Design considerations for future affective automotive interfaces: a review of self-regulation strategies to manage affect behind the wheel

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Like inattention, dysregulated emotions can seriously distract motorists and disrupt their driving performance. The current review examined the literature on emotion regulation to find relevant strategies for managing intense emotions while driving a motor vehicle. Next, we considered whether those relevant strategies could be used to design future affective automotive interfaces. Results suggested that problem-solving, task-focused coping, mindfulness, and relaxation effectively regulate emotions while driving. These findings highlight that some strategies may be effective but costly to implement while driving (cognitive reappraisal and distraction), which need to be better understood before implementing them into automotive interfaces. Together, these findings suggest the potential benefits of embedding self-regulatory interventions in future automotive interfaces that can help maintain an optimal affective state to reduce distraction and improve safe driving.

1 Introduction

Distracted driving is a significant cause of on-road accidents, and automotive interfaces[1] can play an active role in helping motorists drive safely. While most past research has focused on countering inattention (for review, see Regan et al., 2017), limited work has evaluated effective ways to regulate intense emotions while driving. However, the transactional model of driver stress (Matthews, 2001) suggests an inherent connection between the motorist operating the vehicle and their environment, which has meaningful impacts on cognition, affect, and performance. In other words, the internal intra-individual factors of the driver (such as emotions and stress) and inter-personal factors (such as socializing in-person or virtually) can have a pervasive association with cognitive resources, thereby impacting optimal driving behavior (Braun et al., 2021; Matthews, 2001).

Regarding internal factors, an important consideration is the emotional state of the motorist. Past research has recognized several specific emotions of particular concern in the

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1 Automotive interfaces are advanced technological systems installed in vehicles to support.

driving context (for a targeted review, see Braun et al., 2021; Eyben et al., 2010; Bernstein and Calamia, 2019). One of the most researched emotions is anger while operating vehicles. A 20-year meta-analysis found that angry driving is linked to poor driving outcomes such as risky and aggressive driving with higher driving errors (Zhang and Chan, 2016). Anger was found to cause more errors (Jeon et al., 2011), speeding (Mesken et al., 2007), and unsafe driving (Roidl et al., 2014). When left dysregulated, impulsive behavior is an important contributor to aggressive road rage (Kovácsová et al., 2016). Frustration while driving is also a closely related affective state that's known to increase negative emotional experiences, often causing anger and road rage (Harris and Nass, 2011). Similarly, stress can be detrimental to attention and engagement, lowering driving performance (Matthews et al., 1998; Tavakoli et al., 2023). A common stress-inducing situation is time pressure, which is harmful to human performance (Szalma et al., 2008) and can lead to risky driving (Shukri et al., 2022). While anger and stress can be higher-intensity states, even sadness, a lower-intensity state, can worsen and increase unsafe driving conditions (Dula and Geller, 2003). These findings are in line with theoretical perspectives (Yerkes and Dodson, 1908; Cai and Lin, 2011) that suggest motorists should be in an optimal driving state (i.e., not too much or too little physiologically aroused) that allows them to have adequate resources for attentive and safe driving. Thus, effective emotion regulation is essential for optimal driving performance (Matthews, 2001; Wickens et al., 2022).

In terms of external factors, inter-personal social conditions are critical. Past work on dual-task interference models in automation research suggests that conflicting tasks compete for limited resources (e.g., Engström et al., 2017; Pashler and Johnston, 1998; Wickens et al., 2004; Wickens, 2021a; Wickens et al., 2021b). For instance, road crashes were associated with responding to calls, using the web browser while driving, or even when reaching for the phone (Charlton, 2009; Dingus et al., 2016; Rakauskas et al., 2004; Venkatraman et al., 2021). This is because talking and texting are cognitively demanding (e.g., need working memory and executive control), leading to increased reaction times in vehicle operation and interfering with driving performance (e.g., Charlton, 2009; Hancock et al., 2012). With more demanding cognitive tasks, self-control becomes more difficult, and people start to have selective attention, change blindness, and compromise safe driving conditions (e.g., Wickens et al., 2021b). Furthermore, the availability of infotainment systems and touchscreen displays with social media has further aggravated the sheer number of social distractors available to motorists, thereby compromising safe driving (e.g., Regan et al., 2017). Thus, the secondary task of engaging in social activities may become intrusive toward driving, leading to socially distracted performance on the road.

