Transportation Research Part F 21 (2013) 52–65

Contents lists available at ScienceDirect

Transportation Research Part F

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

Driving with music: Effects on arousal and performance

Ayça Berfu Ünal *, Dick de Waard, Kai Epstude, Linda Steg

Faculty of Behavioural and Social Sciences, University of Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 17 September 2012
Received in revised form 27 June 2013
Accepted 11 September 2013

Keywords:
Car-following
Music
Arousal
Monotonous driving
Low-complexity traffic

ABSTRACT

In the current study, we aimed at exploring the influence of music on driving performance, arousal and mental effort while carrying out a monotonous car-following task in a low-complexity traffic setting. Participants ($N = 47$) were randomly assigned to loud and moderate volume music groups, and completed one drive in the simulator with music and another drive without music (control condition). In addition, during both of the drives we monitored driving performance and recorded participants' heart rate to track physiological indications of arousal and mental effort. Results revealed that listening to music had no effect on accuracy of car-following, and even had a positive effect on response latencies to speed changes of the lead vehicle and on lateral control. Importantly, arousal was higher in the presence than absence of music irrespective of the volume level, suggesting that loud volume music was not more arousing than moderate volume music. In addition, mental effort, which was inferred from the physiological measurement of heart-rate variability, did not differ in conditions with and without music. These findings indicate that listening to music does not impair performance in a monotonous car-following task, and might even improve some aspects of performance as a result of increased arousal.

1. Introduction

Among the various secondary tasks that drivers engage in while driving, listening to music or the radio seems to be the most common (Dibben & Williamson, 2007). Interestingly, drivers report listening to music habitually, and simply for the purpose of "killing time" on the road (North, Hargreaves, & Hargreaves, 2004). Why do drivers need to "kill time" while driving? Can such a need for listening to music be related to the driving task not being sufficiently stimulating all the time? Indeed, the driving task can be monotonous at times, especially while driving in highly predictable environments that are low in complexity. Research indicates that such environments can elicit the experience of adverse driver states, such as boredom or drowsiness resulting from lack of external stimulation (Nelson, 1997; Thiffault & Bergeron, 2003). Importantly, such states might incline drivers to be prone to inattention errors, such as failing to notice changes in the traffic environment on time, which might increase accident-likelihood (NHTSA, 2008). Hence, monotonous driving conditions low in complexity can be quite challenging to handle, as drivers might find it hard to focus on the important aspects of the driving task due to the lack of arousal and stimulation. In the current paper, we explore whether listening to music might provide the external stimulation needed to defeat boredom and to keep focused on the driving task in situations where both the driving task and the traffic environment are monotonous, such as car-following in low-complexity traffic. Importantly, we not only study the influence of music on performance in such monotonous low-complexity situations, but also whether arousal is a relevant process variable explaining how music may influence driving performance in monotonous conditions.

* Corresponding author. Tel.: +31 50 363 3180.
E-mail address: a.b.unal@rug.nl (A.B. Ünal).

1369-8478/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.trf.2013.09.004

Studies on music and driving typically regard music as a secondary task that might be distracting to the driver. Various scholars have examined to what extent music disrupts one's driving performance (Beh & Hirst, 1999; Brodsky, 2002; North & Hargreaves, 1999; Pêcher, Lemercier, & Cellier, 2009). Interestingly, in simulated driving studies, impairment in driving performance with the presence of music was seldom reported (Brodsky, 2002; Pêcher et al., 2009). In addition, drivers have been found to adopt cognitive or behavioural compensatory strategies while listening to music to cope with increased task demands and protect their driving performance, especially when they were in relatively high-complexity traffic settings (Hughes, Rudin-Brown, & Young, 2013; Ünal, Platteel, Steg, & Epstude, 2013; Ünal, Steg, & Epstude, 2012) or/and when music-listening was somewhat cognitively demanding, such as when the volume was high (see North & Hargreaves, 1999). For instance, as indicative of cognitive compensations (see Hockey, 1997), drivers invested more mental effort when driving and listening to music in a high-complexity traffic setting, and prioritized the driving task by blocking-out radio-content to a large extent while driving (Ünal et al., 2012, 2013). Also, drivers who listened to demanding types of music (i.e., high volume and high tempo) were found to have longer lap times (due to lower speed) in a computer-based racing game as compared to drivers who listened to less demanding types of music (i.e., low volume and low tempo; North & Hargreaves, 1999). This finding indicated that drivers might compensate for the cognitive load induced by certain types of music by reducing their vehicles' speed. So, there is evidence suggesting that when the traffic demands or listening demands (or both) are high, drivers cope with the increased task demands by adopting compensatory strategies. In many cases, however, driving does not take place in complex environments. Indeed, driving often involves monotonous conditions that are very low in complexity, such as prolonged driving on rural roads or car-following for extended periods. So, would drivers employ compensatory strategies while driving in low-complexity traffic settings as well? And how would music affect their driving performance?

To our knowledge, little is known about the influence of music on task performance in monotonous driving conditions. A study that examined the influence of loud music on driving performance in various conditions, including two driving tasks that took place in a highly-predictable environment (namely monotonous driving and car-following tasks, respectively), revealed that listening to loud music did not impair driving performance (Ünal et al., 2012). Specifically, music had no influence on the lateral vehicle control of participants in a monotonous driving task, while in a car-following task they even appeared to better respond to speed changes of the lead vehicle. These findings provide some preliminary evidence that the presence of music may increase vigilance while following a car in low complexity situations. However, the car-following task that was used in that study was relatively short (6 min), and was embedded within a hectic driving environment with many critical incidents, meaning that it was not monotonous. Hence, the questions of whether music would have no or positive effects on task performance in monotonous conditions in low-complexity settings and how performance is maintained in such conditions remain open.

Investigations regarding prolonged and monotonous driving conditions in the presence of other types of secondary tasks and in-vehicle distracters, such as talking on a mobile phone, indicate that such secondary tasks do not necessarily impair driving performance. For example, although some studies showed a negative influence of using a mobile phone on car-following performance, as reflected by delayed responses to speed changes of the lead vehicle (Alm & Nilsson, 1995; Brookhuis, De Vries, & De Waard, 1991; Brookhuis, De Waard, & Mulder, 1994; Lamble, Kauranen, Laakso, & Summala, 1999), this tendency of having higher response latencies was absent while driving in low-complexity traffic with less perceptual load (Strayer, Drews, & Johnston, 2003). In addition, lane-keeping performance, which is an indication of lateral vehicle-control, was maintained in car-following tasks that were accompanied by a secondary task such as dialling a number or executing a working memory task on a mobile phone (Alm & Nilsson, 1995; Lamble et al., 1999). Importantly, some studies revealed that car-control performance even improved in low-complexity driving situations with the presence of a secondary task as compared to when there was no secondary task (Atchley & Chan, 2011; Brookhuis et al., 1991; Verwey & Zaidel, 1999). For instance, drivers who were required to carry out a concurrent mobile-phone task exhibited less swerving on the road as compared to drivers who did not have the additional mobile phone task (Brookhuis et al., 1991). These findings indicate that, different to those observed in complex driving conditions, secondary tasks might not necessarily have adverse consequences on driving performance in monotonous conditions that are low in complexity. This raises the question of which processes will enable driving performance to be maintained or even improved in the presence of a secondary task such as music.

