The impacts of in-car audio systems on driving performance: a systematic literature review

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Abstract

Driving is an intricate task that demands complete attention and concentration from the driver. Although numerous papers investigated the impacts of in-car audio systems, no synthesizing systematic literature review (LR) was found. This study aims to explore those effects and answers the research question, - "What effects do automobile audio systems have on a driver's focus and concentration?" Therefore, I conducted a systematic LR comparing and contrasting relevant papers. As a result, the study concludes that in-car music has an ambiguous impact on vehicular performance. The more intense or forceful the music is, the greater the degree of distraction it produces, although the absence of music causes a low cognitive load on the driver, which might be dangerous in a monotonous environment. Additionally, the study recognizes a tactile audio control interface as potentially destructive. Other options for music recommendations and controls are proposed; however, their impacts are not investigated comprehensively. As the research was conducted as an educational project, a significant risk of bias exists. Moreover, no professionals in the sphere of driving performance contributed to this paper, and the number of observed sources is narrow. Despite the limitations of this study, it provides valuable insights into the impact of in-car audio systems on driver focus and concentration, highlighting the potential risks associated with intense or forceful music and the need for further investigation into alternative music recommendations and controls.

Keywords: Driving performance, Attention, Audio, Music, Literature review, Car music controls

1 Introduction

Driving is a challenging task that necessitates a driver's undivided concentration. However, drivers often perform a range of activities while driving, including regulating and enjoying music, singing along to it, and pounding out drum kicks [1]. The influence of music on driving behavior has been a topic of interest in recent years, as music can potentially affect the driver's mood and attention.

Despite this interest, a comprehensive synthesis of the outcomes of studies in this area has been lacking. Understanding the impact of in-car audio on driver distraction and the role of music control interfaces in this context is important. Several studies investigated these topics, but a systematic literature review synthesizing the findings of these studies has not been found. Such a review is crucial to provide a complete comprehension of the connection between music and driving behavior and to identify potential interventions that could mitigate the negative effects of music on driving.

Therefore, the objective of this paper is to conduct a systematic literature review of the existing research on the impact of music on driving behavior with a particular focus on driver distraction and music control interfaces. Specifically, I aim to answer the research question (RQ), "What effects do automobile audio systems have on a driver's focus and concentration?" By synthesizing the outcomes of the existing studies, this review aims to provide insights into the effects of music on driving behavior and to identify potential avenues for future research and interventions.

2 Methodology

2.1 First-layer limitations: basic filters

ScienceDirect database was selected as the primary database for this study since it is among the most user-friendly. Moreover, only finished English-language articles published in scientific journals were considered. To recapitulate, Table 1 represents basic limitations.

TABLE 1
Basic Search Limitations

Limitation type	
Publication stage	Final
Document type	Research/Review article
Source file	Journal
Database	ScienceDirect
Language	English

TABLE 2
Searching Procedure Steps

search step	TAK	full-text search	N of results
1		(accuracy OR precision OR attentiveness) AND (driver OR driving OR drive) AND (music OR "audio system")	~8700
2	(accuracy OR precision OR attentiveness) AND (driver OR driving OR drive) AND (music OR "audio system)		9
3	(driver OR driving OR drive) AND music	(accuracy OR precision OR attentiveness) AND (car OR vehicle OR auto)	47

2.2 Second-layer limitations: searching procedure

The second stage of data collection is searching ScienceDirect.Each step request is registered in Table 2, whose rows represent search steps described in the following paragraphs.

My RQ contains three main terms: "focus and concentration," "driver," and "audio system." Therefore, in my request, I decided to combine them into three groups separated by the "AND" operator. Each group contained the word itself and some of its most common synonyms. The search outcome contained approximately 8700 hits.

Due to the unmanageable number of received articles, I decided to use the advanced search function and placed my previous request into the field "Title, abstract, and keywords" (TAK). Thus, I received only nine articles, which is unaffordably few.

After applying the pilot search, I established that moving the "(accuracy OR precision OR attentiveness)" term from TAK to the full-text search field is appropriate. In my opinion, this is because authors usually do not specifically mention these words but use their synonyms or antonyms, such as "focus," "concentration," or "distraction." Moreover, during the pilot search, I established that some of the articles I found irrelevantly relate to the topic of car driving. That is why the term "auto" with its synonyms was added to the full-text search field. In such a way, I received 47 articles.

