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The influence of music on mental effort and driving performance

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ABSTRACT

The current research examined the influence of loud music on driving performance, and whether mental effort mediated this effect. Participants ($N = 69$) drove in a driving simulator either with or without listening to music. In order to test whether music would have similar effects on driving performance in different situations, we manipulated the simulated traffic environment such that the driving context consisted of both complex and monotonous driving situations. In addition, we systematically kept track of drivers' mental load by making the participants verbally report their mental effort at certain moments while driving. We found that listening to music increased mental effort while driving, irrespective of the driving situation being complex or monotonous, providing support to the general assumption that music can be a distracting auditory stimulus while driving. However, drivers who listened to music performed as well as the drivers who did not listen to music, indicating that music did not impair their driving performance. Importantly, the increases in mental effort while listening to music pointed out that drivers try to regulate their mental effort as a cognitive compensatory strategy to deal with task demands. Interestingly, we observed significant improvements in driving performance in two of the driving situations. It seems like mental effort might mediate the effect of music on driving performance in situations requiring sustained attention. Other process variables, such as arousal and boredom, should also be incorporated to study designs in order to reveal more on the nature of how music affects driving.

1. Introduction

Imagine that you are driving in a very quiet neighborhood, listening to one of your favorite bands and singing along with the music. Suddenly you realize that you are approaching an intersection and the traffic is getting busy. There are traffic lights, pedestrians and other vehicles that you should monitor all at the same time to avoid possible accidents. You stop singing along, but the music is still playing. You may have encountered this kind of situation many times while driving, but what would you do? Would you feel like the driving task is more effortful due to the music? Would you turn off the music? In this paper, we aim to explore to what extent music influences drivers' mental load and performance in different situations, and whether drivers are able to cope with task demands in the presence of music.

Driving is executed along with secondary tasks, distracters or stressors most of the time, such as talking to a passenger, tuning the radio, attending to irrelevant on-road stimuli like advertisements or talking on the cell-phone (Haigney et al., 2000; Horberry et al., 2005; Crundall et al., 2006; Drews et al., 2008), all of which may significantly affect task demands and driving performance. Listening to music or the radio is among the most common auditory stimuli that drivers are exposed to on the road (Dibben and Williamson, 2007). Indeed, listening to music is often a habitual behavior that accompanies driving and is perceived as helping drivers to easily pass the time (North et al., 2004). As a result of this habitual use of music, drivers seldom find music as distracting as talking to passengers or talking on the mobile-phone, and therefore do not tend to perceive music as a distracter that would impair their driving performance (Dibben and Williamson, 2007). Do self-reports of drivers reflect the reality however? Or does music have an influence on mental load and task performance while driving?

In previous investigations of this issue, researchers have tended to use two main methods: computer-based tasks that measure variables related to driving skills (e.g. reaction-time, brake response time) or simulated driving tasks which allow for directly observing the impact of music on driving (Brodsky, 2002; North and Hargreaves, 1999; Beh and Hirst, 1999; Turner et al., 1996). In simulated driving studies, the focus has been mainly on general driving behavior parameters such as speed, rather than specific measures of driving performance such as brake response or reaction time. In one particular driving simulator study, music that was high in arousal potential (i.e., high tempo music played at a high volume) resulted in longer lap times and therefore decreases in speed as compared to music that was low in arousal potential (North and Hargreaves, 1999). In this case highly arousing music was also associated with

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a high processing demand, indicating the music was influencing driving behavior through an effect on cognitive resources and information processing. Similarly, a different study found that listening to happy music was related to decreases in speed, as well as a deterioration of vehicle-control measured by lateral positioning of the car in a simulated drive (Pêcher et al., 2009). It was suggested that high engagement with the music in the happy music condition distracted the participants to the extent that their attention was directed more on inner thoughts and feelings than on the road, resulting in impaired vehicle-control. However, contrary to these findings, Brodsky (2002) found that high-tempo music lead to increases in speed and red-light violations during a simulated drive. Brodsky (2002) also reported that the arousal level, measured by heart rate, was not related to changes in the tempo of the music. Therefore, in contradiction with North and Hargreaves (1999), Brodsky (2002) concluded that the effect of music on driving can best be explained by its potential to distract rather than its arousal potential. So, the findings derived from the studies on simulated driving are somewhat mixed, and there is little known yet about the processes through which music influences driving performance.

Music has also been found to have varying effects in computer-based tests of driving related skills. For instance, in a simple vigilance signal detection task, participants who listened to familiar music detected more signals than the participants who listened to non-familiar music (Fontaine and Schwalm, 1979). However, vigilance did not differ significantly between no-music and non-familiar music conditions. Since arousal was found to be the highest in the familiar music condition, this was interpreted as familiar music affecting vigilance levels through arousal, although this assumption was not tested empirically. In a similar computer-based task, Turner et al. (1996) compared the effect of music played at three different sound levels on signal detection. Neither low-volume (60 dBA) nor high-volume (80 dBA) music facilitated performance, but a moderate sound level of 70 dBA resulted in faster reactions to signals. These results were interpreted as music being facilitative when listened to at amplitudes close to one's comfort level, which was around 72 dBA for male participants and 66 dBA for female participants. Moreover, the authors reasoned that loud music, which is demanding to listen to, had a negative influence on attention capacity, which therefore impaired the early detection of relevant signals. The overloading effect of a demanding type of music on information processing and attention resources has been supported by other studies as well. For instance, Dalton et al. (2007) found that loud music of 95 dBA impaired sustained attention resulting in slower reaction and movement times in a vigilance task. Based on this result, the authors concluded that music competes for one's available cognitive resources, which results in a high mental load and processing demand while busy with another task, such as driving. Indeed, Beh and Hirst (1999) found that task demands might interact with the demands induced by music, potentially leading to differential effects on performance. In their study, Beh and Hirst (1999) compared the influence of no-music, along with low-volume and high-volume music on reaction time in a vigilance task in which participants had to respond to centrally and peripherally presented signals. In both music conditions, participants responded faster to the signals in the centre of the screen than participants in the no-music condition. There was no difference between the groups in reaction times to peripherally presented signals. However, when the task demands were increased by making the participants work on two other tasks (a stop-light task and a tracking task) while carrying out the vigilance task, high-volume music impaired the reaction times to the peripherally presented signals while low-volume music did not. Beh and Hirst (1999) interpreted their results by suggesting that at times of overload due to external stimulation (e.g. loud music), people tend to regulate their attention in such a way that they are focused on the task of primary importance, while their ability to allocate their attention to peripheral information or other tasks is temporarily impaired.