As stated earlier, monotonous driving in situations characterized by low complexity is associated with low-arousal driver states such as boredom, drowsiness or fatigue, and drivers lack vigilance when they experience such states (Nelson, 1997; O'Hanlon, 1981; Thiffault & Bergeron, 2003; Wertheim, 1991). One potential explanation for drivers performing well in monotonous conditions in the presence of secondary tasks is that these tasks may increase arousal to a more optimal level that would increase vigilance (Atchley & Chan, 2011; Heslop, Harvey, Thorpe, & Mulley, 2010). This argument is in line with predictions of the Yerkes–Dodson law (Teigen, 1994; Yerkes & Dodson, 1908), which posits that the relationship between task performance and arousal can be depicted by an inverted U-shaped curve. When one's arousal level is too high or too low, performance is predicted to be inhibited, while a moderate arousal level is expected to result in higher performance. Easterbrook (1959) explained this phenomenon by the cue-utilization theory, suggesting a link between arousal and attention. More specifically, Easterbrook (1959) argued that both under-arousal and over-arousal would have a negative influence on attention by impairing the efficient processing of the relevant cues needed to perform well on a task. However, a moderate level of arousal was associated with facilitating selective attention and the processing of relevant cues, resulting in a better performance attainment. Based on Easterbrook's framework, we assume that in monotonous driving situations that are low in complexity, drivers would experience under-arousal due to the absence of external stimulation, which would impair their attentional processes. In such situations, performance might benefit from an external stimulation source, such as music, which would increase the arousal closer to optimal in monotonous situations, and thereby facilitate attention on the main task.

Research suggests that increases in arousal would particularly improve performance in easy tasks and less so in difficult tasks (Beh & Hirst, 1999; McGrath, 1963) because an arousing stimulus would influence mental workload and demands on information processing differently in simple and complex tasks. For instance, in difficult and complex tasks an additional arousing stimulus (e.g. loud noise) might increase mental workload above the ideal level, thereby competing for the cognitive capacity needed for primary task performance (Beh & Hirst, 1999; Boggs & Simon, 1968; Konečni & Sargent-Pollock, 1976). As a result, we might expect mental effort to increase due to task-related factors (e.g., task-demands). In relatively easy and monotonous tasks, however, performers have a higher threshold for arousal, and therefore, an arousing stimulus can be tolerated well (Yerkes & Dodson, 1908). Interestingly, for monotonous tasks, an increase in mental effort might be expected when the arousal level is below ideal and when the performer is deactivated due to feelings of fatigue or boredom (De Waard, 1996; Hancock & Verwey, 1997; Warm, Dember, & Hancock, 1996; Warm, Parasuraman, & Matthews, 2008). This type of effort that is mobilized as a consequence of monotony is called state-related effort or compensatory effort (see De Waard & Brookhuis, 1997; G. Mulder, 1986), meaning that drivers are inclined to invest more effort in the driving task in order to keep focused despite being bored or fatigued. Based on this reasoning, we assume that in highly monotonous tasks, increases in arousal might lead to a decrease in required mental effort investment by reducing state-related demands (i.e., fighting boredom or fatigue), which may increase vigilance, as a result of which driving performance would be secured. Can music provide the drivers with the levels of arousal that is needed to handle dull monotonous driving tasks?

Music, and especially some aspects of music that are associated with high energy such as loud and high tempo music, has been documented to increase self-reported and physiological arousal (Dalton, Behm, & Kibele, 2007; Davenport, 1972; Fontaine & Schwalm, 1979; Husain, Thompson, & Schellenberg, 2002; Konečni & Sargent-Pollock, 1976; McNamara & Ballard, 1999; North & Hargreaves, 1999). However, little is known about the relationship between music and arousal in monotonous driving conditions. Similarly, although there is preliminary evidence suggesting that in high-complexity environments music might increase mental effort by competing for the shared resources needed for the driving task (Ünal et al., 2012), to our knowledge, as yet no study has tested how mental effort is affected by music in monotonous driving conditions that are very low in complexity. In the current study, we aim to investigate these issues by employing a monotonous car-following task that takes place in a low complexity traffic setting, and examine how music-induced arousal affects driving performance, arousal, and mental effort in such settings. In addition, as individuals might have a higher threshold for arousal when busy with tasks that are not complex (McGrath, 1963; Yerkes & Dodson, 1908), we manipulate the loudness of music in an attempt to test whether loud (i.e., 85 dB) music with a higher arousal potential will improve performance on a monotonous car-following task more than moderate volume music (i.e., 70 dB) with a lower arousal potential. Studies suggest that both arousal and mental effort can be inferred from physiological changes, and especially, by changes in heart-rate (arousal) and heart-rate variability (mental effort; Dalton et al., 2007; L. Mulder, De Waard, & Brookhuis, 2005). In the current study, we not only assess arousal by self-reports but also by means of heart-rate data. In addition, heart rate (variability) information is used to track changes in mental effort.

Based on the above, and in line with the Yerkes–Dodson law (1908) and findings on the positive or nonnegative effects of secondary tasks on performance in monotonous tasks (Brookhuis et al., 1991; Heslop et al., 2010; Mayfield & Moss, 1989), we hypothesize that listening to music will either have no effect or positive effects on performance in a monotonous car-following task (Hypothesis 1). Hence, we expect that music will not impair car-following performance. Second, based on the premises of the cue utilization theory (Easterbrook, 1959), we hypothesize that the arousal level of the participants, as measured by both self-reports and the physiological indicator mean heart rate, will be higher when the monotonous driving task is accompanied by music as compared to when it is not accompanied by music (Hypothesis 2a). We further hypothesize that the influence of music on arousal will be more pronounced when driving with loud volume music as compared to when driving with moderate volume music (Hypothesis 2b). Lastly, in line with the literature on increased mental workload in monotonous driving conditions that are low in complexity (see De Waard, 1996), we hypothesize that mental effort as inferred from the physiological indicator heart-rate variability will be higher in the absence of music than in the presence of music (Hypothesis 3).

2. Method[1]

2.1. Participants

Fifty-two psychology students of the University of Groningen participated in the study in exchange for course credits. Five of the participants suffered from simulation sickness, and could not complete the simulated drive. Therefore, data analyses were carried out with the remaining 47 participants (21 female, 26 male) whose ages ranged from 19 to 25, with a mean age

[1] The study was approved by the Ethics Committee of the University of Groningen.

of 20.7 years ($SD = 1.34$). Participants' mean driving experience was 2.6 years ($SD = 1.61$), and they drove on average 5107 km in the year preceding the study ($SD = 5850$). None of the participants reported having any hearing deficiencies.

2.2. Experimental design

The study employed a 2 (driving with and without music) by 2 (loudness: listening to loud or moderate volume music) mixed-subjects design with repeated measures on the first factor. The repeated measures involved two assessments in the driving simulator: an experimental condition with music and a control condition without music; the order of these sessions was counterbalanced across participants. The between factor, which was labelled as "loudness", involved listening to music with either loud (85 dB) or moderate volume (70 dB); participants were randomly assigned to one of the loudness groups.[2] In all assessments, the same driving route was used which was monotonous and low in complexity, and which took 30 min to complete. In order to avoid possible learning effects, there was at least a 2-week interval between the first and second assessments of the participants. All the assessments were carried out during the day (i.e., 09.00–17.00), and participants had their first and second assessments at the exact same time of the day.

2.3. Driving simulator and driving environment

The driving simulator of the Psychology Department of the University of Groningen (StSoftware) was used, which had a usual car-control interface. The simulator was surrounded by four LCD screens, providing a 240° view of the traffic environment. The data were recorded in the database of the main computer with a sample rate of 10 Hz. (see Van Wolffelaar & Van Winsum, 1995). The simulated world depicted an intercity driving situation, in which drivers were on a single carriageway consisting of two lanes. Participants had to execute a car-following task in the simulator. As we aimed to induce monotony through the car-following task, we kept the car-following task relatively uninterrupted and longer (30 min) than in previous research (Alm & Nilsson, 1995; Lamble et al., 1999). The lead car that was placed in the lane of the participant had a variable speed that ranged between 60 and 80 km/h. The phase-length (length of accelerations and decelerations) ranged between 10 and 40 s randomly. In order to prevent the participants from overtaking the lead car out of boredom, there was oncoming traffic in the opposite lane at all times. The oncoming traffic was programmed in such a way that other vehicles never posed threat on the driver. In addition, both the speed of the oncoming vehicles and the distance between the vehicles was fixed. As such, we ensured that the traffic environment was highly predictable and monotonous.