2.3 Third-layer limitations: TAK screening and checking the source credibility

The next stage I applied is citation screening and checking source credibility. Based on the title and abstract contents, more than 20 articles were excluded because of thematic inconsistencies with my RQ. In such a way, only 24 articles were analysed fully.

2.4 Full-text screening and sources categorizing

Then, a full-text screening of each article was performed. As a primary source manager, Mendeley was chosen because it was integrated with ScienceDirect and user-friendly.

At this stage, the final decision on the article's inclusion was made. I found several articles that did not reply to my RQ, which is why they were excluded. Thus, 17 research projects were assumed for profound analysis.

Moreover, during the full-screening, in each paper I aimed to find the answer to the question, "In which way does the audio system affect the driving behavior?" Then, according to the answer, each source was distributed into one of several groups.

Next, a reading log with the most significant information — such as methodology, results, credibility, and relevance — was compiled in table form. It helped me navigate through sources faster and more easily.

Finally, to achieve the most convenient structure for reporting the findings, the arrow diagramming method was applied. The vertices of the obtained graph represented groups of articles, single articles, and main conclusions made from them. Arrows of different types and colors were used to indicate logical connections between vertices. This diagram is only mentioned for reporting purposes but not presented in this paper due to complexity of its visualization.

2.5 Summary of methodology section

The methodology, thus, entails three stages (Fig. 1). More precise conditions of search in search attempts 1-3 can be observed from Tables 1 and 2.

3 Analysis

The study analyzed selected articles and established two main points of how vehicle audio systems influence driving performance. The first point is "Music and audio impact,"