Even though drivers should give a higher priority to maintain the appropriate allocation of resources to driving, ignoring any socioemotional interference (Wickens, 2021a; Wickens et al., 2021b), often, this is quite challenging to do (e.g., Engström et al., 2017; Ma et al., 2024), especially when motorists experience intense emotions. Taking the example of road rage (Hennessy and Wiesenthal, 2005; Takaku, 2006; Zhang and Chan, 2016), dysregulated emotions can lead to unsafe driving practices (such as impulsive driving) with tragic consequences, as revealed by 67% of crashes attributed to aggressive driving

(Goodwin et al., 2015). While emotional dysregulation can lead to risky, angry, or anxious driving, successful self-regulation can support safe driving behavior (Bjureberg and Gross, 2021). A similar pattern is predicted by the transactional model of driver stress, which suggests that driving performance is impacted by dysregulated socioemotional cognitions (Matthews et al., 1998). Therefore, despite these well-documented adverse effects on driving performance, motorists often experience disruptive internal and interpersonal conditions, and a better understanding of ways to counter emotionally distracted driving is critical.

Yet, a limited understanding exists of efficient approaches motorists can implement to regulate emotions and behavior to maximize safety. How can drivers manage their emotional states to ensure safe driving? Furthermore, given the growth in artificial intelligence, what can automotive user interfaces do to mitigate sub-optimal driving conditions? These questions informed the current literature review. The overarching goal of this work was to identify adaptive approaches to counter the adverse effects of driving under socioemotional distraction with the long-term goal of designing effective strategies for automotive interfaces. We looked for possible self-regulation strategies that effectively manage the dysregulated states of motorists and can potentially be embedded in automotive interfaces. In this paper, we first provide background literature, summarize the key findings from our literature review, and then recognize the current challenges and future implications.

2 Research scope and approach

Emotion regulation includes all attempts to modify emotions people are experiencing, when they experience them, and how they express them (Gross, 1998; Koole, 2009). Emotion regulation is generally implemented to meet an underlying goal (Inzlicht et al., 2021), such as the goal to get less angry because it will otherwise hurt driving performance. Given that the current review focused on identifying strategies that lead to positive outcomes (e.g., better health or good driving performance), we adopted the strategy-based effectiveness framework as quantitatively examined by Aldao et al. (2010). Past meta-analysis in the psychopathology context has empirically examined the effectiveness of different strategies by connecting them to mental health outcomes and categorizing them as effective *versus* ineffective (Aldao et al., 2010). In line with this framework, emotion regulation strategies can be classified as *effective* if they are linked to adaptive outcomes (e.g., better health or performance; Aldao et al., 2010). In contrast, *ineffective* strategies are maladaptive in achieving the desired outcomes (e.g., failing to control anger or improve driving performance).

While there are hundreds of emotion regulation strategies, only a few have thus far been examined in the driving context. Following the effectiveness framework (Aldao et al., 2010), we examined the adaptiveness of existing approaches that motorists commonly adopt to manage their socioemotional responses while operating a motor vehicle. Specifically, we examined existing research to establish which emotion regulation strategies effectively regulated motorists' socioemotional states to improve/maintain optimal driving performance. After reviewing the literature, the following emotion regulation strategies were found to be relevant to socially

TABLE 1 Summary of past work on emotion regulation in a driving context.

