a significantly strong effect on constructive behaviors in the long term (d = 0.84, 95 % CI [0.20, 1.48], Z = 2.58p = 0.01; k = 6).

Heterogeneity analyses suggested that there is significant unexplained variance in the true effect sizes for almost all outcomes (with 81 to 99 % of the observed variance being due to real variations of the effects). The only outcomes with non-significant unexplained variance were long-term anger-aggression (about 43 %) and driving skills (about 0 %).

Table 1
Main Effects of Interventions on Driving Outcomes.

Variable	Time point	k	d [95 % CI]	Z	Q	I^2
Errors	POST	5	0.94 [0.08, 1.80]	2.15*	Q (4) = 61.93**	93.54
	LT	4	0.50 [−0.87, 1.86]	0.71	Q (3) = 83.79**	96.42
Violations	POST	11	0.45 [0.12, 0.78]	2.64**	Q (10) = 69.38**	85.59
	LT	28	0.23 [0.12, 0.35]	3.93**	Q (27) = 572.51**	95.28
Risky driving overall	POST	49	0.53 [0.35, 0.71]	5.72**	Q (48) = 656.39**	92.69
	LT	60	0.34 [0.25, 0.43]	7.09**	Q (59) = 1278.90**	95.39
Driving Under the Influence (DUI)	POST	8	0.35 [0.00, 0.71]	1.96	Q (7) = 72.46**	90.34
	LT	33	0.22 [0.10, 0.35]	3.53**	Q (32) = 590.86**	94.58
Fatigued driving	POST	1	–	–	–	–
	LT	2	–	–	–	–
Seat belt	POST	1	–	–	–	–
	LT	9	0.41 [0.21, 0.60]	4.04**	Q (8) = 42.31**	81.09
Speeding	POST	35	0.59 [0.35,0.84]	4.73**	Q (34) = 464.39**	92.68
	LT	18	0.67 [0.40, 0.94]	4.84**	Q (17) = 569.41**	97.01
Distracted driving overall	POST	7	1.87 [1.12, 2.60]	4.94**	Q (6) = 213.39**	97.19
	LT	6	0.65 [0.15, 1.16]	2.55*	Q (5) = 341.16**	98.53
Distracted driving – Phone use	POST	1	–	–	–	–
	LT	4	0.80 [0.11, 1.49]	2.27*	Q (3) = 309.40**	99.03
Anger-Aggression	POST	6	0.78 [0.34, 1.22]	3.46**	Q (5) = 34.95**	85.69
	LT	5	0.74 [0.62, 0.85]	12.42**	Q (4) = 7.10	43.66
Skills	POST	20	0.52 [0.24, 0.79]	3.66**	Q (19) = 197.87**	90.40
	LT	5	0.11 [0.05, 0.17]	3.47**	Q (4) = 1.43	0.00
Constructive driving	POST	2	–	–	–	–
	LT	6	0.84 [0.20, 1.48]	2.58**	Q (5) = 102.59**	95.13

Notes: * p < 0.05; ** p < 0.01; k = the number of studies included in the analysis. d = the average effect size; Z = the statistical test used for computing the significance of the average effect size; Q = the statistical test used for the estimation of heterogeneity; I^2 = the proportion of effect size variance that can be attributed to moderator variables. POST = post-intervention. LT = long-term.

3.3. Moderator analysis

Considering the fact that the effects were quite heterogeneous, it is necessary to verify the effect of possible moderators. There was significant heterogeneity in all outcomes at both post-intervention and long-term, with the exception of anger-aggression and skills in the long term. For errors, distracted driving overall and phone use, anger-aggression, and constructive driving, there were too few studies to test moderation effects on each outcome. Hence, these analyses were performed only for the remaining outcomes.

The following moderators were considered and tested:

- the type of control group (i.e., no intervention, placebo, standard intervention, usual care, or waiting list);
- the intervention type (i.e., cognitive-behavioral, educational, feedback, training, motivational/ goal-setting/coping interventions, awareness campaign, or mixed interventions);
- the standardization of the intervention (i.e., if the intervention was or was not based on a theory/an instruction manual regarding its delivery; coded as yes or no);

- the number of sessions (i.e., 1, 2–7, 8–34, 120);
- the duration of the intervention (in ranges of days, i.e., 1–7, 10–30, 35–60, 84–180, 240–365, 510–730);
- the format of intervention delivery (i.e., collectively, individually, or mixed);
- the measurement of the dependent variable – outcome measure type – (i.e., objective, self-report, direct observation, or mixed);
- type of participants (i.e., general population, young drivers, learner drivers, professional drivers, elderly drivers, or offenders);
- participants' nationality (American, Asian, Australian, European or mixed);
- average age (i.e., 16–25; 25–65; > 65);
- the percentage of male gendered participants (i.e., % Male: <50 %; 50–70 %; >70 %);
- dropout (coded as yes or no).

For each moderator, we reported whether the variation in effects is related to that moderator. The significance threshold for each moderator category can be consulted in Tables 2 and 3 for significant moderators. For each outcome and moderator, the analyses were run only on the categories of the moderator where there were at least three studies (the other categories being excluded).