The above explanation is in line with Hockey's (1997) compensatory control model, which proposes that people regulate their attention and effort constantly to preserve primary task-performance at a desired level. Specifically, following Kahneman's (1973) theory of attention control, Hockey (1997) proposed that individuals allocate more resources to a primary task when there is a secondary task, a distracter or a stressor that is competing for shared cognitive resources, than when there is only a single task. Hockey calls this process as the energetical-control framework, and stresses that performance maintenance is "an active process under the control of the individual, requiring the management of cognitive resources through the mobilization of mental effort" (p. 78). In particular, Hockey (1997) proposed that we constantly regulate our effort based on the relative importance of the goals we have (such as succeeding in the primary task versus the secondary task), and changes in mental effort are representative of information processing, task-difficulty and the value of the tasks. Hockey argued that people constantly monitor their performance and, based on feedback on whether there are sufficient cognitive resources available, they try to adjust their resources to meet the current task demands. The adjustments in allocation of resources are done by relying on compensatory strategies such as increasing the mental effort to meet increased demands of the primary task or ignoring the secondary task.

Driving is a complex task, which if not carried out adequately can have serious safety consequences. So, do drivers also engage in compensatory strategies as to not fail the primary task of driving when the task demands increase? There is some evidence, based on simulated driving studies, showing that drivers employ behavioral compensatory strategies to handle the effects of distracters or secondary tasks (Young and Regan, 2007). At times of mental overload due to distracters and secondary tasks, decreasing the speed or increasing the headway with the lead car are among the common compensatory behaviors that drivers employ to make driving less demanding (Törnros and Bolling, 2006; Landsdown et al., 2004; North and Hargreaves, 1999; Strayer and Drews, 2004). Besides behavioral adaptions, drivers also seem to use cognitive compensatory strategies such as the ones proposed by Hockey (1997). For instance, drivers were found to report higher mental effort when they were forced to drive at a speed that was lower than they would normally do, indicating that diverging from the habitual pattern of driving needs the regulation of mental resources to cope with task demands (Lewis-Evans et al., 2011). Similarly, in the presence of distracters or secondary tasks, drivers reported higher mental load and effort, but they still maintained the primary task of car control and vehicle handling at a desirable level (Brookhuis et al., 1991). In short, drivers seem to adopt various strategies to allocate their cognitive resources to more important tasks or regulate their mental effort to meet increased task demands.

Can music have a similar impact on mental effort while driving? And if so, are drivers able to cope with the increased mental load and still perform well? In this study, we aimed to look at the influence of music on mental load and on a variety of driving performance measures that are relevant in different types of traffic situations. Our study differs from earlier studies on music and driving in three important aspects. First, previously simulator studies on the effects of music on driving performance have tended to focus on general indicators of driving performance such as speed, and did not focus on more specific criteria that are critical to driving performance such as reacting to unexpected events or brake responses to hazards. In this study, we aim to distinctively examine the influence of music on such performance measures as well. Second, in earlier simulated driving studies, the traffic environment was stable, and there was no fluctuation in the level of complexity due to traffic flow or other road users. However, the complexity of the traffic environment is a key factor increasing the mental load of drivers (Horberry et al., 2005). For instance, driving in high-density traffic is more challenging than driving in low-density traffic due to the abundance of information flow (Strayer et al., 2003; Baldwin and Coyne, 2003). In addition, critical situations such as hazardous events lead to an increase in mental load (De Waard, 1996). Therefore, given that contextual factors are likely to have an effect on feelings of invested mental effort, we simulated a broad range of critical events that differed in complexity during which participants were also exposed to music. Third, although previously researchers used mental load or information processing to explain why music impaired performance by acting as a distracter (North and Hargreaves, 1999; Brodsky, 2002), this explanation has not been explicitly tested. That is, the studies did not include a direct measure of mental load, nor did they assess the effect of mental load as a process variable to explain why music affects driving. In our study therefore, we included a measure of mental effort which is an indication of mental load and information processing and allows us to measure cognitive processes in a more systematic way.

Based on Hockey's (1997) compensatory control model, our first hypothesis was that music would induce an extra load on the driver in addition to that of created by contextual factors (such as hazardous incidents or high-density traffic), and that the extra mental load would be reflected in mental effort ratings. More specifically, we expected the drivers who listened to music would experience a higher mental effort level while driving as compared to drivers who do not listen to music, irrespective of the complexity of the traffic situation. Second, we expected that drivers who listen to music would still perform as well or even better as drivers who do not listen to music. In other words, we expected that drivers would hold their primary task performance at the desired level. Finally, we hypothesized that any difference in the performance levels between drivers who did and did not listen to music would be mediated by mental effort. That is, we expected that if music affects driving performance, this is due to changes in mental effort: music affects mental effort, which in turn influences performance. So, in line with Hockey's (1997) theory we expected that drivers would regulate their effort to compensate for the distracting nature of music.