Emotion regulation strategy	Evidence summarized	References	Study design	Participant information	Effect size	Relevance for design interfaces
Mindfulness	↓ driving related anger and aggression (Duany and Mouloua, 2022; Kazemeini et al., 2013; Stephens et al., 2018)	Duany and Mouloua (2022)	Correlational	N = 122; 71 females; M = 25.25, SD = 16.32	r = .6	High to Medium[a]
		Kazemeini et al. (2013)	Experimental	N = 10; M = 46.70, SD = 11.97	η2 = .52	
		Stephens et al. (2018)	Correlational	N = 309; M = 46.05, SD = 13.77	r = .34	
Acceptance	↓ driving-related anger experience and behavior (Feng et al., 2018; Kazemeini et al., 2013)	Feng et al. (2018)	Experimental	N = 54 males; M averaged = 41.22, SD = 7.67	η^2 = .228	High to Medium[a]
		Kazemeini et al. (2013)	(reported above)	(reported above)	*	
Relaxation	↓ driving-related anger and aggression (Dmitrenko et al., 2020; Moss et al., 2023) ↑ driving performance (Dmitrenko et al., 2020; Kwak et al., 2015; Moss et al., 2023; Suzuki et al., 2006)	Dmitrenko et al. (2020)	Experimental	N = 40; M = 30.73, SD = 9.11	*	High to Medium[a]
		Kwak et al. (2015)	Experimental	N = 10 males; M = 30.9, SD = 7.7	*	
		Moss et al. (2023)	Experimental	N = 50; 26 females; M = 21.60; SD = 2.16	η^2_P = 0.098	
		Suzuki et al. (2006)	Experimental	N = 10[b]	*	
Instrumental problem-focused coping	↓ driving related anxiety and aggression (Shamoa-Nir, 2023) ↑ driving performance (Hancock et al., 2012)	Shamoa-Nir (2023)	Experimental	N = 237; M = 29, SD = 6.73	η^2 = 0.49	High[a]
		Hancock et al. (2012)	Experimental	N = 72; 50% male[b]	*	
Forgiveness	↓ driving-related anger experience and behavior (Bumgarner et al., 2016; Feng et al., 2018; Lakshitha and Padmakumari, 2023) ↑ driving performance (Feng e tal., 2018; Navon & Taubman-Ben-Ari, 2019	Bumgarner et al. (2016)	Correlational	N = 445; M = 19.80, SD = .08; 69% females	f² = 0.16	Medium to low[a]
		Navon & Taubman-Ben-Ari (2019)	Correlational	N = 287; 158 women; M = 35.84, SD = 12.78	r = .32	
		Lakshitha and Padmakumari (2023)	Correlational	N = 310; M = 25.6	r = −.46	
		Feng et al. (2018)	(reported above)	(reported above)	η^2 = .35 (averaged)	
Reappraisal	↓ driving-related anger and aggression (Corzo et al., 2024; Feng et al., 2018; Popușoi and Holman, 2016) ↑ driving performance (Feng et al., 2018; Harris and Nass, 2011)	Corzo et al. (2024)	Experimental	N = 78; M = 22.2, SD = 7.16	r_{anger} = .32 $r_{hostility}$ = .24	High to Medium[a]
		Feng et al. (2018)	(reported above)	(reported above)	η^2 = .348	
		Popușoi and Holman (2016)	Correlational	N = 314; 158 females; M = 35.64; SD = 12.56	r = .182	
		Harris and Nass (2011)	Experimental	N = 36; 18 females; M = 5.1, SD = 1.84	*	
Hostile confrontive coping	↑ driving-related anger and aggression (Emo et al., 2016; Kontogiannis, 2006) ↓ driving performance (Emo et al., 2016)	Emo et al. (2016)	Experimental	N = 112; 72 females; M = 20.90. SD = 3.43	r_{anger} = .359 $r_{aggression}$ = .642	Low
		Kontogiannis (2006)	Observational	N = 714; 33% females; appx. 25–55[b]	*	
Self-criticism	↑ driving-related anger and aggression (Kontogiannis, 2006)	Kontogiannis (2006)	(reported above)	(reported above)	*	Low
Rumination	↑ driving-related aggression (Suhr and Nesbit, 2013)	Suhr and Nesbit (2013)	Correlational	N = 142; 104 females; M = 19.04, SD = 2.40	f² = .23	Low

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TABLE 1 *(Continued)* Summary of past work on emotion regulation in a driving context.

Emotion regulation strategy	Evidence summarized	References	Study design	Participant information	Effect size	Relevance for design interfaces
Suppression	↑ driving-related anger (Deffenbacher et al., 2000)	Deffenbacher et al. (2000)	Experimental	N = 121; 67 females; M = 19	Average η^2 = .122	Low

[a]Remains to be tested.
[b]Not available.

distracted driving and were associated with potential impact on driving performance, health, or affective states: cognitive reappraisal, instrumental problem-focused coping, task-focused coping, mindfulness, relaxation, forgiveness, hostile emotional coping and confrontation, self-criticism, rumination, and suppression. Below, they have been categorized by the effective (or adaptive) *versus* ineffective (maladaptive) framework (Aldao et al., 2010).