Regarding violations at post-intervention, no significant covariates were identified. In the long term, delivery of intervention, type of outcome measure, and dropout rate were significant covariates. It seems that interventions worked better delivered collectively, those delivered individually having a small effect and the mixed ones not being effective. Interventions also worked well both when objective and self-report measurements were used, with objective measures showing higher results, and they worked well even if there were participants who dropped out.

For risky driving overall at post-intervention, control group design, intervention type, standardization, number of sessions, outcome

Table 2
Meta-analytical Findings for Violations and Risky driving overall for Each Moderator's Level.

Variable	Moderator	Moderator level	*k*	*d [95 % CI]*	*Z*	*Q*	I^2
Violations LT	Delivery of intervention	Collective	13	0.31 [0.11; 0.51]	3.04**	*Q* (12) = 544.55**	97.80
		Individually	10	0.07 [0.02; 0.13]	2.44*	*Q* (9) = 13.58	33.74
		Mixed	4	0.33 [−0.08; 0.74]	1.57	*Q* (3) = 12.47*	75.94
	VD Measure	Objective	13	0.39 [0.17; 0.61]	3.49*	*Q* (12) = 540.47**	97.78
		Self-report	12	0.08 [0.03; 0.13]	2.91**	*Q* (11) = 18.18	39.49
	Dropout	No	9	0.07 [0.01; 0.13]	2.19*	*Q* (8) = 10.94	26.86
		Yes	17	0.32 [0.14; 0.50]	3.48**	*Q* (16) = 558.62**	97.14
Risky driving overall POST	Control group design	No intervention	20	0.75 [0.46; 1.04]	5.05**	*Q* (19) = 355.79**	94.66
		Placebo	4	1.51 [−0.09; 3.12]	1.85	*Q* (3) = 58.65**	94.89
		Standard intervention	15	0.10 [−0.13; 0.33]	0.88	*Q* (14) = 58.52**	76.08
		Usual care	7	0.81 [0.58; 1.04]	6.85**	*Q* (6) = 13.10*	54.20
	Intervention type	Awareness campaign	8	0.14 [−0.26; 0.54]	0.67	*Q* (7) = 59.41**	88.22
		Cognitive-behavioral	6	0.27 [0.05; 0.49]	2.38*	*Q* (5) = 9.10	45.07
		Feedback	16	0.90 [0.61; 1.19]	6.05**	*Q* (15) = 185.24**	91.90
		Mixed	3	0.34 [−0.18; 0.87]	1.27	*Q* (2) = 15.98**	87.49
		Training	14	0.59 [0.25; 0.94]	3.35**	*Q* (13) = 124.39**	89.55
	Standardized intervention	No	30	0.77 [0.55; 1.00]	6.74**	*Q* (29) = 372.96**	92.22
		Yes	18	0.16 [−0.06; 0.37]	1.40	*Q* (17) = 103.71**	83.61
	Sessions	1	28	0.70 [0.42; 0.98]	4.96**	*Q* (27) = 374.01**	92.78
		2–7	11	0.38 [0.05; 0.72]	2.22*	*Q* (10) = 89.86**	88.87
		8–34	5	0.06 [−0.24; 0.36]	0.38	*Q* (4) = 21.88**	81.72
	VD Measure	Objective	31	0.70 [0.46; 0.94]	5.75**	*Q* (30) = 344.70**	91.30
		Observation	7	0.02 [−0.47; 0.51]	0.06	*Q* (6) = 72.77**	91.75
		Self-report	9	0.46 [0.12; 0.80]	2.65**	*Q* (8) = 121.15**	93.40
	Participants	General population	5	1.50 [0.71; 2.30]	3.70**	*Q* (4) = 52.26**	92.35
		Offenders	5	0.32 [0.09; 0.55]	2.69**	*Q* (4) = 9.64*	58.49
		Elderly drivers	5	0.24 [−0.34; 0.83]	0.81	*Q* (4) = 22.89**	82.53
		Young drivers	34	0.50 [0.28; 0.72]	4.44**	*Q* (33) = 504.71**	93.46
Risky driving overall LT	Intervention type	Awareness campaign	4	0.24 [−0.15; 0.64]	1.20	*Q* (3) = 52.81**	94.32
		Cognitive-behavioral	12	0.30 [0.15; 0.45]	3.90**	*Q* (11) = 66.27**	83.40
		Educational	17	0.12 [0.02; 0.22]	2.45*	*Q* (16) = 156.21**	89.76
		Feedback	3	0.54 [0.32; 0.76]	4.74**	*Q* (2) = 0.71	0.00
		Mixed	7	0.23 [0.04; 0.42]	2.38*	*Q* (6) = 82.20**	92.70
		Motivational/Goal-setting-Coping	11	0.90 [0.37; 1.43]	3.34**	*Q* (10) = 807.19**	98.76
		Training	6	0.40 [0.12; 0.68]	2.83**	*Q* (5) = 13.76**	63.67
	Sessions	1	24	0.46 [0.28; 0.65]	4.84**	*Q* (23) = 797.27**	97.12
		2–7	18	0.12 [0.01; 0.23]	2.10*	*Q* (17) = 123.12**	86.19
		8–34	10	0.36 [0.14; 0.57]	3.23**	*Q* (9) = 131.56**	93.16
	VD Measure	Objective	20	0.16 [0.05; 0.26]	2.87**	*Q* (19) = 136.46**	86.08
		Observation	3	0.64 [0.47; 0.81]	7.43**	*Q* (2) = 3.67	45.43
		Self-report	34	0.40 [0.25; 0.55]	5.29**	*Q* (33) = 1032.97**	96.81
	Participants	General population	13	0.69 [0.23; 1.06]	3.67**	*Q* (12) = 364.93**	96.71
		Learner drivers	3	0.13 [−0.08; 0.34]	1.26	*Q* (2) = 4.56	56.11
		Offenders	16	0.09 [−0.04; 0.21]	1.39	*Q* (15) = 253.34**	94.08
		Elderly drivers	3	0.24 [−0.01; 0.49]	1.88	*Q* (2) = 1.18	0.00
		Young drivers	24	0.41 [0.26; 0.57]	5.21**	*Q* (23) = 505.52**	95.45
	Dropout	No	24	0.23 [0.09; 0.37]	3.23**	*Q* (23) = 201.54**	88.59
		Yes	35	0.43 [0.30; 0.55]	6.51**	*Q* (34) = 1054.88**	96.78