2.4. Music stimuli

In order to have high ecological validity for the music-listening task, we did not use a specific playlist in the current study. Rather, participants created their own playlist at the beginning of the experimental session, by using an online music library. This methodology ensured high familiarity with and liking of music while driving, and therefore any effects observed on driving performance or heart-rate measures would not be related to being unfamiliar with the music or disliking the music. We checked whether we indeed succeeded in having everyone listening to their preferred type of music by asking participants to indicate the extent to which they liked the music. Responses were given on a 5-point Likert type scale (1 = totally disagree, 5 = totally agree).[3]

2.5. Dependent measures

2.5.1. Driving performance indicators

The main performance indicator for car-following was delay in response (sec.) which is a measure reflecting the delay in seconds in terms of responding to accelerations and decelerations of the lead vehicle. Specifically, delay in response was determined from the phase shift between the speed signal of the lead and following vehicle. However, in order for delay to be calculated correctly, the precondition of following the lead car coherently should be met (see De Waard & Brookhuis, 2000). Therefore, we also monitored coherence, which reflects the accuracy of car following as reflected in the correlation between the speed signals of the participant's car and the lead car. Hence, coherence values could range from 0 (no relation) to 1 (perfect relation), with higher values reflecting more accurate following of the lead car's speed changes. Brookhuis and colleagues (1994) suggested 0.70 to be a sufficiently high value for coherence. In the current study, we set this threshold to 0.60 in order not to exclude the participants who performed moderate to high. Individual scores for these car-following performance indicators were calculated by using the CARSPAN program (L. Mulder, 1992), which uses the speed signals of the lead and following vehicles in calculating "the co-occurrence of rhythmic changes in two signals measured" (p. 428; Brookhuis et al., 1994). Mean coherence and delay scores were computed for every 5 min of the 30-min simulated drive. Therefore,

[2] There were no systematic differences between the groups in terms of age ($F < 1$, ns) and driving experience measured by the annual km driven in the year preceding the study ($F < 1$, ns). In addition, the gender distribution was the same in the groups, meaning that both groups held similar characteristics.

[3] Inspection of the ratings revealed that participants reported a high liking for the music they listened to ($M = 4.7$, $SD = 0.54$). Importantly, there was no difference between the moderate and high volume groups in terms of liking the music ($F < 1$, *ns*), meaning that regardless of the loudness of the music, all participants enjoyed the songs they listened to.

we calculated six delay and six coherence scores for each drive, allowing us to detect any changes in car-following performance over time as well (i.e., time-on-task effects).

In addition to these specific indicators of car-following, participants' lateral control was recorded by assessing the standard deviation of lateral positioning (SDLP in metres) on the road, which is a general indicator reflecting lane-keeping performance (O'Hanlon, Haak, Blaauw, & Riemersma, 1982). Three SDLP values were calculated automatically by the data processing tool of the simulator. As a consequence, lateral control is reflected in 10 rather than 5-min intervals (i.e., 0–10 min, 10–20 min and 20–30 min). The lower the SDLP scores, the better one's lane keeping performance.

2.5.2. Physiological measures of arousal and mental effort

Participants' electrocardiogram (ECG) was measured by three Ag–AgCl electrodes; one of them placed at the sternum, the other two placed in between the two lower ribs on the right and left. The ECG signal was recorded with a sampling rate of 250 Hz. R-peaks (i.e., peak in the electrical signal) were detected online using Portilab (version 1.10, Twente Medical Systems International) with an accuracy of 1 ms. Data were checked for artefacts and corrected automatically using the CARSPAN program, and were visually inspected (see L. Mulder, 1992). Spectral analysis of the cardiovascular data was also performed with the CARSPAN program. The first three and the last 3 min of the ECG data were resting measurements (labelled Resting 1 and Resting 2). For resting and experimental sections, mean heart rate and heart-rate variability in the mid (0.07–0.14 Hz) frequency band were computed, the former as an indication of arousal and the latter of mental effort (see L. Mulder, 1992).

Similar to the procedure with the car-following performance indicators, mean heart rate and heart rate variability scores were recorded based on 5-min intervals of the 30-min driving task. As such, we calculated eight scores (two resting measures and six task measures) for mean heart rate and heart rate variability for each simulated drive (i.e., the drive with music and without music), reflecting changes in heart rate over time. In addition, overall means for heart-rate and heart-rate variability (over 30 min) were calculated to compare heart-rate recordings during the driving task to the resting periods in order to check whether heart rate recordings were sensitive to driving task-characteristics and the presence of music while driving.

2.5.3. Self-reported deactivation after the simulated drives

Subjective arousal level was assessed by using an explicit self-report that measured relevant emotions in terms of deactivation in monotonous driving conditions. Specifically, the measure consisted of three emotions that depict negative valence and low-arousal in Russell's Circumplex Model of Affect (1980), namely bored, tired and sleepy. In addition, we also included the item energized that depicts positive valence and high-arousal. Participants indicated to what extent they felt bored, tired, sleepy and energized after the simulated drive on a Likert-type scale (1 = strongly disagree, 7 = strongly agree). The item energized was reverse coded. A factor analysis revealed that all four items loaded on a single factor, which we labelled deactivation. The scale had an acceptable level of reliability (Cronbach's alpha = .70). So, mean scores were calculated reflecting the self-reported deactivation level during the drives with music and without music; higher scores reflect higher self-reported deactivation.

2.6. Procedure

We followed the same procedure in all assessments. Participants were instructed that they were going to complete a driving session in the simulator during which their heart rate would be recorded. At this point, participants in the music condition were informed that they would listen to music while driving, and they were asked to create a playlist representative of what they like to listen to on the road. Prior to both of the simulated driving sessions, all participants received training in the simulator. The training took approximately 5 min to complete, and involved a car-following task. Participants were instructed to follow the lead car's speed changes as well as possible, while maintaining a safe headway to it. Participants who were observed not to conform with the instructions were instructed further during the training that they should always follow the lead car by having a close but safe headway distance, meaning that all participants were acquainted with the task of car-following before the experimental session began. Following the training period, participants drove in the simulator for 30 min for each test drive during which their heart rate was recorded. In addition, we took two resting heart-rate measurements before and after each drive with participants seated in the simulator (see Section 2.5.2). The resting periods were not accompanied by music. After the second resting heart-rate measurement, participants were seated behind a desk, and they filled in the self-reported deactivation scale (see Section 2.5.3). After the drive with music, participants also completed a brief questionnaire on whether they indeed liked the music they had listened to (see Section 2.4).

2.7. Analyses

The analyses included within-subjects comparisons in the music and no-music conditions, and between group comparisons of the music volume groups. Therefore, we used a mixed-ANOVA for data analyses. Specifically, we first ran an overall mixed-ANOVA to check whether the multivariate test was significant. When the multivariate test results were significant, we ran separate mixed-ANOVAs to explore the differences within conditions in car-following performance, mean heart-rate and heart rate variability (which were measured over 5 min intervals), and standard deviation of lateral positioning (which was measured over 10-min intervals). Partial eta square (η_p^2) was used to report the effect sizes, and a significance level of .05 was set for statistical significance.

Prior to analysing the data on car-following performance indicators, we inspected the data to identify participants who failed at following the lead car coherently. Inspection of the data revealed that thirteen participants (7 from the loud volume music and 6 from the moderate volume music group) had coherence scores below 0.60 in almost all instances of car-following, and in both of the assessments. These participants' car-following data were not included in the analyses because they did not perform the car following task according to instructions. Hence, the analyses of car-following performance were carried out with the remaining 34 participants' data sets. Finally, inspection of the heart-rate recordings revealed two participants whose heart rate data showed a high number of artefacts resulting from technical problems during the recording process. These participants' data were excluded from the analyses regarding the heart-rate measures.