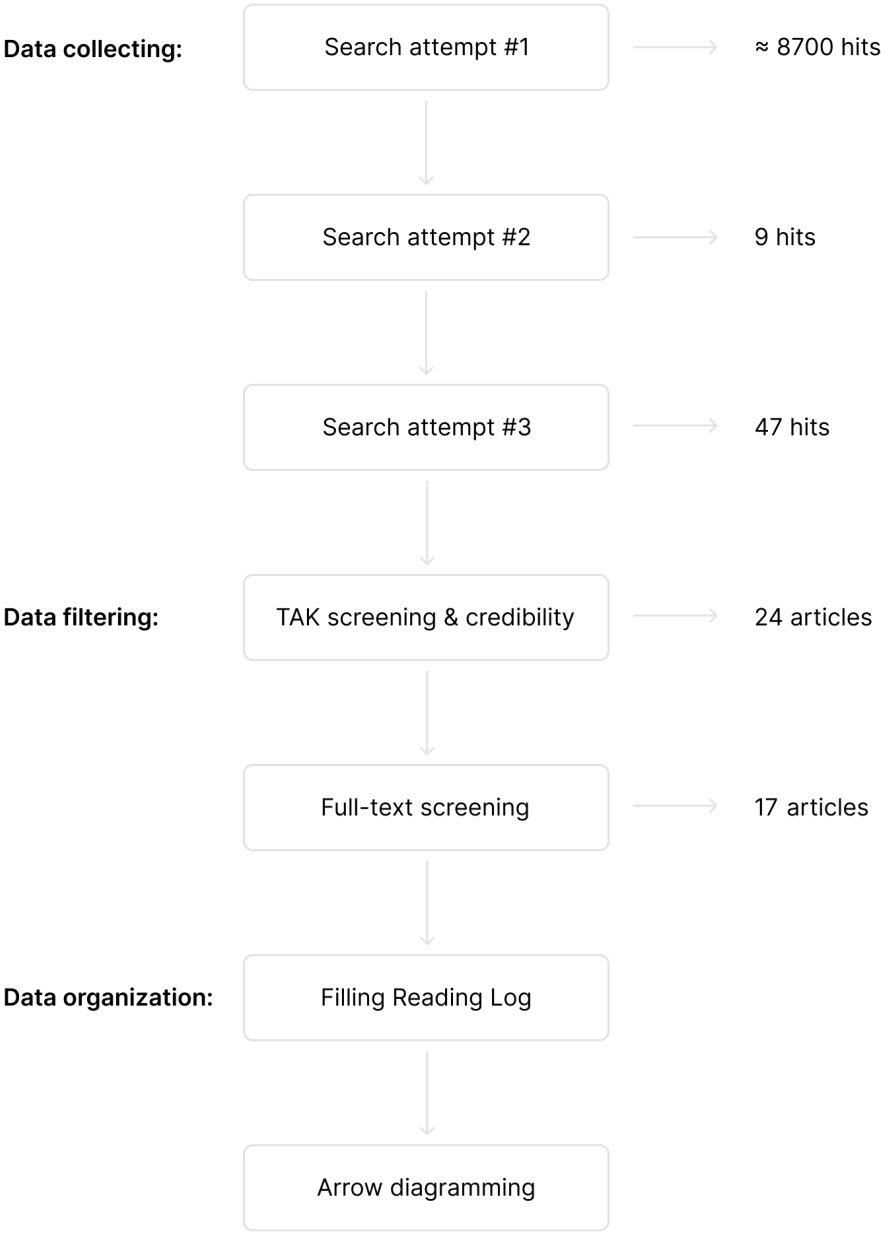

Fig. 1. The abstraction of the study methodology

where I scrutinize the outcomes of different audio types and their aspects. The second point investigates the influence of the music player control interface on the driver's attention and focus.

3.1 Music and audio impact

This subsection looks at how drivers' performance and accuracy are affected by sound. It is split into three points: "Music and cognitive load," "Effects of different music parameters," and "Useful audio".

3.1.1 Music and cognitive load

The first point I would like to mention is the cognitive influence of music. Singing, pounding out drum kicks, synchronizing vehicle control movements such as twisting the rudder and gear shifting with music rhythm, and even dancing in their seats are common accompaniments to music that drivers listen to [1]. These actions increase the driver's cognitive load, the consequences of which are ambiguous. On the one hand, this is an essential reason for distraction and loosing control on the road. On the other hand, in a monotonous environment, the extra intellectual load can be an effective countermeasure.

Most commonly, listening to music leads to poor driving performance[1]–[4]. For instance, Sheykhfard and Haghighi [5] aimed to find the most significant factors that affect driving accuracy during pedestrian liaisons with drivers. The authors show that speed and distance have the most significant impact, but listening to music increases the probability of pedestrian collisions. Additionally, Zimasa *et al.* [6] established that driving performance directly depends on sentiment: the better the mood the driver has, the better his accuracy is. In the study experiments, the researchers used music as one of the factors to control the subject's mood, and the "no music" option showed the best performance. In such a way, many authors agree that additional cognitive load in the form of music is a distraction factor.

Meanwhile, some cases when listening to music is essential exist. For example, Unal *et al.* [7] conducted a series of simulator experiments with low traffic, where they established that extremely low cognitive load during monotonous movement makes drivers lose attention and precision. In this scenario, the music returns cognitive load to a normal state and helps the driver focus on the road. The same position is expressed by [8]. Summing up, during long periods of repetitive traffic, listening to music creates the necessary level of cognitive

stress to prevent dozing off.

In conclusion, music either diverts attention or helps it return in certain situations, with the former being more prevalent.

3.1.2 Effects of different music parameters

Several studies investigate the effects of various musical parameters on vehicle driving performance.

To investigate how music tempo affects drivers' performance and heart rates (HR), Brodsky [9] conducted two experiments in 2001. Each experimental group consisted of either music-oriented or non-music-oriented students. Independently of drivers' backgrounds, the author found that music tempo had no significant effect on HR or HR variability. The lack of effect on physiological arousal suggests that any effects of music tempo on driving performance were likely due to distraction rather than increased arousal. Additionally, the study did not find a significant relationship between HR and driving accuracy. Similarly to [9], Miao *et al.* [4] conducted a study for novice drivers, where the researchers also established that high-tempo music significantly increases mental load and decreases hazard perception ability. Summing up, the effects of music on driving performance are complex and likely influenced by a variety of factors beyond simple physiological arousal, although it was found that faster music distracts more, especially for novices.

Meanwhile, the genre of music playing in the car also affects driving performance [2]. Babic *et al.* aimed to examine how music genres can affect driving behavior. Similarly to [9], the authors used a computer-based driving simulator station with an eye-tracking system. For their experiment, the researchers chose six music genres, including the "no music" option. As a result, the authors claim that listening to Balkan folk and metal leads to the highest driving speed and the fewest number of noticed road signs. Thus, the authors assent with other studies (including [9], [10]) and confirm that high music tempo leads to inappropriate driving behavior.