Notes: * $p < 0.05$; ** $p < 0.01$; k = the number of samples included in the analysis. d = the average effect size; Z = the statistical test used for computing the significance of the average effect size; Q = the statistical test used for the estimation of heterogeneity; I^2 = the proportion of effect size variance that can be attributed to moderator variables. POST = post-intervention. LT = long-term.

Table 3
Meta-analytical Findings for Seatbelt use, Speeding and Skills for Each Moderator's Level.

Variable	Moderator	Moderator level	*k*	*d [95 % CI]*	*Z*	*Q*	I^2
Seatbelt LT	VD Measure	Observation	3	0.64 [0.47; 0.81]	7.43**	*Q* (2) = 3.67	45.43
		Self-report	4	0.21 [0.07; 0.35]	2.89**	*Q* (3) = 5.58	46.22
Speeding POST	Control group design	No intervention	15	0.80 [0.47; 1.13]	4.80**	*Q* (14) = 187.83**	92.55
		Placebo	3	2.19 [−0.56; 4.94]	1.56	*Q* (2) = 49.65**	95.97
		Standard intervention	11	0.10 [−0.21; 0.40]	0.62	*Q* (10) = 57.60**	82.64
		Usual care	5	0.85 [0.62; 1.09]	7.12**	*Q* (4) = 5.36	25.36
	Intervention type	Awareness campaign	8	0.14 [−0.26; 0.54]	0.67	*Q* (7) = 59.41**	88.22
		Cognitive-behavioral	3	0.03 [−0.30; 0.36]	0.20	*Q* (2) = 0.96	0.00
		Feedback	13	0.95 [0.62; 1.29]	5.64**	*Q* (12) = 145.37**	91.75
		Training	11	0.65 [0.19; 1.12]	2.77**	*Q* (10) = 104.07**	90.39
	Standardized intervention	No	22	0.88 [0.61; 1.16]	6.30**	*Q* (21) = 252.65**	91.69
		Yes	12	0.09 [−0.24; 0.42]	0.52	*Q* (11) = 65.39**	83.18
	Participants	General population	3	2.35 [0.16; 4.54]	2.10*	*Q* (2) = 47.87**	95.82
		Elderly drivers	4	-0.04 [−0.39; 0.31]	-0.22	*Q* (3) = 4.72	36.41
		Young drivers	27	0.57 [0.31; 0.84]	4.22**	*Q* (26) = 373.35**	93.04
	Nationality	American	8	1.39 [0.58; 2.20]	3.36**	*Q* (7) = 79.61**	91.21
		Asian	9	0.20 [−0.29; 0.69]	0.80	*Q* (8) = 98.73**	91.90
		Australian	11	0.73 [0.38; 1.08]	4.08**	*Q* (10) = 162.37**	93.84
		European	7	0.21 [−0.08; 0.51]	1.41	*Q* (6) = 15.58*	61.49
	% Male	<50 %	10	0.39 [0.16; 0.62]	3.31**	*Q* (9) = 23.23**	61.25
		50–70 %	8	1.02 [0.69; 1.35]	6.03**	*Q* (7) = 71.19**	90.17
		> 70 %	13	0.38 [−0.05; 0.73]	1.72	*Q* (12) = 161.80**	92.58
Speeding LT	Sessions	1	8	0.85 [0.36; 1.33]	3.44**	*Q* (7) = 362.91**	98.07
		2–7	8	0.21 [−0.01; 0.43]	1.87	*Q* (7) = 46.77**	85.03
	VD Measure	Objective	9	0.19 [0.03; 0.36]	2.28*	*Q* (8) = 41.56**	80.75
		Self-report	8	1.20 [0.51; 1.87]	3.44**	*Q* (7) = 473.99**	98.52
	Mean age	16–25	10	0.35 [0.12; 0.58]	3.02**	*Q* (9) = 153.98**	94.16
		25–65	5	1.40 [0.39; 2.39]	2.72**	*Q* (4) = 322.54**	98.76
	% Male	<50 %	8	1.25 [0.61; 1.90]	3.80**	*Q* (7) = 464.17**	98.49
		50–70 %	4	0.15 [−0.08; 0.39]	1.26	*Q* (3) = 18.05**	83.38
		> 70 %	5	0.48 [0.32; 0.64]	5.93**	*Q* (4) = 4.04	0.93
	Dropout	No	6	0.29 [0.01; 0.56]	2.04*	*Q* (5) = 13.64*	63.33
		Yes	11	0.94 [0.55; 1.32]	4.78**	*Q* (10) = 549.65**	98.18
Skills POST	Intervention type	Feedback	9	0.85 [0.33; 1.37]	3.21**	*Q* (8) = 164.18**	95.13
		Training	11	0.27 [0.02; 0.52]	2.08*	*Q* (10) = 33.63**	70.28