3. Results

3.1. Car-following performance

3.1.1. Accuracy in car-following (coherence)

Initially, an overall mixed-ANOVA was run with all six coherence scores in the music and no-music conditions as a within-subjects factor, and loudness as a between-groups factor. Results revealed a significant multivariate effect for coherence ($F(11,22) = 2.77$, $p < .05$), which implies that there might be within-subjects differences while driving with music and without music over a 30-min long drive. In addition, we found a significant group difference in coherence ($F(1,32) = 8.62$, $p < .01$, $\eta_p^2 = 0.21$). The interaction of the presence of music and volume of music, however, was not significant ($F < 1$, *ns*). We

Table 1
Results of a mixed-ANOVA: *F*-statistics for the heart rate measurements and driving performance indicators.

	Mean heart-rate			Heart rate variability			Coherence			Delay		
	df	*F*	η_p	df	*F*	η_p	df	*F*	η_p^2	df	*F*	η_p^2
Resting 1												
Music/No-Music	1,42	0.44	.01	1,42	1.66	.04						
Amplitude	1,42	0.13	.00	1,42	0.21	.01						
Music/No-Music × Amplitude	1,42	0.20	.00	1,42	0.81	.02						
Car-following task												
0–5 min												
Music/No-Music	1,43	8.18**	.16	1,43	0.44	.01	1,32	0.00	.00	1,32	5.46*	.15
Amplitude	1,43	0.16	.00	1,43	0.10	.00	1,32	3.54δ	.10	1,32	4.47*	.12
Music/No-Music × Amplitude	1,43	0.12	.00	1,43	0.00	.00	1,32	0.26	.00	1,32	0.09	.00
5–10 min												
Music/No-Music	1,43	5.77*	.12	1,43	2.23	.05	1,32	0.48	.02	1,32	9.20**	.22
Amplitude	1,43	0.17	.00	1,43	0.00	.00	1,32	9.12**	.22	1,32	5,14*	.14
Music/No-Music × Amplitude	1,43	0.28	.00	1,43	1.51	.03	1,32	0.09	.00	1,32	2.01	.06
10–15 min												
Music/No-Music	1,43	5.85*	.12	1,43	0.45	.01	1,32	0.45	.01	1,32	14.41**	.31
Amplitude	1,43	0.15	.00	1,43	0.08	.00	1,32	5.70*	.15	1,32	5.21*	.14
Music/No-Music × Amplitude	1,43	0.25	.01	1,43	0.01	.00	1,32	0.33	.01	1,32	6.52*	.17
15–20 min												
Music/No-Music	1,43	3.93σ	.08	1,43	0.18	.00	1,32	0.05	.00	1,32	8.27**	.20
Amplitude	1,43	0.18	.00	1,43	0.79	.02	1,32	6.36*	.17	1,32	4.44*	.12
Music/No-Music × Amplitude	1,43	0.01	.00	1,43	0.94	.02	1,32	0.14	.00	1,32	2.45	.07
20–25 min												
Music/No-Music	1,43	3.16	.07	1,43	0.01	.00	1,32	0.77	.02	1,32	4.30*	.12
Amplitude	1,43	0.06	.00	1,43	0.07	.00	1,32	6.10*	.16	1,32	4.20*	.12
Music/No-Music × Amplitude	1,43	0.01	.00	1,43	1.84	.04	1,32	0.10	.00	1,32	0.80	.02
25–30 min												
Music/No-Music	1,43	2.34	.05	1,43	0.01	.00	1,32	0.78	.02	1,32	4.23*	.12
Amplitude	1,43	0.02	.00	1,43	0.60	.01	1,32	4.06σ	.11	1,32	1.37	.04
Music/No-Music × Amplitude	1,43	0.05	.00	1,43	0.25	.01	1,32	1.34	.04	1,32	0.02	.00
Resting 2												
Music/No-Music	1,43	1.66	.04	1,43	1.01	.02						
Amplitude	1,43	0.17	.00	1,43	1.43	.03						
Music/No-Music × Amplitude	1,43	0.31	.01	1,43	0.00	.00						
n				45					34			

* $p < .05$.
σ $p = .05$.
** $p < .01$.
δ Marginally significant at $p < .07$.

explored the differences in coherence while driving with and without music in more detail by running separate mixed-ANOVAs for each of the 5-min intervals of the simulated drive. As can be seen in Table 1, there was no main effect of the presence of music on coherence in any of the 5-min interval (all *F*s < 1, *ns*). However, there was a main effect of loudness group on coherence during all intervals (see Table 1): regardless of the presence or absence of music, participants who were in the loud volume music group followed the lead car more coherently than participants who were in the moderate volume music group (see Fig. 1). Again, there were no interaction effects of the presence of music and music volume (*F* values ranging from 0.09 to 1.34; all being non-significant at $p < .05$; see Table 1). In non-statistical terms, these results indicate that the main effect of loudness resulted from initial differences among participants in each group, and not because of the volume of the music.

Together, the findings gave support to the first hypothesis, as participants were able to follow the lead car accurately both with music and without music, indicating that the presence of music did not impair car-following performance. Also, loudness of the music did not significantly affect car-following performance. Next, we examined whether the same pattern would be observed for the main performance indicator: delay in response in car-following.

3.1.2. Differences in delay in response in car-following

An overall mixed-ANOVA was run with the mean delay scores during the 5-min intervals in the music and no-music conditions as a within-subjects factor, and loudness as a between-groups factor. Results revealed a significant multivariate effect for delay in response to the speed changes of the lead vehicle ($F(11,22) = 3.30$, $p < .01$), which implies that there might be within-subjects differences while driving with music and without music over a 30-min long drive. In addition, we found a main effect of loudness on delay ($F(1,32) = 5.28$, $p < .05$, $\eta_p^2 = 0.13$) while the interaction term was again not statistically significant ($F(11,22) = 1.07$, *ns*). As the overall mixed-model ANOVA revealed significant multivariate effects, delay scores were further investigated by running separate mixed-ANOVAs for each 5-min interval of the car-following task. Supporting the first hypothesis, the results revealed a significant main effect of the presence of music in all six parts of the car-following task (see Table 1). It appeared that participants responded faster to the speed changes of the lead car when they listened to music while driving than when there was no-music (see Fig. 2). There was a significant main effect of loudness group on delay during the first 25 min of the car-following task (see Table 1). Regardless of the presence or absence of music, participants who were in the loud volume music group responded faster to the speed changes of the lead vehicle as compared to the participants who were in the moderate volume music group, again suggesting initial differences between groups (see Fig. 3). Lastly, we observed a significant interaction effect of the presence of music and loudness on delay for the third part of the car-following task (i.e., 10–15 min). Contrast analysis revealed no significant differences in delay between the groups while driving with music. However, when driving without music, the loud volume music group responded faster to the speed changes of the lead vehicle ($M = 3.30$, $SE = 0.51$) as compared to the moderate volume music group ($M = 5.20$, $SE = 0.48$; $F(1,32) = 7.28$, $p < .05$).

We also checked whether there was an effect of time-on-task on delay in response while driving with music and without music. A mixed-ANOVA with all six scores reflecting the delay scores in every 5-min of driving revealed no main effect of time-on-task on delay while listening to music ($F(5,220) = 1.32$, *ns*, $\eta_p^2 = 0.03$). So, in the presence of music, delay did not change significantly over time. Also, loudness had no main effect on delay scores ($F < 1$, *ns*) and the interaction of loudness and time-on-task was not statistically significant either ($F(5,220) = 1.15$, *ns*, $\eta_p^2 = 0.03$). A second mixed ANOVA with the six delay scores while driving without music revealed a significant main effect of time-on-task ($F(5,225) = 2.57$, $p < .05$, $\eta_p^2 = 0.05$). However, contrast analysis did not reveal a significant linear or quadratic trend for this effect. There was no main effect of loudness on delay scores while driving without music ($F < 1$, *ns*), and the interaction of loudness and time-on-task was not statistically significant either ($F < 1$, *ns*).