2. Methods

2.1. Participants

Initially 74 psychology students who held a valid driving license participated in the study. However, five of the participants could not manage to finish the simulated drive due to simulation sickness. Therefore, the total number of participants was 69 (46 female, 23 male) whose age ranged from 18 to 31, with a mean age of 21.04 (*SD* = 1.96). Their mean driving experience was 2.92 years (*SD* = 1.90), and mean annual km driven in the last year was 5818.84 (*SD* = 11,443.99). None of the participants reported having any hearing deficiencies.

2.2. Research design and procedure

To avoid any possible learning effects for the critical incidents used to assess overall driving performance, the current study employed a single factor between-group design with a music and no-music condition. Participants were randomly assigned to one of the two conditions. Participants in the music condition created their own playlists by selecting songs from a website called Grooveshark that covered a broad range of genres. The first reason to adopt this strategy instead of making everyone listen to the same type of music was to increase the ecological validity of the study, as our participants made a selection based on what they would usually listen to while driving. In addition, by employing this method we made sure that participants were familiar with the music they were listening to, so that any effects observed in mental effort would not be attributable to unfamiliarity with the music or to disliking the music they were exposed to. In addition, in order to check whether the music condition was similar to a real-life situation in which drivers listen to their preferred type of music, participants filled out a brief questionnaire after the simulated drive. Responses were given on a five points scale (1 = totally disagree; 5 = totally agree). Participants reported that they enjoyed listening to the music ($M = 4.53$, $SD = 0.56$), the music was similar to what they usually listen to while driving ($M = 4.38$, $SD = 0.65$), and they did not find the music boring ($M = 4.79$, $SD = 0.41$).

The volume of the music was set relatively loud in order to create a demanding listening situation, with a sound level of approximately 90 dBA (with a variation between 85 dBA and 95 dBA based on the physical features of the songs). A digital sound meter was used throughout the whole music condition to control for loudness.

Upon arrival participants were given an informed consent form and an instruction booklet. The booklet provided participants with information on the mental effort rating scale (explained below) as well as the experimental procedure. Participants were told that the researcher could ask about their mental effort any time while they were driving and that they needed to report their mental effort verbally by saying out loud the number representative of the mental effort at that moment. Prior to the experimental simulated driving, all the participants completed a training session in the simulator that lasted around 10 min. Participants in the music condition had the training with their preferred type of music on the background. This training ensured that all the participants got used to the equipment and the task of verbally reporting their mental effort. In addition, during the training session we were able to identify the participants who had simulation sickness and were unable to carry on with the experimental session. The experimental simulated driving took approximately 35 min to complete. After the experimental simulated driving, all participants completed a questionnaire that consisted of items asking about demographics and background information, and they were debriefed about the research.

2.3. Dependent measures

2.3.1. Performance indicators

Participants drove in the University of Groningen Driving Simulator. The simulator was on a fixed-base and surrounded by three screens that provided a 180° view of the road environment. The cabin looked like the inside of a car and had all the usual car-control equipment. All data on driver performance was automatically recorded throughout the drives in the database of the main computer at a sample rate of 10 Hz. This allowed us to make detailed analysis of different segments of the road (see Van Wolffelaar and Van Winsum, 1995 for a detailed description).

For the current study, we created a simulated world featuring a regular driving context for the Netherlands that included 11 traffic incidents. We used a variety of road types such as residential roads, intercity roads and rural roads. Nine of the incidents were hazardous in nature, designed specifically for the purpose of creating conflict situations in traffic, and we called them as "critical incidents". Six of these critical incidents took place in residential areas which consisted of heavy traffic, other cars violating the rules and several go/no-go type of situations such as traffic lights turning red. More specifically, the critical incidents that took place in the residential roads were: 1. car coming from the right; 2. car coming from the left and violating the give way rule; 3. a parked car suddenly driving off (two times); 4. gap acceptance at an intersection; 5. gap acceptance at a T-junction. The remaining three critical incidents, which took place on intercity and rural roads, were 1. merging with the traffic on a highway; 2. traffic pile-up on a highway; and 3. traffic jam on a highway. In addition, for the intercity and rural roads, we included two driving situations that were not critical in nature, and which took approximately five to six minutes each: 1. car following, and 2. monotonous driving. All participants encountered all of the critical and non-critical incidents, and in the same order.

The simulator recorded the relevant performance indicators for all incidents. These performance indicators were brake response to hazardous situations, maximum deceleration during the incidents, time-headway to the lead car, time-to-contact with the lead car, lateral positioning and speed. Appendix A gives a full description of all the incidents, driving situations and performance indicators.

2.3.2. Mental effort

The Rating Scale Mental Effort (Zijlstra, 1993) was used to measure self-reported mental effort experienced at a given moment. The scale is unidimensional and participants simply indicated their mental effort on a scale ranging from 0 to 150 (0 = no effort, 150 = extreme effort). In a series of studies Zijlstra (1993) demonstrated that the scale is sensitive to changes in task load and correlates well with physiological changes based on task difficulty. Therefore the scale is a valid and reliable measure for subjective ratings of mental effort, and an indicator of workload and information processing during the execution of a task.

Participants reported their mental effort 13 times during the course of simulated driving: shortly after they started to drive (baseline measure), after each critical incident, during the two non-critical incidents, and at the end of the drive (end measure). More specifically, the baseline mental effort was measured after participants simply had been driving straight ahead for one minute, and therefore there was no incidents preceding the baseline measure. Following the baseline measure, participants were asked to report their mental effort right after every critical incident (e.g. parked car suddenly pulling out). As the non-critical incidents of car following and monotonous driving took longer to complete, we asked the participants to report their mental effort in the middle of the car following and the monotonous driving tasks, rather than at the end. Finally, participants reported their mental effort approximately 30 s before the end of the simulated driving which was labeled as the end measure. The mental effort ratings obtained during the experimental drive were immediately recorded by the researcher.