Apparently, the presence or absence of lyrics in the songs does not affect the driver's affective arousal [3]. The researchers checked several hypotheses about the influence of different music parameters on driving performance. Study participants underwent a driving simulator test, during which physiological arousal indicators such as heart rate, mean arterial

pressure, and changes in electrodermal activity were measured. In contradiction to [2], the results show no strong dependency between music type and driving behavior. However, soft music without lyrics causes the best mental state for driving.

Summing up, researchers on this topic obtained more or less similar conclusions. They converge on the idea that drivers should reduce listening to music with a high pace (such as metal or Balkan folk) and use slower genres instead. Overall, mid-paced and slow music are both performed as music that should be played in the car; however, using the "no music" option is still arguable and requires more research to be conducted. The influence of lyrics was not found to be significant; however, music without lyrics showed the best driving performance.

3.1.3 Useful audio

This section provides the reader with two unusual applications of an in-car audio system - an alternative background that is semantically music but without most of its negative aspects and an audio sonification tool that can be applied in autonomous cars that still should be controlled by humans.

As rejecting music is hard for most drivers, Brodsky and Kizner [10] suggest alternative music backgrounds. Such backgrounds combine the most beneficial features of typical music and create the ideal environment for driving. The authors conducted several experiments where they established the effects of alternative backgrounds, compared them to drivers' favorite music, and estimated the period of addiction. As a result, they concluded that their experiments were successful, and their musical backgrounds should be introduced to novices in driving schools and more experienced drivers. They recommend using these backgrounds not permanently but in critical moments, when the driver is tired or in the wee hours. Thus, a music alternative without most of its distraction factors exists, but no proof or statistics regarding its use in real life was found.

Another beneficial usage of audio in autonomous vehicles (AV) was suggested. Chen and Chen [11] developed and tested a sonification system for AV to keep drivers prepared to take control in an emergency. The system is designed to have several levels of feedback that depend on the reliability of the road situation. The system decreases the music semitone when the level of hazard increases and returns it when the danger is over. This system may be

helpful for AVs that still rely on human drivers in emergent situations. The authors discuss several limitations of such a system and introduce its second version [12] with additional displays indicating the reliability level. However, both systems were introduced recently (2021 and 2023) and should be tested more precisely, as the authors indicate.

3.2 Music control interface

Observing distraction factors of music, researchers found that many drivers pay much attention to the music control interface. As drivers are often responsible to regulate the audio stream, some studies below focused on examining and resolving this effect.

The influence of two main music player types on the driver's focus was estimated [13]. The researchers compared different built-in music layout interfaces and compared their efficiencies. When testing drivers, the researchers gave them a variety of activities involving simultaneous driving and music choices. As a result, they conclude that drivers delay the look at the player unaffordably long, which usually leads to loosing control and lateral displacements. The influence of distraction on portable music players was also evaluated [14]. Using a similar study methodology as in [13], the authors conclude that the task of music search is problematic for drivers and requires extra attention. Thus, any traditional car music control interface causes extra distraction for the driver.

Jacubec and Chmulik [15] suggest using a music genre recognition system to release the driver's attention from the music player. Literally, the authors propose a music app that recommends the user music with the genre they prefer. For this purpose, the researchers developed a system that automatically classifies songs of various music genres and returns to the user the music they like. Thus, drivers can pay more attention to the road.

Another idea to reduce the number of sights on a music player is to make it voice-controlled. Garay-Vega *et al.* [16] aimed to evaluate the driving performance while using sensor and voice-controlled music players. Using a simulator, the authors proved that the voice-control music interface causes significantly less driver distraction. Moreover, the researchers showed almost no difference between single-turn and multiple-turn control interfaces, so even the simplest version of a voice-controlled player can reduce the number of distractions for the driver. Thus, a voice-recognition music control interface performed as a better option than a traditional one.

3.3 Limitations

In this subsection, I would like to report two biases that occur in my paper. As this study is an educational project, for each bias type, I provide its definition and then an explanation of how this bias is found in my work.

3.3.1 Selection bias

Selection bias is an irrelevant or incomplete selection of sources to observe. The absence of selection bias means selecting all possible sources, including grey literature and even sources in various languages.

Firstly, as this paper is an educational project, it cannot cover all possible sources for such a broad question. I searched for studies only in ScienceDirect, which is not the only portal of scientific works; IEEE, Google Scholar, and other databases were omitted. Moreover, I did not perform search among books. Thus, not all papers that could contain the answer to my RQ were collected.