For each emotion regulation strategy, we describe what effects on driving performance were found and whether they were effective vs ineffective. In order to determine which strategies are effective vs ineffective in regulating driving behavior in emotional contexts, their effect on performance and wellbeing was evaluated. Accordingly, we assessed which adaptive approaches can be built as features into automotive user interfaces to modify motorists' states and support safe driving. Finally, we recognize gaps in the current literature and highlight steps moving forward to adopt approaches that can mitigate the negative impacts of social distraction while driving. See Table 1 for study summaries.

3 Effective emotion regulation strategies

Following the effectiveness framework for emotion regulation strategies, the adaptiveness of each strategy was examined. If an emotion regulation strategy was found to maintain or improve performance and/or reduce stress or negative emotions, it was deemed *effective*. Based on these criteria, the following families of strategies were categorized as effective.

3.1 Mindfulness

Mindfulness is an effective strategy focused on living in the moment when dealing with driving-related stress. It is found to have a calming effect that can reduce anger and make motorists less likely to express aggressive driving behavior (Deffenbacher et al., 2000; Deffenbacher et al., 2003; Deffenbacher et al., 2016; Galovski et al., 2003; Kazemeini et al., 2013). Trait-level mindfulness is generally linked to less anger and aggressive driving (Stephens et al., 2018). Those who are more mindful at trait levels are less aggressive drivers (Duany and Mouloua, 2022). Moreover, mindfulness-based cognitive therapy was found to reduce driving anger and aggression relative to a control group that received typical cognitive-behavioral therapy (Kazemeini et al., 2013). The evidence suggests that tailored mindfulness interventions would help reduce driving stress and aggression.

However, several kinds of mindfulness interventions exist (Lohani et al., 2020), and certain specific elements of it can be adapted to driving context. In terms of adapting mindfulness to vehicular interfaces, mindfulness-based interventions could be introduced to help regulate emotions, but this work is in its infancy. Much needs to be empirically determined regarding components of mindfulness interventions that can be successfully employed while operating a motor vehicle safely. For instance, past research has adopted acceptance to regulate emotions, which includes nonjudgemental processing of one's experiences (Lohani et al., 2018). In future work, forms of acceptance as an emotion regulation strategy can be taught to drivers to help them accept negative cognitions before acting on them (Kazemeini et al., 2013).

3.2 Relaxation

Relaxation is a generic term that includes all efforts to self-soothe, such as calming one's body (e.g., breath) or manipulating the environment (e.g., aroma). A motorist can initiate relaxation internally, such as efforts to regulate one's breathing. In fact, a recent study (Balters et al., 2019) tested an intervention to reduce the breathing rate, which can relax the motorist while driving in real-time. At the same time, other forms of relaxation can be built within the environment of automotive interfaces. A good example is from recent literature that supports the use of aroma (Demitrenko et al., 2020) to regulate negative states link anger while operating vehicles (Dmitrenko et al., 2018). These findings suggest that relaxation techniques initiated by automotive interfaces are a promising way to manage intense emotional states that may arise while driving.

3.3 Instrumental problem-focused coping

Instrumental problem-focused coping involves finding an alternative solution to resolve the issue, such as acknowledging error when at fault. It has been shown to effectively resolve situations intended to engage the other driver without aggression (e.g., short honks and light flashing) without escalating them (Shamoa-Nir, 2023). A particular form of problem-solving strategy is *task-focused coping*, which focuses on engaging with the driving task and helps motorists not get distracted. While problem-focused coping is a more generic umbrella term, task-focused coping addresses the problem of distraction that may worsen performance. Past research has found that being task-focused helps motorists perform safe driving (Hancock et al., 2012; Shamoa-Nir, 2023). For instance, task-focused drivers drove more carefully when considering speed limits (Hancock

et al., 2012). Given the wide range of problems that may arise while driving, this is a challenging strategy to build in automotive interfaces. However, more manageable and frequently occurring problems could be examined and built into future vehicular systems.