3. Results

3.1. Mental effort ratings

A mixed ANOVA was used with the mental effort ratings for driving situations as a within subjects factor and music as a between groups factor.[1] There was a significant main effect of the type of the driving situation on mental effort ($F(12, 732) = 30.33$, $p < .001$) suggesting that we succeeded in simulating situations that required different levels of mental effort. More importantly, as expected, there was also a significant main effect of music on mental effort ($F(1, 61) = 11.76$, $p < .001$) while the interaction effect of music and type of critical event was not significant. Contrast statistics revealed that, in line with our expectations, the mental effort ratings of the music group were systematically higher than that of the no-music group (F values ranging between 4.90 and 14.26, all being significant at $p < .05$), irrespective of the type of the critical situation (see Fig. 1).

3.2. The effect of music on performance in critical driving situations

The driving performance of the music and no-music groups for each critical event was compared by using independent samples t-tests. Two-tailed test of significance was employed to test our hypothesis (equal variances assumed). In line with our hypothesis, the results revealed that the music and no-music groups performed equally well in all but two scenarios. In other words, there was no significant effect of music on driving performance in the majority of the driving situations. The two situations in which the performance of the groups differed were the car-following task and a parked car suddenly driving off from a parking lot.

In the car-following scenario, drivers had to follow a car for approximately 6 min. The lead car was programmed in such a way that it had an irregular pattern of driving, characterized by sudden accelerations and decelerations which lead to a high standard deviation of speed. Therefore, a good performance in the particular task was produced by driving in coherence with the lead car, having little delay in reacting to speed changes of the lead car (De Waard and Brookhuis, 2000), and therefore producing a higher standard deviation of speed (similar to the lead car). The coherence in car-following did not differ ($t(58) = 1.02$, ns) between the music ($M = 0.71$, $SD = 0.16$) and no-music groups ($M = 0.66$, $SD = 0.18$). However, there was a significant difference between the groups in delay of responding to the accelerations and decelerations of the lead car ($t(57) = -2.82$, $p < .01$). The music group had a smaller delay ($M = 3.44$, $SD = 1.29$) than the no-music group ($M = 4.65$, $SD = 1.92$), indicating that the music group responded approximately 1 s earlier than the no-music group. Importantly, there was a significant difference ($t(67) = 2.49$, $p < .05$) in the standard deviation of speed between the music ($M = 6.72$, $SD = 1.48$) and no-music groups ($M = 5.74$, $SD = 1.81$), indicating that the music group performed better by adjusting their speed in accordance with the speed changes of the lead car. There was no significant difference between the groups in any of the other performance criteria for the car-following scenario, which were speed, lateral positioning, standard deviation of lateral positioning and time-headway.

In the scenario of a parked car suddenly driving off, we recorded three performance criteria: time-to-contact with the parked car driving off, maximum deceleration during the incident, and maximum brake percentage executed during the incident. Performing well in this scenario meant keeping a higher time-to-contact, along with faster deceleration and braking scores, since all three measures were indicative of the urge to stop in order to avoid a collision with the parked car driving off. We found that the music group had a

[1] The parametric assumption of normality was checked separately for the music and no-music groups. We used the Shapiro–Wilk test which is more appropriate in case of a small sample size. Four of the mental effort rating variables (out of 13) did not meet the normality assumption in the no-music group. Similarly, 2 of the mental effort rating variables (out of 13) did not meet the normality assumption in the music group. The data distributions were also checked for the homogeneity of error variances. Results of the Levene's test revealed that for some of the mental effort ratings, the assumption of homogeneity was violated. Therefore, the mental effort scores were transformed by using log-transformation. After transforming the data, Levene's test revealed that the assumption of homogeneity was met for all the variables. We carried out a separate mixed ANOVA analysis to test our first hypothesis by using the transformed mental effort scores. The F-statistics did hardly differ from the F-statistics that were obtained by using the untransformed data. Therefore, we report the results of the mixed ANOVA analysis that was carried out with the untransformed data here, for the ease of interpretation and for being more straightforward.

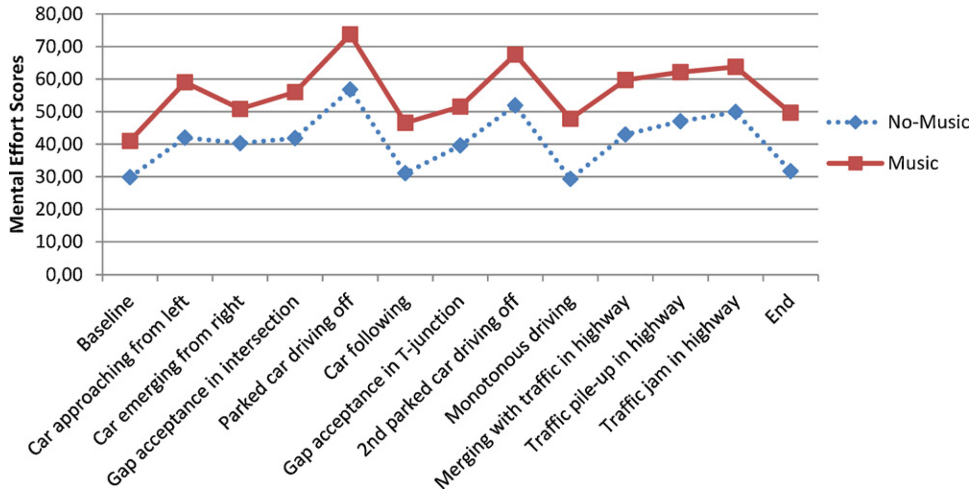

Fig. 1. Mental effort scores based on the RSME ratings for the critical and non-critical situations in the music and no-music groups.

significantly ($t(67) = 2.22$, $p < .05$) higher time-to-contact ($M = 1.12$, $SD = 0.25$) than the no-music group ($M = 0.97$, $SD = 0.30$), indicating that they performed better. However, there was no significant difference between the groups in the other two performance criteria.