Secondly, the search procedure in ScienceDirect was conducted less systematic. As can be seen in the methodology section, I used only a systematic search, but many papers could be lost because authors could use terminology other than what was included in the search string. Although I tried to use synonyms for each search keyword, most probably I did not cover some other valuable articles. Moreover, during full-text screening, I noticed some additional articles that other authors mentioned in their papers, but I skipped them to avoid the snowballing technique. So, the search procedure might contain essential mistakes.

Thirdly, full-text screening was applied selectively. Sometimes, certain parts of the paper were prioritized. This fact also adds some irrelevance into my research.

To conclude, this paper does not provide appropriate number of well-observed sources on the mentioned topic.

3.3.2 Reporting bias

Additionally, other biases and limitations are found in the observed literature. First, the majority of the observed studies was conducted on computer simulators. Such conditions of driving reduce the driver's sensory spectrum. Second, most part of those driving tests were conducted on relatively small respondent groups. This also reduces the objectivity of

investigated studies. Thus, the limitations of the observed literature are also present.

4 Discussion

The current review provides a summary of a significant chunk of the already-available literature concerning the impact of in-car music systems on driving. In this section, I will summarize the main conclusions of those studies (subsection 4.1), analyze the outcomes of some limitations that affected the results of the current study (subsection 4.2), and compare my study with existing literature (subsection 4.3).

4.1 Summary of results

As I mentioned in the analysis section, all reviewed articles' contents can be split into two indents dedicated to the impacts of audio and tactile interfaces on the driver's attention. Then the results of the current study are compared to another Literature Review (LR) on the same topic.

4.1.1 Music and audio impacts

After summing up the mentioned literature outcomes, I came to several conclusions regarding the effects of ancillary audio on the driver.

To start with, overall music influence is ambiguous. Situations where music can increase or decrease driving performance exist. First, listening to any type of audio causes an additional cognitive load, which can be either beneficial in the case of a continuous monotonous trip or detrimental while driving in an environment with plenty of traffic [1], [6]–[8]. Second, the faster the music's tempo, the more destructive it is. The majority of the tests conducted by researchers showed that aggressive music caused increased heart rate, blood pressure, and anxiety, which can lead to distracted and aggressive driving behaviors [2]–[4], [9], [10]. Although some study conducted by extremely credible author states that high-paced music seems to be a direct distraction factor rather than the reason for increased arousal [9]. To sum up, the driver should carefully choose the music audition time and its type.

After reading negative reviews about listening to in-car music, the question of music cancellation or its replacement arises, although such an approach seems questionable. The

first possible option that the driver has is to to abandon listening to music completely. A minimal number of studies [2], [4] compared this option to other types of music, and none of them stated that stopping listening to music is reasonable. Moreover, [4] provides statistics showing the "no music" option implies a higher hazard perception score than slow-paced music. The second option was provided by Brodsky [10], who suggests replacing traditional music with alternative backgrounds. The tests conducted by the author showed increased performance; however, the lack of statistics pertaining to studying alternative background effects is obvious. To finalize, music has become a crucial part of modern driving, and no option to cancel or replace it seems reasonable or reliable enough.

4.1.2 The influence of music control interface

The current study observed that the necessity of interacting with the audio system control interface might distract the driver as much as the audio itself. The existing literature shows that tactile player interfaces occupy an enormous amount of the driver's attention [13], [14]. To reduce the driver's interaction time with the player, the use of music genre recognition and voice control systems was proposed [15], [16]. Both systems performed well in tests and are currently accessible in real life; however, no statistics on using such technologies in reality are mentioned. To sum up, although tactile interfaces used to be a significant problem, the solution of using music genre recognition and voice control systems has been found to reduce driver distraction.

4.2 Discussion of limitations

In this subsection, I discuss some of the limitations of the current review, including issues related to the selection and analysis of the articles, and potential sources of bias that may have affected the conclusions.

4.2.1 Selection bias

Selection bias is a crucial limitation that needs to be acknowledged when interpreting the findings of this review. Despite my efforts to minimize bias, several limitations are inherent in my search process that might affect the generalizability of my results.

First, my paper covers only English-language studies published in ScienceDirect. Obviously, it is not the only source of scientific literature, and it might be that some relevant

studies were missed. This causes a smaller number of observed sources and less objective outcomes in the current paper, which should be fixed in future research.

Second, my searching methodology has some gaps. As I mentioned in the methodology section, only a systematic search was conducted. Although systematic search is an appropriate way of collecting sources, using it as the only manual might be irrelevant. Thus, many works might be skipped because of a limited set of search terms.