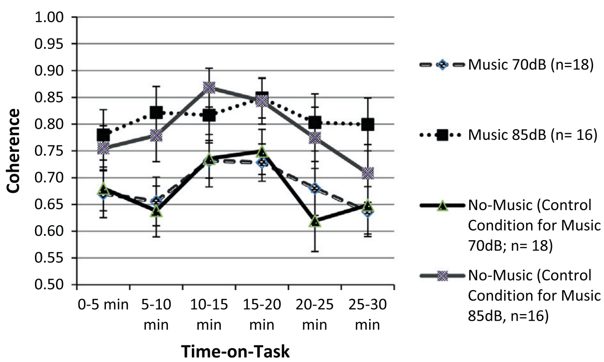

Fig. 1. Coherence in car-following while driving with and without music in loud and moderate volume music groups. Bars represent the standard errors for the means.

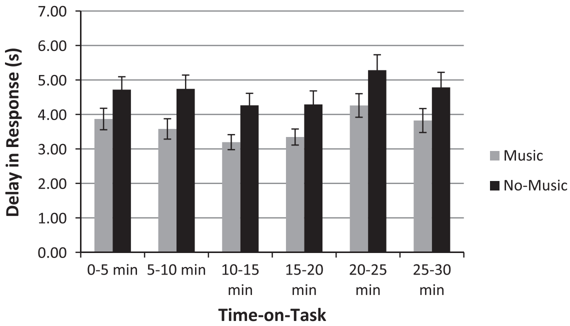

Fig. 2. Delay in response while following a lead car when driving with and without music. Bars represent the standard errors for the means ($n = 34$).

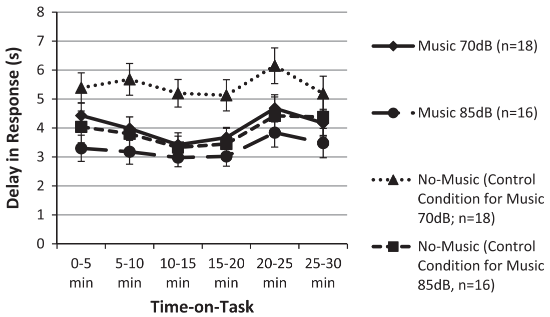

Fig. 3. Delay in car-following while driving with and without music in loud and moderate volume music groups. Bars represent the standard errors for the means.

3.1.3. Effect of music on standard deviation of lateral positioning

Standard deviation of lateral positioning (SDLP) was used as a general indicator of driving performance during car-following with and without music. First, an overall mixed-ANOVA was run with the SDLP scores while driving with music and without music as a within-subjects factor and loudness as a between groups factor. Results revealed a significant multivariate effect for SDLP ($F(5,27) = 3.30$, $p < .05$). There was no main effect of loudness on the SDLP scores ($F < 1$, *ns*) with music or without music, and the interaction term was not significant either ($F(1,31) = 1.46$, *ns*).

We then ran separate mixed-ANOVAs for three 10-min sections of the simulated drive in order to further explore the differences in lane-keeping performance with music and without music. Results revealed significant main effects of the presence of music on SDLP during the last two time intervals (see Table 2). Supporting Hypothesis 1, participants had a slightly

Table 2
Mixed-ANOVA results for standard deviation of lateral positioning (SDLP) during 10-min intervals of the car-following task with and without music.

	SDLP (m)		SDLP (m)		df	F	η^2_p
	Music (70 dB) Mean	No-Music (70 dB) Mean	Music (85 dB) Mean	No-Music (85 dB) Mean			
Car-following task							
0–10 min							
Music/No-Music	0.25 (.09)	0.25 (.06)	0.25 (.07)	0.27 (.07)	1,31	1.22	.04
Amplitude					1,31	0.34	.01
Music/No-Music × Amplitude					1,31	1.39	.04
10–20 min							
Music/No-Music	0.24 (.07)	0.25 (.07)	0.24 (.05)	0.28 (.08)	1,31	6.27*	.17
Amplitude					1,31	0.32	.01
Music/No-Music × Amplitude					1,33	2.43	.07
20–30 min							
Music/No-Music	0.25 (.06)	0.27 (0.8)	0.24 (.05)	0.27 (.06)	1,31	6.03*	.16
Amplitude					1,31	0.00	.00
Music/No-Music × Amplitude					1,31	0.44	.01
n	18		15				

Note: Values in parentheses are the standard deviations for mean SDLP (m).
* $p < .05$.

smaller standard deviation of lateral positioning while driving with music than while driving without music during 10–20 min ($F(1,31) = 6.27$; $p < .05$) and 20–30 min ($F(1,31) = 6.03$; $p < .05$) of the car-following task, while SDLP during the first 10 min of car-following did not differ between conditions with and without music ($F(1,31) = 1.22$, *ns*). Finally, there was no main effect of loudness on the SDLP, and no interaction of the presence of music and loudness on the SDLP scores in any of the time intervals with music and without music (see Table 2). Inspection of time-on-task effects revealed no effects for drives with music and without music either ($F(2,62) = 1.76$, *ns* and $F(2,64) = 1.42$, *ns* respectively).

3.2. The effect of music on self-reported deactivation after the simulated drives

A mixed-ANOVA revealed a main effect of the presence of music on self-reported deactivation ($F(1,45) = 55.33$, $p < .001$, $\eta_p^2 = 0.55$). As expected (Hypothesis 2a), participants reported being less deactivated (i.e., more aroused) after driving with music ($M = 3.69$, $SD = 1.16$) than without music ($M = 5.01$, $SD = 0.94$). The analysis did not reveal a main effect of loudness on deactivation ($F(1,45) = 2.12$, *ns*). However, a statistically non-significant trend towards an interaction effect between the presence of music and loudness was found ($F(1,45) = 3.86$, $p = .06$, $\eta_p^2 = 0.08$). Specifically, in line with Hypothesis 2b, after a drive with music, participants who listened to loud volume music scored lower on deactivation ($M = 3.33$, $SD = 1.26$) compared to those who listened to moderate volume music ($M = 4.03$, $SD = 0.94$). After a drive without music, however, participants in both groups scored equally high in self-reported deactivation ($M = 5.01$, $SD = 0.85$ and $M = 5.01$, $SD = 1.04$, respectively for the no-music condition of 85 dB and 70 dB volume groups). In non-statistical terms, loud volume music showed the expected pattern of being more arousing than moderate volume music, while however, this difference was not significant and remained as a trend.

3.3. The effect of music on mean heart rate

Prior to testing for differences between mean heart rate while driving with and without music, we first checked whether there were systematic differences in mean heart rate during resting periods and driving. As such, we aimed at exploring the sensitivity of the heart rate measurement, because a difference between task and resting periods would reflect that mean heart rate was sensitive to task-related factors. Results of an overall mixed-ANOVA revealed a significant within-subject difference in mean heart rate between task and resting periods ($F(5,210) = 7.57$, $p < .001$, $\eta_p^2 = 0.15$). Repeated contrasts revealed that when driving without music, mean heart rate while driving ($M = 81.49$, $SD = 11.92$) was significantly higher than the mean heart rate during the Resting 2 period ($M = 77.68$, $SD = 10.68$; $F(1,42) = 36.56$, $p < .001$), but not significantly different from the mean heart rate during the Resting 1 period ($M = 81.57$, $SD = 13.56$; $F < 1$, *ns*). So, participants' heart rate during driving did not differ from the first baseline measure; however, it differed from the second baseline measure, with a decrease in average heart rate of about 4 beats/min in Resting 2. Contrasts analyses indicated that for the drive with music, mean heart rate during the driving task ($M = 84.64$, $SD = 12.39$) was significantly higher than in the Resting 1 ($M = 82.69$, $SD = 12.79$; $F(1,42) = 6.90$, $p < .05$) and Resting 2 ($M = 79.17$, $SD = 12.26$; $F(1,42) = 71.70$, $p < .001$) periods. The findings thus indicated that the heart-rate measure was sensitive to driving task characteristics.