Notes: * $p < 0.05$; ** $p < 0.01$; k = the number of samples included in the analysis. d = the average effect size; Z = the statistical test used for computing the significance of the average effect size; Q = the statistical test used for the estimation of heterogeneity; I^2 = the proportion of effect size variance that can be attributed to moderator variables. POST = post-intervention. LT = long-term.

measure, and type of participants were significant covariates. The interventions worked well for studies that used the usual control group or a no-intervention one, and for studies that used feedback, training, and cognitive-behavioral interventions. Also, non-standardized interventions worked better, although the smaller number of studies with standardized interventions could have determined the non-significant effects. Apparently, a smaller number of sessions was more efficient. Interventions worked better when the measurements used were objective as also self-reported (no significant effects for observation). The interventions had the strongest effects on the general population, followed by young drivers and offenders, but had no effect on elderly drivers.

For risky driving in the long term, there were some significant covariates: intervention, number of sessions, type of outcome measure, participants, and dropout rate. Motivational interventions had the higher effects, followed by feedback, training, cognitive-behavioral interventions, mixed and educational. Awareness interventions were not effective. Both interventions with a small number of sessions and those with more sessions were effective. All outcome operationalizations registered significant effects. Observations also recorded high effects, but there were only a few studies. This time there were effects only on the general population and young drivers. At the same time, the results were maintained even in studies with dropouts.

Regarding DUI behavior, all covariates for both post-intervention and long-term periods were non-significant.

For seatbelt use in the long-term, the type of outcome measure was the only significant covariate. Both observations and self-report measurements recorded significant effects, but the number of studies was low. For speeding at post-intervention, the majority of covariates were significant (only dropout was non-significant). As in the case of violations, the interventions were more effective when compared with a usual care control group or a no-intervention one. Only feedback and training interventions had significant effects. Non-standardized interventions proved effective, but it is worth noting that the number of studies (compared to the ones with standardized interventions) is almost double. The results were significant for the general population for young drivers, and in the case of Americans and Australians. The interventions were effective when the sample was more balanced regarding gender distribution.

For speeding in the long-term, the number of sessions, outcome measure, mean age, percentage of males, and dropout were significant covariates. Fewer sessions had a higher effect, and both objective and self-report measures registered significant effects. Even if the effect was higher this time in the case of self-report measurements, the remaining heterogeneity was still significant and high (I^2 = 98.52). The interventions worked both for people aged between 16 and 25 years, as well as for those over 25 and up to 65 years old. Regarding the gender distribution, taking the unequal number of studies, it can be concluded that a more balanced sample is preferable. Also, even if the participants gave up along the way in some studies, the effects persisted.

For driving skills at post-intervention, only intervention type was a significant covariate. In this case, feedback interventions appear to be more effective than those based on training.

3.4. Publication bias

To increase readability, all funnel plot figures are presented as Supplementary Material. Regarding errors at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S2) and Egger's test was not statistically significant (intercept = 2.81, $p = 0.33$). The Duval and Tweedie trim and fill procedure imputed no studies. The adjusted effect was similar to the observed value ($d = 0.94$, 95 %CI [0.08, 1.80]). In the case of errors in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S3). Egger's test was not statistically significant (intercept = 7.46, $p = 0.38$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed value ($d = 0.50$, 95 %CI [−0.87, 1.86]).

When it came to violations at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S4). Egger's test was not significant (intercept = 3.23, $p = 0.12$), and the Duval and Tweedie trim and fill procedure imputed no studies. The adjusted effect was similar to the observed value ($d = 0.45$, 95 %CI [0.12, 0.78]). In the case of violations in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S5). Egger's test was on the verge of being non-significant (intercept = 2.35, $p = 0.047$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed value ($d = 0.23$, 95 %CI [0.12, 0.35]).