3.3. Mental effort as a mediator of the effect of music on driving performance

For the three performance measures that differed between the music and no-music groups (standard deviation of speed in car following, delay in car following, and time-to-contact with the parked car), we ran mediation analysis (see Baron and Kenny, 1986) to see whether mental effort mediated the relationship between music and driving performance. As Fig. 2 illustrates, music significantly predicted the dependent variable standard deviation of speed ($\beta = .28$, $p < .05$) as well as the mediator mental effort ($\beta = .41$, $p < .001$). Most importantly, after controlling for the effects of mental effort, the effect of music on the standard deviation of speed was no longer significant ($\beta = -.04$, *ns*) while mental effort predicted the scores in standard deviation of speed ($\beta = .27$, $p < .05$) even after controlling for the effects of music. So, as expected, mental effort mediates the effect of music on performance, suggesting that music influences mental effort, which in turn affects performance. A Sobel test revealed that the mediation effect was marginally significant ($Z = 1.79$, $p = .07$).

As shown in Fig. 3, music significantly predicted the delay in the car following task ($\beta = -.33$, $p < .05$). Music also significantly predicted the mediator mental effort ($\beta = .40$, $p < .01$). After controlling for the effects of mental effort, the effect of music on the dependent variable delay slightly decreased, but remained significant ($\beta = -.28$, $p = .05$). Importantly, mental effort did not predict the delay of response after controlling for the effects of music ($\beta = -.11$, *ns*), indicating that mental effort did not mediate the effect of music on delay scores in the car following situation.

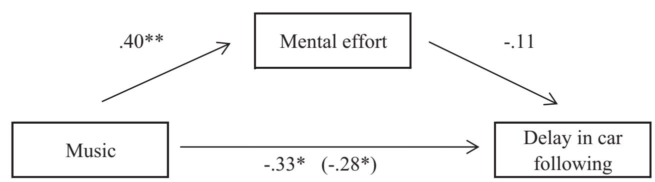

Fig. 3. Mediation analysis to test whether mental effort mediates the relationship between music and delay scores in car following. *Note*: The beta value in parenthesis refers to the effect of the independent variable on the dependent variable after controlling for the effect of the mediating variable.

Finally, as illustrated in Fig. 4, music significantly predicted time-to-contact with the parked car ($\beta = .24$, $p < .05$) and the mediator mental effort ($\beta = .36$, $p < .01$). After controlling for the effects of mental effort, the effect of music on the dependent variable time-to-contact with the parked car became stronger ($\beta = .33$, $p < .01$), indicating a suppression effect (see MacKinnon et al., 2000) rather than a mediation effect. So, for the time-to-contact with the parked car scenario, the inclusion of mental effort increased rather than decreased the effect of music on performance.

4. Discussion

The current study aimed to examine the effects of music on mental effort while driving, and on driving performance. We hypothesized that listening to music at a high volume adds to mental load, and therefore increases the mental effort while driving. Second, we hypothesized that despite the increase in mental effort, listening to music does not impair driving performance, and drivers

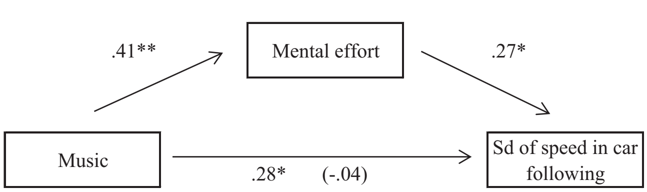

Fig. 2. Mediation analysis to test whether mental effort mediates the relationship between music and standard deviation of speed in car following. *Note*: The beta value in parenthesis refers to the effect of the independent variable on the dependent variable after controlling for the effect of the mediating variable.

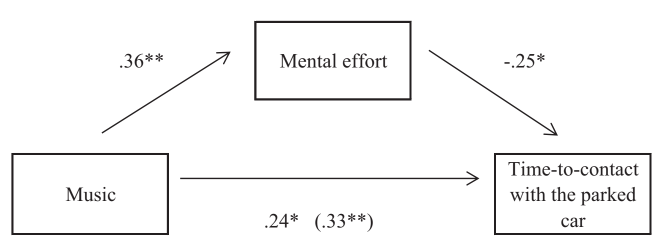

Fig. 4. Mediation analysis to test whether mental effort mediates the relationship between music and time-to-contact with the parked car. *Note*: The beta value in parenthesis refers to the effect of the independent variable on the dependent variable after controlling for the effect of the mediating variable.

who listened to music will perform as well as the drivers who did not listen to music. In fact, we expected that the music group could even perform better than the no-music group in certain situations, as a result of the regulation of mental effort to meet task demands. Third, we expected that any difference in driving performance of the music and no-music groups would be mediated by mental effort.

Our first hypothesis was confirmed. Drivers who listened to music reported systematically higher levels of mental effort than drivers who did not listen to music. Importantly, the ratings of the drivers who listened to music were higher irrespective of the complexity of the traffic environment (see Fig. 1). As expected, the complexity of the traffic environment also appeared as a factor increasing the mental effort while driving. For instance, both in the music and no-music groups, drivers reported a higher mental effort when the context of driving was demanding, such as when confronted with a hazard (e.g. parked car driving off from a parking lot). However, importantly, listening to loud music increased the mental effort even more in such situations. Indeed, the influence of music on mental effort was so robust that we even observed significant effects of music on mental effort during the baseline and end measures, during which the traffic environment was relatively undemanding. Therefore, our findings clearly suggest that loud music increases the mental load while driving, and this applies in both monotonous and complex traffic environments.