Next, we compared the mean heart rate of the participants during the 30-min task period in the conditions with and without music. A mixed-ANOVA revealed that mean heart rate of the participants was approximately 3 beats/min higher while driving with music ($M = 84.20$, $SD = 12.62$) than while driving without music ($M = 81.00$, $SD = 12.38$; $F(1,43) = 5.12$, $p < .05$; $\eta_p^2 = 0.10$). Therefore, in line with the Hypothesis 2a, listening to music increased arousal while driving.

We further explored in which part of the simulated drive mean heart rate was significantly different while driving with music as compared to driving without music. Separate mixed-model ANOVAs were run for each time interval as well as for the resting measurements. As can be seen in Fig. 4, participants' mean heart rate was significantly higher during the first

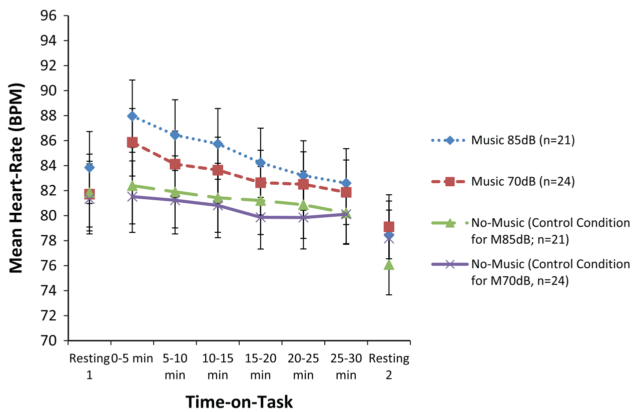

Fig. 4. Mean heart-rate while driving with and without music in loud and moderate volume music groups. Bars represent the standard errors for the means.

20 min of the 30-min long simulated drive when driving with music as compared to when there was no-music (see Table 1). For the last 10 min of driving, this trend of a higher mean heart rate while driving with music remained, but the differences were only marginally significant. There were no interaction effects, and no differences between the groups who listened to music with volumes of 85 dB versus 70 dB. So, Hypothesis 2b on loud volume music being more arousing than moderate volume music was not supported (see Table 1).

We further explored how the volume of the music affected mean heart rate of participants by calculating difference scores by subtracting the mean heart rate in the condition without music from the mean heart rate in the condition with music. As seen in Fig. 5, the difference scores were always different from 0 for both volume groups. Visual inspection of Fig. 5 also shows that the difference in mean heart rate when driving with music and without music was approximately one-beat higher for the loud volume music group as compared to moderate volume music group during the first half of the driving task, while there was no statistically significant difference between the loudness groups on this measure.

We also see that the difference in mean heart rate with music and without music diminished over time, suggesting a habituation effect for both groups (see Fig. 5). Indeed, an overall mixed-ANOVA revealed a main effect of time-on-task on mean heart rate while driving with music ($F(5,225) = 27.32$, $p < .001$, $\eta_p^2 = 0.38$). Contrast statistics revealed a significant linear trend ($F(1,45) = 48.53$, $p < .001$, $\eta_p^2 = 0.52$), indicating a decrease in mean heart rate as an effect of time-on-task while driving with music. There was no main effect of loudness ($F < 1$, *ns*), and no interaction effect of loudness and time-on task ($F(5,225) = 1.32$, *ns*) on mean heart rate. A second overall mixed-ANOVA was run for the condition without music. The results of the analysis again revealed a main effect of time-on-task on mean heart rate while driving without music ($F(5,215) = 3.96$, $p < .01$, $\eta_p^2 = 0.08$). Contrast statistics revealed a significant linear trend again ($F(1,43) = 4.85$, $p < .05$ $\eta_p^2 = 0.10$), suggesting a decrease in mean heart rate over time. There was no main effect of loudness ($F < 1$, *ns*) and no interaction effect of loudness and time-on-task ($F < 1$, *ns*) on mean heart rate.

3.4. The effect of music on heart rate variability

Prior to examining whether music would lead to decreased heart rate variability (in the mid, 0.10 Hz frequency band) reflecting increased mental effort, we again explored the sensitivity of the heart-rate measures by examining whether the driving task-induced heart rate variability differed from the baseline heart rate variability measurements taken before and after each drive (Resting 1 and Resting 2 for each condition). An overall mixed-model ANOVA with the resting and driving task-induced heart rate variability scores for the music and no-music conditions revealed a main effect of driving on heart rate variability ($F(5,210) = 12.34$, $p < .001$, $\eta_p^2 = 0.23$). Repeated contrasts revealed that heart rate variability during driving without music ($M = 6.90$, $SD = 0.66$) was significantly lower than heart rate variability during Resting 2 ($M = 7.60$, $SD = 0.68$; $F(1,42) = 50.68$, $p < .001$), but not significantly different from Resting 1 ($M = 7.00$, $SD = 0.96$; $F(1,42) = 2.90$, $p < .10$). Contrasts further revealed that mental effort was higher while driving with music compared to when not driving, as findings indicate that heart rate variability during the drive ($M = 6.90$, $SD = 0.62$) was significantly lower than heart rate variability during Resting 1 ($M = 7.20$, $SD = 0.94$; $F(1,42) = 6.98$, $p < .05$) and Resting 2 ($M = 7.40$, $SD = 0.87$; $F(1,42) = 23.43$, $p < .001$). These findings suggested that heart-rate variability was sensitive to driving task characteristics.

Next, we compared the heart rate variability of the participants during 30-min task periods in the conditions with music and without music. A mixed-ANOVA revealed no significant differences in heart rate variability while driving with music ($M = 6.90$, $SD = 0.62$) compared to while driving without music ($M = 6.89$, $SD = 0.68$; $F < 1$, *ns*). Inspection of the heart rate variability of the participants during each of the 5-min intervals with music and without music revealed a similar finding, and as opposed to our expectations, results revealed no main effect of the presence of music on heart rate variability (see Table 1). There was no main effect of loudness on heart rate variability, and no interaction of loudness group and the presence of music either.

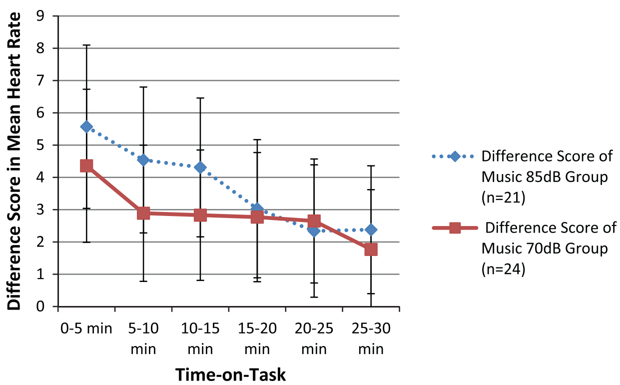

Fig. 5. Difference scores between mean heart rate while driving with and without music. Bars represent the standard errors for the difference scores.

4. Discussion

In the current study, the influence of music on driving performance in monotonous and low-complexity driving conditions was examined. We first hypothesized that listening to music would either have no effects or a positive effect on performance in a car-following task (Hypothesis 1). Second, we hypothesized that arousal level of the participants would be higher when the driving task was accompanied by music as compared to when it is not accompanied by music (Hypothesis 2a). We further hypothesized that the expected influence of music on arousal would be more pronounced in a condition with loud volume music than moderate volume music (Hypothesis 2b). Third, we hypothesized that mental effort inferred from heart-rate variability would be higher in the absence of music than in the presence of music (Hypothesis 3).