Regarding risky driving overall at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S6). The Egger's test was not statistically significant (intercept = 0.08, $p = 0.47$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed one ($d = 0.53$, 95 %CI [0.35, 0.71]). In the case of risky driving overall in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S7). The Egger's test was statistically significant (intercept = 2.70, $p < 0.01$), but the Duval and Tweedie trim and fill procedure imputed no studies, and the adjusted effect was similar to the observed value ($d = 0.34$, 95 %CI [0.25, 0.43]).

Concerning driving under the influence at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S8). Also, Egger's test was not statistically significant (intercept = -2.13, $p = 0.24$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar ($d = 0.35$, 95 %CI [0.00, 0.71]). In the case of DUI behavior in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S9). Egger's test was not significant (intercept = 1.14, $p = 0.21$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being the same ($d = 0.22$, 95 %CI [0.10, 0.35]).

When it came to seat belt use in the long term, the visual inspection of the funnel plot indicated some asymmetry (Fig. S10). However, Egger's test was not significant (intercept = 0.37, $p = 0.41$), but the Duval and Tweedie trim and fill procedure imputed two studies. The adjusted effect was $d = 0.35$, 95 %CI [0.15, 0.55], being quite different from the observed value ($d = 0.41$, 95 %CI [0.21, 0.60]).

Regarding speeding at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S11). The Egger's test was not statistically significant (intercept = -1.96, $p = 0.10$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed one ($d = 0.59$, 95 %CI [0.35, 0.84]). In the case of speeding in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S12). The Egger's test was statistically significant (intercept = 5.18, $p < 0.01$), and the Duval and Tweedie trim and fill procedure imputed no studies, and the adjusted effect was similar to the observed value ($d = 0.67$, 95 %CI [0.40, 0.94]).

Regarding distracted driving overall at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S13). The Egger's test was statistically significant (intercept = 6.55, $p < 0.01$), but the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed one ($d = 1.87$, 95 %CI [1.12, 2.60]). In the case of distracted driving overall in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S14). The Egger's test was not statistically significant (intercept = 2.11, $p = 0.39$), and the Duval and Tweedie trim and fill procedure imputed no studies. The adjusted effect was similar to the observed value ($d = 0.65$, 95 %CI [0.15, 1.16]).

Concerning phone use behavior in the long term, the visual inspection of the funnel plot indicated some asymmetry (Fig. S15). However, Egger's test was not significant (intercept = 3.12, $p = 0.41$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed one ($d = 0.80$, 95 %CI [0.11, 1.49]).

Concerning anger-aggression at post-intervention, the visual inspection of the funnel plot indicated some asymmetry (Fig. S16). Egger's test was not significant (intercept = 3.10, $p = 0.16$), but the Duval and Tweedie trim and fill procedure imputed one study to the left of the mean, the adjusted effect being a little bit different from the observed value ($d = 0.62$, 95 %CI [0.18,0.1.07]). In the case of anger-aggression in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S17). Egger's test was significant (intercept = -1.93, $p = 0.02$), but the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar to the observed value ($d = 0.74$, 95 %CI [0.62, 0.85]).

When it came to skills at post-intervention, the visual inspection of the funnel plot indicated symmetry (Fig. S18). The Egger's test was significant (intercept = 3.18, $p = 0.02$). The Duval and Tweedie trim and fill procedure imputed no studies. The adjusted effect was similar to the observed value ($d = 0.52$, 95 %CI [0.24, 0.79]). In the case of skills in the long term, the visual inspection of the funnel plot indicated some asymmetry (Fig. S19), but Egger's test was not significant (intercept = 0.41, $p = 0.17$). However, the Duval and Tweedie trim and fill procedure imputed two studies, the adjusted effect being almost similar ($d = 0.10$, 95 %CI [0.04, 0.16]) to the observed value ($d = 0.11$, 95 %CI [0.05, 0.17]).

Concerning constructive driving in the long term, the visual inspection of the funnel plot indicated symmetry (Fig. S20). Egger's test was not significant (intercept = 5.83, $p = 0.06$), and the Duval and Tweedie trim and fill procedure imputed no studies, the adjusted effect being similar ($d = 0.84$, 95 %CI [0.20, 1.48]).

Thus, the presence of a slight publication bias can be observed. However, even where the trim and fill method added some studies, the adjusted effects were similar to the observed ones. Therefore, it can be concluded that publication bias does not seem to affect the observed results.

4. Discussion

The objective of the present *meta*-analysis was to test the effectiveness of psychoeducational interventions on driving behavior. As expected, significant effects on most of the targeted outcomes were identified, except for errors over a longer period of time and DUI at post-intervention (the latter effect was partially significant). Several significant moderators were also found for the majority of outcomes.