Self-reports of drivers have indicated that drivers do not generally perceive music as a distracting auditory stimulus on the road (Dibben and Williamson, 2007; North et al., 2004). However, the current finding on music's influence on mental effort suggests that music can be a distracting stimulus while driving. Given that this is the case, why do drivers hold positive evaluations for listening to music despite the explicit increases in mental effort? Our findings imply that this might be related to the nonnegative experiences with music in terms of driving performance. We found that drivers who listened to music performed at least as well as drivers who did not listen to music in all of the driving situations. This indicates that, generally music did not cause driving performance to deteriorate, providing support for our second hypothesis.

Previously, loud music has been associated with reduced vigilance and impaired peripheral detection in the computer-based tasks (Dalton et al., 2007; Beh and Hirst, 1999). Our results did not support such a link. This could be due to our experimental method in which we used the driving simulator instead of a computer-based signal detection task. However, we think that this is not the case, because all the hazardous situations in the driving simulator were also depicting signals or unexpected stimuli as they are commonly referred to in the computer-based tasks of vigilance (Turner et al., 1996). Moreover, the simulator allowed us to infer about vigilance and other performance related measures in a more realistic setting, which is close to actual driving. In short, our participants were quite good at the early detection of hazardous situations, such as when a parked car suddenly drove off from a parking lot. Moreover, they were also all good at responding to the traffic coming from the periphery, such as a car violating the give-way rule. So, drivers who listened to music were still vigilant of the stimuli that popped up unexpectedly. Given that the mental effort ratings of the drivers who listened to music were higher than the ones who did not listen to music, our results indicate that drivers regulate their mental effort to maintain their primary task performance (driving) when there is a distracting auditory stimulus in the car. Therefore, our results fully support Hockey's (1997) compensatory control model, and show that regulation of mental effort is a cognitive compensatory strategy that the drivers employ to cope with the task demands.

In addition, we found that the music group performed better than the no-music group in two of the critical situations. The first situation was a hazardous event that required braking hard in order to avoid a crash with a car driving off suddenly from a parking lot. The second situation was a car following task in which participants had to follow a lead car with an irregular pattern of driving. In the parked-car driving off scenario, time-to-contact with the parked car was higher for participants who listened to music. In the car following scenario, participants who listened to music were better in adjusting their driving to the driving pattern of the lead car, and they responded with a smaller delay to the speed changes of the lead car. Indeed, the situations were quite different in nature, as the former represented a sudden hazard requiring faster decision making for response selection, while the latter represents a relatively monotonous situation requiring sustained attention to follow the lead car. Still, both situations required the driver to be alert and focused on the driving task. In addition, in both situations, the mental effort ratings of the participants who listened to music were higher than the ratings of the participants who did not listen to music. Then, can mental effort explain the positive influence of music on performance indicators for the car following and parked car driving off situations?

In line with our third hypothesis, mental effort mediated the effect of music on performance, but this applied only to the standard deviation of speed in the car following task. In terms of the delay in following a lead car, mental effort showed no mediating effects. Car following is a monotonous but effortful task that requires high vigilance (Brookhuis et al., 1994). Our findings suggest that while driving at the same pace with the lead car (standard deviation of speed), regulation of mental effort leads to a better performance for drivers who listened to music. However, in terms of faster reactions to speed changes of the lead car (delay), factors other than mental effort might be mediating the effects of music on performance. One of these factors can be boredom, which is highly relevant to monotonous driving conditions as it represents an underload situation that might cause potential loss of attention (De Waard, 1996). It might be the case that music helped our participants to defeat boredom while busy with a monotonous driving task, leading to faster responses to adjust one's driving to the driving pattern of the lead car. Therefore, future studies should also account for the mediating role of boredom, especially in relation to monotonous driving tasks.

What about the mediating role of mental effort in hazardous situations, such as in the critical event of parked driving off from a parking lot? We found that mental effort did not mediate the effect of music on performance in the parking car driving off scenario. Rather, the effect of music on the performance indicator was stronger when mental effort was controlled for, indicating a suppression effect. Mental effort ratings were very high in the parking car driving off scenario, for both the music and no music groups. Therefore, it might be the case that when a certain threshold of mental effort is exceeded due to the hazard potential of the situation or due to the music, mental effort no longer mediates the effect of music on performance. In such hazardous situations, other process variables might mediate the effect of music on performance, such as the arousal level which is expected to increase with loud music (North and Hargreaves, 1999). However, in the current study we did not include a continuous measure of arousal like we did for mental effort, so we cannot test this assumption. Future studies should therefore consider checking the mediating roles of both arousal and mental effort to further study the effect of music on driving performance.

Although the results of the current study did not show any impairment in driving performance due to listening to music, it should be noted that it is likely that drivers are not always able to deal with the increased task demands while driving. For example, the lengthened experience of high mental effort might lead to decreases in driving performance, as the driver might feel depleted.

In the current study we did not test this assumption because we were mainly interested in whether drivers regulate their invested mental effort to deal with different driving situations. However, it would be interesting to also look at the effects of prolonged driving with music on mental effort and driving performance.

Apart from different driving situations, the characteristics of the music might also influence the effect of music on mental effort and driving performance (Dalton and Behm, 2007). For example, there is evidence that different volume levels affect driving performance differently (Beh and Hirst, 1999). Importantly, listening to music in one's preferred loudness level might be effective for attaining optimal performance levels (Turner et al., 1996). In the current study, we purposefully used only loud music in order to create a demanding listening situation. Future studies could also look at the influence of different sound levels or properties of music (e.g. tempo, complexity, rhythm) on both mental effort and driving performance. Based on our findings we expect that irrespective of the property being manipulated, music would increase mental effort if it is demanding to listen to.