Our first hypothesis on no effects or a positive effect of music on driving performance in monotonous settings was supported, in that listening to music did not impair performance in a car-following task as indicated by a variety of measures. First, drivers performed equally well while driving with music and without music as reflected by the coherence of their driving, i.e., how well speed changes of a lead car were followed. This finding is in line with earlier studies on the effects of using a mobile-phone on coherence (Brookhuis et al., 1994; De Waard & Brookhuis, 1991), and demonstrates that in monotonous situations drivers are able to carry out a car-following task accurately despite the presence of a secondary task, in our case listening to music, and irrespective of the volume of music. Second, and importantly, the findings on the main indicator, namely delay in responses to the speed changes of the lead vehicle, revealed that listening to music even improved this aspect of driving performance, irrespective of the volume level. More specifically, drivers responded to the lead vehicle faster when they listened to music as compared to when there was no music, and this pattern was consistent over time as there were no time-on-task effects for delay. This finding is in line with earlier findings on lowered response latencies in a shorter car-following task (Ünal et al., 2012), and therefore, confirmed that regardless of the length of the car-following task, music improved responses to speed changes of the lead vehicle.

Third, we found that drivers' lateral control was relatively better in the presence than in the absence of music, as indicated by a somewhat smaller SDLP during the last 20 min of car-following while listening to music, irrespective of the volume. The slight increase in SDLP during the last 20 min of car-following in the absence of music might seem small, yet is not negligible as it is in line with the existing criteria for impaired SDLP provided by previous literature (see Brookhuis, De Waard, & Fairclough, 2003). Interestingly, during the first 10 min of car-following no such difference was observed in lateral control between conditions with and without music. Previous research has documented that using a mobile phone while car-following had no or even positive effects on car-control performance (Alm & Nilsson, 1995; Brookhuis et al., 1991; Lamble et al., 1999). The present result extends the findings of this literature by showing that listening to music does not impair lateral control during car-following either. Therefore, the results lend further support to the argument that some aspects of performance might benefit from the presence of secondary tasks or distracters in monotonous driving tasks (Heslop et al., 2010). We should note, however, the pattern of findings on delay scores were not consistent with the literature on using mobile-phones during car-following. While using a mobile phone was associated with impairment in response latencies to the speed changes of the lead vehicle (Alm & Nilsson, 1995; Lamble et al., 1999), listening to music improved response latencies. This suggests that not all secondary tasks may influence driving performance similarly in monotonous tasks. Indeed, our finding on the improved responses to the lead vehicle in the presence of music indicates that listening to music might somehow work differently to affect performance in monotonous tasks compared to other secondary tasks. For instance, the listening component of a mobile phone task might be more engaging as compared to listening to music or the radio (Strayer & Johnston, 2001), which might explain the findings on impaired response times with the use of mobile phones.

In the current research, we were mainly interested in arousal as a relevant process variable that could explain the observed no-effects or positive effects of music on performance in monotonous driving tasks. Specifically, we proposed that music would lead to increased arousal (Hypothesis 2a), and therefore, would provide drivers with external stimulation while busy with monotonous driving tasks. Our findings on both the self-reported and physiological indicators of arousal indicated that listening to music indeed increased the arousal level of the participants. Specifically, self-reports of drivers suggested that drivers were more aroused when there was music accompanying the driving task as compared to driving without music. A similar pattern was evident from the physiological indicator of arousal, namely mean heart rate, which was higher while driving with music compared to driving without music, particularly in the first part of the simulated drive. So, Hypothesis 2a on increases in arousal when driving with music was supported. When interpreted together with the findings on performing the lane-keeping task better in the presence of music, the results suggest that drivers were more attentive when they were more aroused due to listening to music while driving. As such, our study gives support to the predictions based on Easterbrook's (1959) cue-utilization theory that increases in arousal would facilitate the processing of relevant cues in tasks that require continuous attention. Interestingly, the inspection of time-on-task effects revealed that the differences observed in mean heart rate when driving with music versus without music were more pronounced for the first 20 min of a 30 min drive, suggesting a habituation effect. So, participants seemed to accommodate to the arousing effect of music close to the end of the drive. Together, the findings showed that music is indeed a powerful source of arousal (Fontaine & Schwalm, 1979; McNamara & Ballard, 1999), while in instances of driving for longer periods in monotonous conditions, the arousing effects of music appear to diminish over time.

Apart from investigating the influence of music on arousal in general, we also aimed to explore whether loud volume music would increase arousal more than moderate volume music does (Hypothesis 2b). As opposed to our expectations, arousal as reflected in mean heart rate was not influenced differently by the volume of the music. There was a trend for loud volume music to increase self-reported arousal though, as compared to moderate volume music, but this trend did not reach statistical significance. In addition, there was no difference in driving performance of people listening to music with either loud or moderate volumes. So the findings indicate that, regardless of the volume level, listening to music as such was the main reason for a higher arousal and a better performance attainment while following a lead vehicle.

As an increased level of arousal was expected to ease task demands while driving in monotonous conditions, we predicted that mental effort inferred from heart-rate variability would be higher in the absence of music than in the presence of music (Hypothesis 3). The findings did not support this hypothesis. More specifically, mental effort that was tracked by the changes in heart rate variability was not lower while driving with music than without music. Research suggested increases in self-reported mental effort and workload in the presence of music while busy with not only demanding driving tasks consisting of hazardous incidents (Hughes et al., 2013; Ünal et al., 2012), but also while busy with short monotonous driving tasks (Ünal et al., 2012). Therefore, the current finding of no-differences in mental effort measured by heart-rate variability supports earlier predictions that heart-rate variability might not be a sensitive measure in detecting changes in state-related mental effort that is expected to increase in monotonous conditions (see L. Mulder et al., 2005). An alternative explanation is that the expected relationship between increases in state-related effort in the absence of external stimulation might be observed only when the performer is busy with the same monotonous tasks for even longer periods. Maybe then, the decrease in arousal due to habituation effect would lead to increases in mental effort in the expected direction.

5. Limitations and future research

The current research had some limitations. First, although driving simulators are being commonly used in traffic research due to their practicality and high level of experimental control, replications of the study in real-life driving settings, such as via on-road assessments involving monotonous driving tasks, are needed in order to ensure the generalizability of the findings. Second, in the current study, we aimed at a high ecological validity in terms of the music stimuli, and therefore, made participants chose their own music. As a consequence, we did not have control over the structural properties of music (e.g. tempo, mode, rhythm). Future research might examine whether the effects of music on driving performance, arousal and mental effort in monotonous settings depends on structural properties of the music presented to participants.

Third, although listening to music with loud or moderate volume did not influence the vast majority of our main variables differently, we observed an unexpected group difference in terms of some aspects of car-following performance. In particular, irrespective of the presence and absence of music, one group of participants (who were in the loud-volume music group) performed better in terms of coherence of driving and delay of response to speed changes of the lead car, suggesting they outperformed the other group in the car-following task. Participants were randomly assigned to the experimental groups, which is a strong and preferred method (c.f. Pelham & Blanton, 2007) as matching groups on every possible factor of influence is not feasible. In the current study, randomization indeed seemed to work well, as there were no differences between the groups in terms of driving experience, age, and gender distributions. Therefore, the current finding is surprising. We suspect that the observed group differences might have resulted from some other uncontrolled driver or personality characteristics, such as sensation-seeking or extraversion. For instance, research indicates that high and low sensation-seekers have different preferences for optimal level of arousal (Litle & Zuckerman, 1986), meaning that monotonous driving conditions or the presence of music in such conditions might affect them differently. Therefore, future research could also take into account the possible interaction of personality factors with arousal while studying driving performance in monotonous conditions. Furthermore, our study employed young drivers who might tolerate loud volume music better than elderly drivers. Future studies may also target employing an older group of drivers in order to explore whether our results can be replicated in different samples.