4.1. Main effects

For errors, there was a significant effect in post-intervention but no significant effect in the long term. One possible explanation is that most studies assessing errors were on older drivers. Porter (2013) pointed out that it is possible that training in an unfamiliar vehicle interferes with cognitive performance, thus leading to non-significant results. He also pointed out that interventions with classes and feedback led to significant results. Consequently, interventions that address both knowledge

and skills may be more effective.

Interventions on violations had significant effects both on the post-intervention and longer term. However, these effects were not very strong, which could be due to some characteristics of the drivers. As in the case of studies that measured errors, Tian et al. (2021) tested the effects of a warning system on violations in a population of older adults. The authors suggested that it is possible for this category of drivers to feel overwhelmed by such a system, which could be unfamiliar to them.

The interventions also had a significant effect of moderate intensity on overall risky driving at post-intervention and a lower one in the long term. As technology increasingly enables automated processes that identify driving events and provide feedback to improve driving behavior, information to engage drivers are essential to maximize driving behavior change. Adolescent driving behavior improves when they receive feedback and instructions about safe driving (Peek-Asa et al., 2019). The not very strong effects and especially the low long-term effect revealed *meta*-analytically could be explained by the high heterogeneity in the data. This argument can be supported by the fact that, when separately analyzed, the effects on risky outcomes seem more constant. Thus, small effects were identified on driving under the influence at both time points and also a small effect on seatbelt use in long-term. The effects on speeding were moderate.

Regarding driving under the influence, the fact that the result was only marginally significant at the post-intervention could be due to the small number of studies and their high heterogeneity. Moreover, the effect in the long term was very weak. One reason the effects are weak may be that, in general, the involvement of additional services (medical/psychological) is not taken into account besides the intervention itself, since these types of behaviors can be hard to change. Jewell and Hupp (2005) tested the effectiveness of a simulated blood alcohol content intervention to increase driver awareness of the effects of driving under the influence. Although the authors expected that the intervention would lead to subsequent behavioral change, participants only changed their attitudes about drunk driving, but there was no behavioral change. Moreover, at follow-up, there were no behavioral changes, and even the initial positive results on attitudes disappeared.

Albery and Guppy (1995) draw attention to the fact that DUI behavior consists of a series of perceptions and assumptions of individuals, such as underestimating the risk or overestimating the ability to drive even while intoxicated. Therefore, intervention programs should focus on these cognitive distortions (Jewell & Hupp, 2005). These aspects underline the fact that behavioral change is difficult. In this context, motivational and self-efficacy factors may be involved, as well as mechanisms of engagement in action. Wells-Parker and Williams (2002) suggested the need to focus much of the intervention content on examining the effectiveness and sustainability of people's actions rather than convincing them that they have problems. The intervention must focus on drivers' self-efficacy and their plans. At the same time, interventions must be based on skills development, supporting changes, and lifestyle choices that facilitate behavioral change.

For seatbelt use, a low to medium effect was identified; however, the number of studies included is not very large. Also, many studies are conducted on samples from emergency departments, thus reducing the external validity of the result (Fernandez et al., 2008; Hempel, 1992; Sommers et al., 2013; 2015). Also, the measurements varied, and several studies emphasized the need for more objective recordings (e.g., Sommers et al., 2015).

Regarding speed reduction, significant effects of interventions were identified at both time points. It appears that speeding is reduced through interventions. In this sense, speed management feedback can significantly reduce speeding violations through financial, safety, performance, or combined feedback (Molloy et al., 2018a; b; c). Molloy et al. (2019) pointed out that the nature of feedback is more important in encouraging young novice drivers to limit their speed rather than their duration.

Interventions also reduced distracted driving behaviors. When drivers receive a report on how many times they have engaged in other activities, they become more aware and changed their behavior (Merrikhpour & Donmez, 2017). Regarding phone use, applications that prevent drivers from using the phone (Creaser, 2015), respectively interventions based on setting goals, especially the implementation intentions interventions (Elliott et al., 2021), are useful in reducing this behavior. However, a few studies addressed phone use while driving, so future research is required to understand if interventions have an effect and if this effect is maintained in the long term.

The interventions had substantial effects on anger-aggression at both time points. This result is in agreement with the review made by Deffenbacher (2016) on traffic anger that showed how learning specific techniques of cognitive restructuring and relaxation, understanding emotions, and expressing them in an adaptive alternative way can help drivers decrease the level of anger and aggression manifested while driving. As other studies have shown, positive acceptance and reappraisal to ameliorate negative emotions can help drivers use more rational and positive attitudes and methods that alleviate their anger (Feng et al., 2018). Anger can also be reduced through positive feedback, as when drivers receive positive comments, they may experience a series of pleasant emotions that counteract negative emotionality (Li et al., 2020).

On skills, the effects were medium at the post-intervention, but decreased in the long term. One explanation for this weak effect could be, as in the case of errors, the fact that the majority of interventions addressed older drivers and unfamiliar technologies (e.g., simulators, vehicles). This fact could affect compliance with treatment.

Regarding constructive driving, the effects were strong over a long period. The interventions that restructure thoughts can determine the adoption of more adaptive behaviors in traffic (Feng et al., 2018). Considering the small number of studies, future research could more accurately explore this category of behaviors.