To sum up, many works might be omitted because of strong limitations on the search scope and an incomplete search procedure.

4.2.2 Limitations of the investigated literature

The limitations of the investigated literature have a significant impact on the results and conclusions of this study.

The first limitation is the prevalence of research conducted on computer simulators. Driving conditions on a simulator may not reflect real-world driving scenarios accurately, which could limit the generalizability of the findings. Therefore, the results obtained from these studies may not be applicable in actual driving situations.

Furthermore, the majority of the observed studies in this field was conducted on relatively small respondent groups, which may lead to less reliable results. The small sample size reduces the objectivity of the study and may not provide a comprehensive view of the research question. However, despite the small respondent groups in many of the observed studies, the consistency of the conclusions across multiple studies suggests that this limitation may not significantly affect the validity of the results. Therefore, the generalization of the findings may be limited.

Overall, it is essential to consider the limitations of the observed literature when interpreting the results of this study. Future research must be conducted on actual driving scenarios and should include larger and diverse respondent groups to increase the generalizability and reliability of the research findings.

4.2.3 Necessity of involving professional researchers in future studies

As a computer science undergraduate, my knowledge in the field of driving psychology is minimal. This study was conducted as an educational project, and the methodology used has limitations that might have affected the results. Therefore, more rigorous research

conducted by professional researchers in the field is required to confirm and build upon the findings of this study. Future research should involve more expert opinions and professionals in the field of driving psychology to provide more accurate and reliable results that can be used in practice.

Nevertheless, despite study limitations, this paper might still be useful for researchers and unprepared readers. The study provides a quantitative picture of possible effects of in-car audio systems with synthesis of the most searchable papers. Moreover, the study remarks the most common limitations of those papers, which can be helpful for future investigators. Meanwhile, as the study is conducted by a person who is not involved in the sphere of driving performance research, it uses a relatively simple vocabulary without unfamiliar to possible reader definitions and notions. That is the reason why this paper can be advised for ordinary drivers without doubt about its misunderstanding.

4.3 The comparison with similar studies

Although the studies answering my RQ are numerous, only one of them performs a systematic literature review [17]. This study covers only a subtopic of my research gap, but this subtopic occupies the most part of my paper. While our studies explore relatively similar research gaps and questions, they have different methodologies and outcomes.

4.3.1 Methodology differences

First, [17] and the current study differ in selection procedure. My study uses ScienceDirect as the only source of papers, while Millet *et al.* [17] conducted the systematic search procedure among several databases. Moreover, [17] used stricter selection criteria, which might imply to more relevant sample of literature. However, despite the different selection methods, both studies received approximately equal number of investigated papers (16 in my case and 12 in the Millet *et al.*).

Second, as the main targets of our studies diverge, different data processing procedures were applied. The current study aims to make inferences from comparisons of various sources, which implies to the lack of statistical methods used and less objective conclusions. In contradiction, [17] used meta-analysis to obtain as veritable and impartial results as possible, while I performed simpler qualitative evaluation.

4.3.2 The comparison of outcomes

Although Millet *et al.* [17] might indeed have reached an authentic conclusion on each music parameter mentioned by other researchers, the synthesis of them was not performed. The study does not extend beyond raw numbers and superficial conclusions, despite the authors' calculations of the effects of a much wider range of studied musical characteristics and mathematical approval. Meanwhile, though my study does not rely on any strict evidence, it makes various connections between different studies' investigations and explores the larger picture. Moreover, my study covers an even wider research gap: the influence of various musical parameters on driving performance is not the only covered subtopic; the impacts of other audio types and in-car music control interfaces are also investigated.

Speaking about the music parameters explored in both papers, they more or less converge on their outcomes. I summarized such parameters as tempo, genre, and style into the one and concluded that the more aggressive music is the more distraction it causes. Meanwhile, Millet *et al.* [17] state that music tempo does not have such a powerful influence on the driving performance; however, instrumentation and style definitely affect the driver's concentration, which requires more research conducted.

4.3.3 The comparison consequences

The current study type is new in the field of audio music influence on driving behavior, which implies unique results. As I mentioned, no qualitative systematic LR regarding in-car audio effects was conducted before. The comparison with the only LR published in this gap showed significant differences in methodologies and results. This means more reviews need to be conducted to verify the effects of in-car audio and music in particular on driving performance.

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