We employed a young sample in our study. It is possible that young drivers can handle more demanding types of music better than older drivers. Furthermore, young drivers are better at dealing with complex traffic situations as compared to older drivers (Cantin et al., 2009). Therefore, the demands induced by music may be even stronger for older participants. Future studies should explore whether our results can be replicated in different samples, including samples of older drivers.

5. Conclusions

The majority of drivers listen to music or the radio while driving (Dibben and Williamson, 2007). Therefore, it is important to track the influence of music on driving performance. The current research makes some important contributions to the existing literature on music and driving. First, based on our finding related to the increases in mental effort while listening to music, we objectively showed that music can be a demanding and distracting stimulus on the road. Yet, drivers seem to be able to keep a desired performance level with the presence of music. Importantly, we clearly showed that drivers make use of cognitive compensatory strategies to deal with the distracting effects of music, and regulation of mental effort seems to be an effective strategy to cope with the additional load created by music. Future studies should test the mediating roles of other process variables such as arousal or boredom, to provide further knowledge on how music influences driving performance.

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Appendix A.

Description of critical driving situations and relevant performance indicators

1. Car emerging from the right: This scenario mirrored a hazardous driving incident in which another car unexpectedly emerged from a merging road to the right of the driver. The following performance indicators were used:

   1.1. Maximum deceleration: The greatest deceleration value in m/s. Higher values of maximum deceleration indicate harder brake responses meaning that the driver started to brake at a shorter distance from the hazardous event.

   1.2. Minimum velocity: The smallest speed in m/s.

   1.3. Maximum brake: The brake pedal position as a percentage from 0 to 100.
2. Car approaching from the left: This scenario mirrored a hazardous driving incident in which another car approached from a merging road to the left of the driver. Although the driver had the right to pass through the intersection first, the other car did not stop, violating the give way rule. The performance indicators were the same as the car emerging from the right scenario.
3. Gap acceptance at an intersection: This scenario depicted a situation in which the participant had to cross an intersection where there were cars coming from left and right. The gap between the oncoming cars increases at a certain frequency. We were interested in the gap that the driver chooses to cross the intersection. The performance indicators for the situation were:

   3.1. Accepted gaptime: A measure in seconds, indicating the time between the movements of two oncoming cars. The higher the gaptime, the longer the driver waited to cross the intersection.

   3.2. Distance to cars that are approaching: It correlates with accepted gaptime, and indicates the distance between the two oncoming cars.
4. Car driving off from a parking lot: In this critical situation, a parked car unexpectedly drove off from a parking lot, and cut into the driver's way when the driver was passing. The driver was expected to brake immediately in order to avoid a collision. The following performance indicators were recorded:

   4.1. Maximum deceleration (see 1.1).

   4.2. Maximum brake (see 1.3).

   4.3. Time to contact: The time in seconds that would lead to a collision to the first object in the same lane as the participant, which is the parked car driving off in this scenario.
5. Car following task: In this scenario, the task was to follow a lead car at a constant but safe distance. The speed of the lead car was varied purposely in an irregular way. The following performance indicators were used:

   5.1. Speed: Mean speed while following the lead car.

   5.2. Standard deviation of speed: A measure aimed at tracking the variations in speed. As the lead car had a high standard deviation of speed due to sudden accelerations and decelerations, a higher score in this measure indicates that the driver was able to adjust his/her driving to the driving pattern of the lead car.

   5.3. Lateral positioning: The position of the car in one's own lane. A negative lateral position means that the car was to the right of the centerline, while a positive lateral position indicates that the car was to the left of the centerline. A lateral position of 0 suggests that the car was exactly in the middle of the driving lane.

   5.4. Standard deviation of lateral positioning: An indicator of swerving on the road and car-control. If high, it indicates that the driver had failed to control the car smoothly.

   5.5. Mean minimum time headway: An indication of the time needed for the following car to reach the location of the lead car.

   5.6. Absolute minimum time-headway: The smallest time-headway to the lead car.

   5.7. Coherence: An indication of accuracy of following a lead car.

5.8. Delay: An indication of the delay of responding to the speed changes of the lead car.

6. Gap acceptance at a T-junction: The driver had to turn left in a T-junction in which there was oncoming traffic. The gap between the oncoming cars increased with a certain frequency. We were interested in the gap at which the driver chose to turn left. The performance indicators for the situation were the same as for the gap acceptance at an intersection scenario.
7. Monotonous driving: In this scenario, the driver drove on an empty intercity road. Therefore, the situation represented a monotonous driving condition where there was a lack of external stimuli. The performance indicators for the monotonous driving were mean speed, standard deviation of speed, mean lateral positioning and standard deviation of lateral positioning (see 5.1, 5.2, 5.3 and 5.4).
8. Merging with the traffic on a highway: In this scenario, the driver had to enter a highway where there was oncoming traffic coming from left. The driver had to watch out for other cars that were approaching at a high speed, and decide on a safe time to merge with the traffic. The performance indicators representing the scenario were:

   8.1. The velocity (in m/s) while merging with the traffic in highway.

   8.2. Time-headway with the lead car while merging.

   8.3. Time-to-contact with the lead car while merging.

   8.4. Time-headway with the rear car while merging.

   8.5. Time-to-contact with the rear car while merging.
9. Traffic pile-up on the highway: While driving on a highway, the driver saw other cars behind, approaching at high speeds. The other cars then started to overtake the driver, and built a heavy traffic in front of the driver. The driver needed to be alert, and to watch out for all the traffic in order to avoid a crash with the cars behind and in front. The performance indicators for the scenario were:

   9.1. Mean minimum time-headway: see 5.5.

   9.2. Absolute minimum time-headway: see 5.6.
10. Traffic jam: In this scenario, the driver ended up in a traffic jam, and needed to control the simulated car very smoothly to avoid a crash with other cars. The performance indicators were:

    10.1. Mean time-to-contact: Mean of all time-to-contact scores.

    10.2. Absolute minimum time-to-contact: The smallest time-to-contact score.

References

Baldwin, C.L., Coyne, J.T., 2003. Mental workload as a function of traffic density: comparison of physiological, behavioral, and subjective indices. In: Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Park City, Utah, pp. 19–24, Retrieved from http://www.drivingassessment.uiowa.edu/DA2003.