4.2. Moderator analysis

There were significant moderators on violations in the long-term, risky driving overall at both post-intervention and long-term, seatbelt in the long-term, speeding on both of them, and skills during the post-intervention. From the selected moderators, control group, intervention type, standardization, number of sessions, outcome measure, participants, nationality, mean age, percentage of males and dropout were identified as being significant on some of these outcomes.

Regarding the type of control group, this was a covariate for risky driving overall and speeding in the post-intervention. In both cases, the interventions were more effective when compared with a usual care control group or a no-intervention, which might be a methodological artifact (participants in control groups without any treatment might feel disappointed by not benefiting directly from the study). Future research should use more frequent active control groups (Brewster et al., 2015). In the present review the number of studies for placebo and usual care groups was not high enough, determining an imbalance between these categories. When considering the standardized interventions, in some studies they were compared with an awareness intervention, which could have determined the non-significant differences between the groups (e.g., Taubman-Ben-Ari et al., 1999).

Intervention type was significant in the case of risky driving overall on the post-intervention and in the long-term speeding and driving skills on post-intervention. Regarding risky driving behaviors on post-intervention, feedback had a higher effect, followed by training and cognitive-behavioral interventions. When drivers are directly informed about the exact implications of their behavior and what that behavior means in terms of performance or costs, they become more responsible (Molloy et al., 2018c). The effects are improved when drivers are trained in a road context or on the simulator and learn to avoid risky behaviors (Sawula et al., 2017). Cognitive behavioral interventions based on changing attitudes, finding coping strategies against social pressure, and

exploring alternatives to make informed choices can also help to reduce risky behaviors such as DUI. In this case, the interventions may be more effective if we focus strictly on reducing DUI, not on other consequences of substance use (Osilla et al., 2019). Awareness does not seem like an effective intervention, an explanation being that making drivers aware of the negative consequences does not automatically translate into behavior (Carcary, 2000; Jewell & Hupp, 2005). Concerning the mixed interventions, there were too few studies to be able to generalize the non-significant effects observed. For risky driving behaviors in the long-term, higher effects were observed for motivational interventions, followed by feedback, training, cognitive-behavioral interventions, mixed and educational. Awareness was still non-significant. So, as expected, when the number of studies was higher, the effect of mixed interventions was significant but still of low magnitude.

For speeding, feedback had the higher effects. This is in agreement with many previous studies (e.g., Molloy et al., 2018a; b; c; 2019, 2021). Trainings were also effective: people drive more slowly when they are instructed on how they should maintain an appropriate speed (Wang et al., 2010). Awareness led to non-significant effects, emphasizing again that such campaigns were not enough, and cognitive-behavioral interventions were also ineffective. It is possible that cognitive-behavioral interventions do not work because they usually address elements related to anger and frustration, and studies have shown that at the base of speeding is possible to find less such emotions (Sârbescu & Rusu, 2021).

For skills, feedback had a higher effect than training. Receiving reports about performance (especially with positive feedback) may help drivers reduce their risk perception and improve driving their skills (Donmez et al., 2008). Horswill et al. (2021) draw attention to the necessity for the training to be permanently supervised by an instructor. The authors had sessions during the intervention in which the participants were not supervised, and it was not known if they did their exercises. So, when training is delivered, monitoring is very important.

Taking into account whether the intervention was standardized or not, for risky driving at post-intervention, non-standardized programs seem to be the only effective ones. This also applies for speeding at post-intervention. However, there was an unequal distribution of studies in the two categories, which makes us cautious in generalizing these effects. Regarding the number of sessions, the same can be said. For risky driving in the long term, when the number of studies was somehow equal, both a smaller number of sessions and more sessions proved effective. For speeding in the long-term, fewer sessions had a higher effect against the equal number of studies across categories. The explanation is likely to be rather methodological. One study (Ekeh et al., 2011) had several moments of measurement at follow-up, which are considered to be long-term effects in this *meta*-analysis, and their intervention had four sessions. Their follow-up effects were not significant, emphasizing the need to do maintenance sessions beyond six months. Compared to the studies that had a single session, this one presenting so many time intervals may have increased the average, which should be why the interventions with more sessions were not significant.

The delivery of interventions was a significant moderator of violations in the long term. Interventions delivered collectively had a higher impact, which can be because the majority of studies were based on an educational program (e.g., Raub et al., 1999), and maybe these are more effective when delivered collectively. Even if the intervention type was not a significant covariate, it had an effect not far from 0.05, and the educational interventions seemed promising.

With the specification to measurement, on all the outcomes where this covariate was significant, both objective measures and self-report registered effects. In general, the objective ones had somewhat stronger effects. When things were the other way around, the number of studies was uneven or small. Also, previous studies have shown correlations between objective and self-report measurements (Elliott & Armitage, 2009). In the few instances when measuring the outcomes through observation, the effects were significant, but the number of studies was too small to allow for any definite conclusions.