3.4 Forgiveness

Forgiveness is pardoning someone and overcoming resentment towards them. It was associated with more patience and careful driving (Feng et al., 2018; Navon and Taubman-Ben-Ari, 2019). Previous studies have found a significant negative relationship between trait forgiveness and driving anger and aggressive driving behaviors (Bumgarner et al., 2016; Moore and Dahlen, 2008). A recent study (Lakshita and Padmakumari, 2023) found a negative correlation between forgiveness and anger experienced while driving. Individuals who could forgive during negative situations displayed less verbal aggression and tended not to use the vehicle to express anger toward other drivers (Lakshita and Padmakumari, 2023). Even though Bumgarner et al. (2016) found a negative association between forgiveness at trait levels and driving anger, they note that they did not find a direct relationship between forgiveness and reckless driving behavior. However, it still suggests that individuals who tend to forgive others (at the trait level) are likely to have less driving anger, even in situations that would provoke negative emotions (Bumgarner et al., 2016). Overall, current literature suggests that individuals who are more likely to forgive are likely to experience less driving anger. However, forgiveness depends on the situation at hand that needs a resolution, so it may not always be feasible. Also, it is a difficult strategy to embed in an automotive system and may even come at the cost of annoying the motorist.

3.5 Cognitive reappraisal

Cognitive reappraisal includes a cognitive reinterpretation of the driving situation (Gross, 1998). It mitigated intense situations by generating alternative explanations for others' (aggressive) behaviors, leading to safer driving behaviors (careful driving, better driving scores, optimal speed, and less road rage; Harris and Nass, 2011; Roberton et al., 2012; Takaku, 2006). Indeed, cognitive interventions designed to adopt cognitive reappraisal effectively reduced anger and aggression (Feng et al., 2018; Kazemeini et al., 2013). Cognitive reappraisal has also been adopted in automotive contexts with some success. When regulatory instructions were played in the vehicle while motorists drove, this intervention helped reduce anger, hostility, and frustration levels (Corzo et al., 2024). This suggests that cognitive reappraisal can be adopted in automotive interfaces.

However, it is noteworthy that cognitive reappraisal is considered a cognitively demanding strategy (Sheppes, 2020), and it may not necessarily be feasible in low cognitive resources, high-stress, and time-sensitive situations. Further work is needed to test this specifically in driving contexts. Past research has found that cognitive intervention efficiently reduced total scores of driving anger and physical aggression expression and promoted positive cognitive strategies to improve negative

emotions better than the control group (Feng et al., 2018). Cognitive intervention groups experienced greater improvements than the forgiveness intervention regarding obstruction in traffic and using positive cognitive strategies (Feng et al., 2018), suggesting the effectiveness of training cognitive reappraisal via cognitive interventions.

4 Ineffective emotion regulation strategies

In line with the effectiveness framework (Aldao et al., 2010), strategies were investigated for being maladaptive. If an emotion regulation strategy was found to hurt performance and/or worsen stress or emotional state, it was deemed *ineffective*. Based on our examination, the following families of strategies were categorized as ineffective.

4.1 Hostile and confrontive emotional coping

Hostile and confrontive emotional coping includes negative, reactive, and often aggressive behaviors toward other motorists during frustrating driving scenarios (Matthews, 2002), which can frequently lead to angry and risky driving performance (Emo et al., 2004). It was associated with higher anger and maladaptive behaviors (Lennon and Watson, 2012; Emo et al., 2004; Emo et al., 2016; Shamoa-Nir, 2023) and predicted unsafe driving behaviors such as tailgating, frequent passing, and shorter delays before passing other vehicles, which reduced safety (Emo et al., 2016). Another study found that men with above-average anger engaged in more physical and verbal aggression with other drivers than controls. For example, they reported more anger and intentional harm toward other motorists who were not driving fast enough (Deffenbacher et al., 2000), highlighting its ineffectiveness.

4.2 Self-criticism and rumination

Self-criticism (tendency to negatively evaluate oneself) resulting in feelings of worthlessness, guilt, and failure) increased worrying in traffic environments and lowered self-esteem, leading to counterproductive behaviors such as risky driving behavior (Matthews et al., 1998). Kontogiannis (2006) found a positive association between aggression and self-criticism. They also suggested that aggressive drivers may be aware of their tendency to display aggressive behavior, but they are unable to take actions that could help them prevent their behaviors (Kontogiannis, 2006). Self-criticism is a sign of dysregulation and is associated with ruminative thoughts and negative emotions (Kalokerinos et al., 2017), which may lead to ineffective driving performance, but this remains to be tested in the driving context. On a related note, rumination (i.e., engaging repetitive thought processes) is also considered ineffective based on some trait-level assessments. Motorists who are higher ruminators have higher anger driving scores and a history of aggressive driving (Suhr and Nesbit, 2013).