Baron, R.M., Kenny, D.A., 1986. The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology 51 (6), 1173–1182.

Beh, H.C., Hirst, R., 1999. Performance on driving-related tasks during music. Ergonomics 42 (8), 1087–1098.

Brodsky, W., 2002. The effects of music tempo on simulated driving performance and vehicular control. Transportation Research Part F 4, 219–241.

Brookhuis, K., De Vries, G., De Waard, D., 1991. The effects of mobile telephoning on driving performance. Accident Analysis and Prevention 23 (4), 309–316.

Brookhuis, K., De Waard, D., Mulder, B., 1994. Measuring driving performance by car-following in traffic. Ergonomics 37, 427–434.

Cantin, V., Lavalliere, M., Simoneau, M., Teasdale, N., 2009. Mental workload when driving in a simulator: effects of age and driving complexity. Accident Analysis and Prevention 41, 763–771.

Crundall, D., Van Loon, E., Underwood, G., 2006. Attraction and distraction of attention with roadside advertisements. Accident Analysis and Prevention 38, 671–677.

Dalton, B.H., Behm, D.G., Kibele, A., 2007. Effects of sound types and volumes on simulated driving, vigilance tasks and heart rate. Occupational Ergonomics 7, 153–168.

Dalton, B.H., Behm, D.G., 2007. Effects of noise and music on human and task performance: a systematic review. Occupational Ergonomics 7, 143–152.

De Waard, D., 1996. The measurement of drivers' mental workload. Unpublished doctoral dissertation. University of Groningen, Groningen, the Netherlands.

De Waard, D., Brookhuis, K., 2000. Drug effects on driving performance. Annals of International Medicine 133 (8), 656.

Dibben, N., Williamson, V.J., 2007. An exploratory survey of in-vehicle music listening. Psychology of Music 35, 570–589.

Drews, F.A., Pasupathi, M., Strayer, D.L., 2008. Passenger and cell phone conversations in simulated driving. Journal of Experimental Psychology: Applied 14 (4), 1–9.

Fontaine, C.W., Schwalm, N.D., 1979. Effects of familiarity of music on vigilant performance. Perceptual and Motor Skills 49, 71–74.

Haigney, D.E., Taylor, R.G., Westerman, S.J., 2000. Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. Transportation Research Part F 3, 113–121.

Hockey, G.R.J., 1997. Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework. Biological Psychology 45, 73–93.

Horberry, T., Anderson, J., Regan, M.A., Triggs, T.J., Brown, J., 2005. Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accident Analysis and Prevention 38, 185–191.

Kahneman, D., 1973. Attention and Effort. Prentice-Hall, Englewood Cliffs, NJ.

Landsdown, T.C., Brook-Carter, N., Kersloot, T., 2004. Distraction from multiple in-vehicle secondary tasks: vehicle performance and mental workload implications. Ergonomics 47 (1), 91–104.

Lewis-Evans, B., De Waard, D., Brookhuis, K., 2011. Speed maintenance under cognitive load—implications for theories of driving behavior. Accident Analysis and Prevention 43 (4), 1497–1507.

MacKinnon, D.P., Krull, J.L., Lockwood, C.M., 2000. Equivalence of the mediation, confounding and suppression effect. Prevention Science 1 (4), 173–181.

North, A.C., Hargreaves, D.J., 1999. Music and driving game performance. Scandinavian Journal of Psychology 40, 285–292.

North, A.C., Hargreaves, D.J., Hargreaves, J.J., 2004. Uses of music in everyday life. Music Perception: An Interdisciplinary Journal 22 (1), 41–77.

Pêcher, C., Lemercier, C., Cellier, J.M., 2009. Emotions drive attention: effects on driver's behaviour. Safety Science 47, 1254–1259.

Strayer, D.L., Drews, F.A., 2004. Profiles of driver distraction: effects of cell phone conversations on younger and older drivers. Human Factors 46, 640–649.

Strayer, D.L., Drews, A.A., Johnston, W.A., 2003. Cell phone-induced failures of visual attention during simulated driving. Journal of Experimental Psychology: Applied 9 (1), 23–32.

Törnros, J., Bolling, A., 2006. Mobile phone use—effects of conversation on mental workload and driving speed in rural and urban environments. Transportation Research Part F 9, 298–306.

Turner, M.L., Fernandez, J.E., Nelson, K., 1996. The effect of music amplitude on the reaction to unexpected visual events. The Journal of General Psychology 123 (1), 51–62.

Van Wolffelaar, P.C., Van Winsum, W., 1995. Traffic modeling and driving simulation—an integrated approach. In: Proceedings of the Driving Simulator Conference (DSC'95), Teknea, Toulouse, France, pp. 236–244.

Young, K., Regan, M., 2007. Driver distraction: a review of the literature. In: Faulks, I.J., Regan, M., Stevenson, M., Brown, J., Porter, A., Irwin, J.D. (Eds.), Distracted Driving. Australasian College of Road Safety, Sydney, NSW, pp. 379–405.

Zijlstra, F.R.H., 1993. Efficiency in work behavior. A design approach for modern tools. Unpublished doctoral dissertation. Delft University of Technology, Delft, the Netherlands.