The type of participants was another relevant moderator. For risky behaviors, the interventions worked on the general population and young drivers (both post-intervention and long-term) but also on offenders (post-intervention). It seems that these are not effective on older drivers, possibly because they lack familiarity with the various methodologies used. Some studies with non-significant effects on older drivers were on DUI, and the samples were under-represented (Sanna et al., 2015). Also, it is necessary to remember that a series of cognitive functions are affected with advancing age. Urlings et al. (2019) draw attention to the learning ability of older drivers, which could be a moderating factor.

In the case of speeding (long-term effects) the interventions worked both for people aged between 16 and 25 years, as well as for those over 25 and up to 65 years old. For the category of older people, there were only two studies. In fact, there have been three studies on risky driving overall in the long-term, so the results are not very conclusive.

For the gender distribution, although in some cases the studies are unequally divided by category, we can still tend to believe that it is better when there is a balance. Last but not least, even if there were participants dropped out, the interventions showed significant results, which is encouraging.

Nationality was relevant only in the case of speeding (post-intervention), and it seems that American and Australian drivers responded better to interventions. With regard to Asians, the studies tested awareness interventions, which could be another reason for the non-significant effects (Taubman-Ben-Ari et al., 1999; Taubman-Ben-Ari et al., 2000). Regarding Europeans, beyond nationality, it could also be about the aspects related to the delivered interventions or type of participants (e.g., Urlings et al., 2019). It could also be about some factors related to legislation. Speed limits in America are lower compared to Europe, and high speeding behavior could have more expensive consequences.

4.3. Limitations

This *meta*-analysis has several limitations. First, there are a small number of studies on some of the examined outcomes, which did not allow us to test moderators on each driving behavior.

Another limitation could be the various measurements of traffic behaviors (e.g., self-report, simulator, police records). On the same line, Af Wåhlberg (2010) drew attention about the fact that self-report instruments have a certain degree of social distortion. The author used scales that allowed for the identification of the level of distortion. The results showed that the initial low levels for the education group were due to the participants' attempt to respond socially desirable, an effect that decreased after they participated in the intervention. Thus, the use of tools that allow the identification of distorted responses for a more accurate evaluation of driving behaviors is encouraged.

Another potential limit could be that although studies included a wide range of cultures around the world, Africa is not represented, which may affect the external validity of the results. However, the review has included studies from almost all other parts of the world, so this aspect should not be considered as a strong limitation.

The fact that we focused more on psychoeducational interventions could be another limitation, so we managed to capture only the educational component of the 3 Es framework. Feedback-based interventions that used different warning systems could support the engineering component to some extent. However, future reviews should target all types of feedback-based measures to be able to draw comprehensive conclusions for their effectiveness. Likewise, the enforcement interventions were not included in this paper because the studies that tested such interventions were done at the community level, so the number of participants was not specified, and consequently we could not use such data. Future research can approach the interventions

taking into account this framework, so that a wider audience can benefit from the conclusions.

4.4. Practical implications

Considering the obtained results, several practical aspects should be taken into account when one develops a driving intervention. Some interventions work better on some types of behaviors than on others. Interventions should be developed depending on the behavior we want to change. For example: feedback, training, motivational, and cognitive-behavioral interventions work better when we address risky driving behaviors. Thus, when risky behaviors are the target, drivers should receive sessions in which they have the opportunity to practice, in which they should be given feedback on positive and negative behaviors, on what are the consequences of their behaviors and on how they could improve their driving behavior. Drivers should also learn to identify dangerous situations and formulate objectives to achieve the desired behaviors. They need to identify solutions and learn how to apply them. Cognitive restructuring sessions, relaxation techniques, and positive re-evaluation also could help. In the same direction, if the target is speeding, feedback (e.g., regarding costs, consequences, and performance) and training are very effective, while cognitive-behavioral approaches do not necessarily work so well.

Overall, the interventions that require drivers to perform activities, not just listen to educational content, seem to work much better. Educational interventions appear to have weak effects. Accumulation of some information is not enough to change behavior. The awareness interventions also proved ineffective, so future interventions should focus less on presenting the negative consequences of dangerous behaviors and rather on skills and strategies to identify and prevent them.

5. Conclusion

The results of the present *meta*-analysis showed that most interventions were effective in reducing negative driving behaviors and improving positive behaviors. If interventions are delivered to increase road safety, it should be taken into account that drivers are more receptive when they receive feedback on their behavior, or when they are involved in practical activities and receive training. They should also be helped to set clear goals to achieve and use relaxation strategies to adopt more functional alternatives in stressful situations. Combined interventions can also be considered, while interventions focused solely on raising awareness might not be the best option (regardless of the targeted driving behavior).

CRediT authorship contribution statement

Lorena Tirla: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paul Sârbescu:** Writing – review & editing, Investigation, Methodology, Conceptualization. **Andrei Rusu:** Writing – review & editing, Methodology, Investigation, 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.

Acknowledgement

The authors would like to thank former MD student Carina Daniela Rostescu for her help with the article screening process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aap.2024.107496.

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