4.3 Suppression

Suppression (inhibiting ongoing emotional response) was also ineffective and associated with aggressive driving (Popuşoi and Holman, 2016). Relative to controls, drivers with trait anger issues were observed to be angry and anxious while driving (Deffenbacher et al., 2000). Perhaps anger suppression may displace those feelings to unrelated situations like driving in traffic (Deffenbacher et al., 2000). It is possible that those who frequently adopt anger suppression may unknowingly use aggressive driving to release pent-up emotions.

5 Discussion and implication

While much work has focused on maintaining optimal levels of attention, a limited understanding exists of effective ways to regulate one's behavior during emotionally distracted driving. Following the approach of an effectiveness framework (Aldao et al., 2010), we reviewed existing work exploring emotion regulation strategies motorists may adapt to emotional challenges experienced in the driving context. This review found several promising approaches to counter dysregulated socioemotional states, such as by engaging in instrumental problem-solving, task-focused coping, mindfulness, relaxation, forgiveness, and cognitive reappraisal to maintain safer driving behaviors and performance effectively. We highlight three implications of these findings.

First, it is important to communicate these empirical findings to users (i.e., on-road motorists). At the same time, it is challenging to implement the known effective approaches to regulating driving behavior in real-world conditions. Thus, motorists need training to implement effective solutions in distracting or stressful environments. Past work on training cognitive behavioral therapy for anger treatment (Galovski et al., 2003; Galovski et al., 2006; Kazemeini et al., 2013) and music therapy (Wiesenthal et al., 2003) had reasonable success in reducing aggressive driving. Evidence-based training platforms need to be developed to help motorists successfully implement effective emotion regulation strategies.

Second, automotive interfaces can be of tremendous support in helping motorists generate relevant (and personalized) strategies to manage emotional dysregulation (Braun et al., 2019). To design such supportive automotive interfaces (also called future in-vehicle assistants), one approach is that the system senses (i.e., record) and assesses (i.e., determine) intense emotional states (e.g., anger) and suggests possible effective ways to regulate (or augment) the drivers' emotional state (Lohani et al., 2020; Stokes et al., 2023; Oehl et al., 2019). However, a major challenge is having reliable systems that can sense emotions in real-world settings (Lohani et al., 2019; Lohani et al., 2024). At the same time, recent work has made progress in utilizing reliable behavioral and psychophysiological measures to assess cognitive states when driving on real roads (e.g., Lohani et al., 2020; Lohani et al., 2021). With an improved understanding of effective regulation and success in detecting dysregulated behavioral and physiological responses (Galovski et al., 2003; Yan et al., 2018), better automated technology could be developed (Wan et al., 2017) to trigger warning signs and intervene and promote driving safety (Lohani et al., 2019; Kim et al., 2024).

Finally, it is also important to recognize that motorists may not always be aware or able to de-escalate the situation themselves, which would be a critical opportunity for the automotive interface to intervene and mitigate the problem. Future work should also utilize automation as an in-vehicle intervention to regulate driver states, such as anger (Li et al., 2021; Wu et al., 2022). Interventions can be developed and implemented into intelligent driving systems to train motorists with the skills needed for effective regulation under stressful driving conditions (Hernandez et al., 2014). For instance, personalized speech-based interventions for aggressive drivers (Feng et al., 2018; Harris and Nass, 2011) have shown promising results and, with further work, can be built for everyday consumers. A related challenge is the high-risk and time-sensitive nature of driving on real roads. Having enough time to consult with the motorist may not always be possible (Yang et al., 2023; Garikapati et al., 2024). Thus, much work is needed to find reliable ways of detecting and regulating emotional states under high-risk scenarios via automotive interfaces.