Finally, the current study was the first attempt to investigate the relationship between music-listening and mental effort during a low-complexity monotonous drive. Yet, our findings did not confirm the expectation that mental effort would be lower in the presence than absence of music. Future research is needed to further explore the relationship between music and mental effort in prolonged monotonous and low-complexity traffic settings, as well as to identify the extent to which the observed finding was an artefact of the measure used for assessing mental effort (i.e., heart rate variability).

6. Conclusions

The current study aimed to explore how music affects driving performance in monotonous driving situations marked by low-complexity. Our findings revealed that listening to music does not impair performance in a car-following task. Rather, we found that music did not inhibit performance and even positively affected performance in relation to lane-keeping and responding to the speed changes of a lead vehicle in a car-following task. In addition, we showed that music increased arousal while driving. Importantly, although loud-volume music had a higher potential to activate individuals as compared to moderate-volume music, the volume of music did not influence car-following performance differently. Together with the findings on maintained and sometimes even improved driving performance, the pattern of results supports the argument that irrespective of the volume level of music, music provides drivers with some additional external stimulation that might be useful to stay vigilant while executing monotonous driving tasks in low-complexity traffic settings.

Our findings suggest that the presence of music might benefit driving safety in low-complexity and monotonous driving conditions. For instance, although not tested in the current study, it is possible that drivers might engage in some risky actions on monotonous roads, such as speeding or close-following, in order to satisfy their need for arousal. Our findings suggest that when busy with monotonous driving tasks listening to music might be a good strategy to counter boredom and to satisfy the need for arousal. Future studies could explicitly focus on potential safety effects of listening to music during longer journeys.

Acknowledgements

We would like to thank our student assistants Jessica Wulf and Ritwik Swain for their help during data collecting. We would also like to thank Chris Dijksterhuis for his help in creating the simulated world, and Peter van Wolffelaar for programming the car-following task.

References

Alm, H., & Nilsson, L. (1995). The effect of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis and Prevention, 27*(5), 707–715.

Atchley, P., & Chan, M. (2011). Potential benefits and costs of concurrent task engagement to maintain vigilance: A driving simulator investigation. *Human Factors, 53*(1), 3–12.

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

Boggs, D. H., & Simon, J. R. (1968). Differential effect of noise on task of varying complexity. *Journal of Applied Psychology, 52*(2), 148–153.

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

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

Brookhuis, K. A., De Waard, D., & Fairclough, S. H. (2003). Criteria for driver impairment. *Ergonomics, 46*, 433–445.

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

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.

Davenport, W. G. (1972). Vigilance and arousal: Effects of different types of background stimulation. *Journal of Psychology, 82*(2), 339–346.

De Waard, D., & Brookhuis, K. A. (1991). Assessing driver status: A demonstration experiment on the road. *Accident Analysis and Prevention, 23*(4), 297–307.

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

De Waard, D., & Brookhuis, K. A. (1997). On the measurement of driver mental workload. In J. A. Rothengatter & E. Carbonell Vaya (Eds.), *Traffic and transport psychology* (pp. 161–171). Amsterdam, The Netherlands: Pergamon.

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

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

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behaviour. *Psychological Review, 66*(3), 183–201.

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

Hancock, P. A., & Verwey, W. B. (1997). Fatigue, workload and adaptive driver systems. *Accident Analysis and Prevention, 29*(4), 495–506.

Heslop, S., Harvey, J., Thorpe, N., & Mulley, C. (2010). Factors that comprise driver boredom and their relationships to preferred driving speed and demographic variables. *Transportation Planning and Technology, 33*(1), 75–89.

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.

Hughes, G. M., Rudin-Brown, C. M., & Young, K. L. (2013). A simulator study of the effects of singing on driving performance. *Accident Analysis and Prevention, 50*, 787–792.

Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of musical tempo and mode on arousal, mood and spatial abilities. *Music Perception, 20*(2), 151–171.

Konečni, V. J., & Sargent-Pollock, D. (1976). Choice between melodies differing in complexity under divided-attention conditions. *Journal of Experimental Psychology: Human Perception and Performance, 2*(3), 347–356.

Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car-following situations: Safety implications for using mobile (cellular) telephones while driving. *Accident Analysis and Prevention, 31*, 617–623.

Litle, P., & Zuckerman, M. (1986). Sensation seeking and music preference. *Personality and Individual Differences, 4*, 575–577.

Mayfield, C., & Moss, S. (1989). Effect of music tempo on task performance. *Psychological Reports, 65*, 1283–1290.

McGrath, J. J. (1963). Irrelevant stimulation and vigilance performance. In D. N. Buckner & J. J. McGrath (Eds.), *Vigilance: A symposium*. New York: McGraw-Hill.

McNamara, L., & Ballard, M. E. (1999). Resting arousal, sensation seeking, and music preference. *Genetic, Social and General Psychology Monographs, 25*(3), 229–250.

Mulder, G. (1986). The concept and measurement of mental effort. In G. R. J. Hockey, A. W. K. Gaillard, & M. G. H. Coles (Eds.), *Energetics and human information processing* (pp. 175–198). Dordrecht, The Netherlands: Martinus Nijhoff Publishers.

Mulder, L. J. M. (1992). Measurement and analysis methods of heart rate and respiration for use in applied environments. *Biological Psychology, 34*, 205–236.

Mulder, L. J. M., De Waard, D., & Brookhuis, K. A. (2005). Estimating mental effort using heart rate and heart rate variability. In N. Stanton, A. Hedge, H. W. Hendrick, K. A. Brookhuis, & E. Salas (Eds.), *Handbook of ergonomics and human factors methods* (pp. 201–208). London: Taylor & Francis.

Nelson, T. M. (1997). Fatigue, mindset and ecology in the hazard dominant environment. *Accident Analysis and Prevention, 29*(4), 409–415.

National Highway Traffic Safety Administration (2008). *National motor vehicle crash causation survey*. <http://www-nrd.nhtsa.dot.gov/Pubs/811059.PDF>.

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.

O'Hanlon, J. F. (1981). Boredom: Practical consequences and theory. *Acta Psychologica, 49*, 53–82.

O'Hanlon, J. F., Haak, T. W., Blaauw, G. J., & Riemersma, J. B. (1982). Diazepam impairs lateral position control in highway driving. *Science, 217*(4554), 79–81.

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

Pelham, B. W., & Blanton, H. (2007). *Conducting research in psychology: Measuring the weight of smoke*. Belmont, CA: Thomson Wadsworth.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*(6), 1161–1178.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 12*(6), 462–466.
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.
Teigen, K. H. (1994). Yerkes-Dodson: A law for all seasons. *Theory Psychology, 4*(4), 525–547.
Thiffault, P., & Bergeron, J. (2003). Fatigue and individual differences in monotonous simulated driving. *Personality and Individual Differences, 34*, 159–176.
Ünal, A. B., Steg, L., & Epstude, K. (2012). The influence of music on mental effort and driving performance. *Accident Analysis and Prevention, 48*, 271–278.
Ünal, A. B., Platteel, S., Steg, L., & Epstude, K. (2013). Blocking-out auditory distracters while driving: A cognitive strategy to reduce task-demands on the road. *Accident Analysis and Prevention, 50*, 934–942.
Verwey, W. B., & Zaidel, D. M. (1999). Preventing drowsiness accidents by an alertness maintenance device. *Accident Analysis and Prevention, 31*, 199–211.
Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459–482.
Van Wolffelaar, P.C., & Van Winsum, W. (1995). Traffic simulation and driving simulation—An integrated approach. In: *Proceedings of the driving simulator conference (DSC '95). Teknea, Toulouse, France*.
Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors, 50*(3), 433–441.
Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 183–200). Mahwah, NJ: Erlbaum.
Wertheim, A. H. (1991). Highway hypnosis: A theoretical analysis. In A. G. Gale, I. D. Brown, C. M. Haslegrave, I. Moorhead, & S. Taylor (Eds.), *Vision in vehicles-III* (pp. 467–472). North-Holland: Elsevier.