6 Future directions and current challenges

Considering the lessons learned from the current literature review, future automotive interfaces could be embedded with options to initiate and support effective emotion regulation. The emotion regulation literature while operating vehicles thus far has several suggestions for designing interfaces to modify the vehicle environment, which are quite feasible. The interface could be designed to provide external and internal regulation settings that are preferred by the motorist. Such settings could be designed to offer options to regulate the vehicle's environment based on presets set by the motorist. For instance, when the motorist feels frustrated, their preset favorite aroma could be introduced to mitigate the negativity in the environment (Dmitrenko et al., 2020). Compared to external and environmental management, internal regulation, as needed to be facilitated by the motorists themselves, is harder to do. However, the automotive interfaces could still initiate the process. For example, an interface could utilize self-soothing emotion regulation strategies to manage stress (as tested in past work; Balters et al., 2019; Hernandez et al., 2014). If the interface was already preprogrammed by the motorist even to initiate task-focused coping (e.g., Shamoa-Nir, 2023; Zhao et al., 2024), it could provide what a motorist may need to break the cycle of negativity and rather choose an efficient emotion regulation approach (self-selected by them) to manage their intense emotions. Importantly, motorists should be given the autonomy to be able to control the automotive technology to their liking (Lohani et al., 2020), without which even the best-designed interfaces will remain under-utilized. With rigorous design and testing, automotive interfaces can help motorists untangle intense emotional states, thereby creating safe driving conditions.

At the same time, some limitations need consideration. First, user-friendly design challenges are anticipated as the same set of strategies do not work for all and across situations (Lohani et al., 2022). Thus, a person-centered approach (e.g., Gu et al., 2024) that accounts for individual preferences and dispositions would be more compatible with effectively managing socioemotionally distracted

driving. Notably, many other emotion regulation strategies are utilized by people in everyday life (Lohani et al., 2022). However, very few relevant ways to regulate emotions in driving contexts have been studied in the literature thus far, which needs further consideration and exploration. Individual difference factors (such as driving style, stress susceptibility, cultural, and demographic characteristics) of a motorist play a key role in the effectiveness of adaptive regulatory approaches (Ellison-Potter et al., 2001; Shamoa-Nir and Koslowsky, 2010; Suhr and Nesbit, 2013; Tillmann and Hobbs, 1949; Wickens and Wiesenthal, 2005). However, only a few studies exist for a handful of strategies, but replicable studies with adequate power are required in order to gain an individual differences perspective. Given the limited number of studies on emotion regulation in a driving context, enough literature does not exist to examine such individual differences, and this was not the focus of the current literature. This will enable a person-centered design approach and identify what kind of regulation attempts work for whom and when.

Second, due to frequent interruptions by the automotive interface, motorists may often get frustrated or annoyed by the automotive interface trying to change their experiences. Furthermore, in-vehicle automation will need to be successful in gaining acceptance and calibrated trust from its users for optimal success (Winterberger et al., 2016; Lohani et al., 2020; Lohani et al., 2016a; Lohani et al., 2016b; Lohani et al., 2017). Third, some emotion regulation strategies had mixed results and could be resource-demanding. For instance, distraction involves redirecting attention away from negativity (e.g., aggression and stress) and focusing on something else, generally more positive, such as music (Wiesenthal et al., 2003). Using music as a distraction could help lower intense emotions, but it can also add to motorists' distracted states, further compromising driving performance. Listening to music is a good example of distraction while driving. Motorists, driving while listening to music, were less aggressive, precisely when there was low time pressure (Weisenthal et al., 2003). Distraction, and even reappraisal, may be helpful, but not necessarily under all conditions. For instance, high-traffic conditions may require more cognitive resources, which could compromise driving performance. Costs (cognitive resources) that come with employing emotion regulation strategies (Sheppes, 2020) need consideration to ensure safe driving conditions. Furthermore, some individuals habitually utilize some emotion regulation strategies, which can make them less effortful in implementing them. This emphasizes the importance of designing a person-centered approach to augmenting emotional states.

In conclusion, this review features promising emotion regulation approaches that can be designed and tested in automotive interfaces to maintain motorists' optimal affective state, thereby reducing distraction and facilitating driving performance. Building support interfaces for regulating drivers' affective states can benefit fast-growing intelligent driving systems and remarkably improve traffic safety.

Author contributions

ML: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing–original draft, Writing–review and editing. AD: Data curation, Formal Analysis, Investigation, Methodology, Project administration, Validation, Writing–original draft, Writing–review and editing. AA: Data curation, Formal Analysis, Investigation, Methodology, Project administration, Writing–review and editing.

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