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EFFECT OF LISTENING TO MUSIC AS A FUNCTION OF DRIVING COMPLEXITY: A SIMULATOR STUDY ON THE DIFFERING EFFECTS OF MUSIC ON DIFFERENT DRIVING TASKS

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Summary: Research in regards to music's effects on driving performance has been mixed. Previous research has found that music adds to mental workload. Other research has found that high mental workload is related to poorer driving performance in simulation. In this study, mental workload was manipulated by varying visual complexity and type of task (i.e., car-following or braking for unexpected obstacles). It was found that steering variance and delay in car-following response were reduced by music under low-workload conditions, while number of collisions with cars and number of lane excursions were increased under high-workload conditions. A practice effect was also found, with participants performing better when listening to music with more practice.

INTRODUCTION

Previous research in regards to music's effects on driving performance has been mixed, with some researchers finding that music has a detrimental effect (e.g., Brodsky & Slor, 2013) and some finding that music has a protective effect (e.g., Ünal, de Waard, Epstude, & Steg, 2013). Induced mental workload is one possible influencer of music's effect on driving. Mental workload has been self-reported as higher when listening to music while driving as compared to driving without music (Hughes, Rudin-Brown, & Young, 2012; Ünal, Steg, & Epstude, 2012). Other evidence—for instance, measured heart rate variability while driving (Brodsky, 2002; Oron-Gilad, Ronen, & Shinar, 2008)—seems to confirm that music adds to mental workload. Induced mental workload above a certain threshold harms driving performance (Cantin, Lavallière, Simoneau, & Teasdale, 2009; Makishita & Matsunaga, 2008; Ross et al., 2014). However, even when participants report increased mental workload from listening to music, they perform as well or better than they do on some driving tasks without listening to music—a finding interpreted by Ünal, Steg, and Epstude (2012) to mean that drivers were able to adjust their allocation of mental resources to maintain driving performance. Their explanation is further supported by another study in which participants who drove in a simulation with complex traffic remembered less talk radio than those who drove in simpler traffic, but showed no significant difference in driving performance based on traffic complexity (Ünal, Platteel, Steg, and Epstude, 2013).

Limited attentional and processing capacity are of concern for driving (e.g., Brookhuis & de Waard, 2010; de Waard, 1996; Ross, et al., 2014). If a driving task is very demanding, a secondary task may distract the driver from the primary driving task and cause a detrimental effect. However, if the driving task is not demanding, a secondary task may not affect task performance, and in some conditions, may enhance arousal and enhance driving performance. This is in keeping with both the Yerkes-Dodson curve and with Easterbrook's hypothesis that too much or too little arousal will lead to poorer allocation of attentional resources (de Waard, 1996; Solovey, Zec, Perez, Reimer, & Mehler, 2014; Turner, Fernandez, & Nelson, 1996; Ünal, de Waard, Epstude, Steg, 2013).

When the cue for a simple braking or vigilance task is presented in the center of the participant's vision, music at a normal volume seems to lead to at least comparable performance than when performing the task in silence (Consiglio, Driscoll, Witte, & Berg, 2003; Turner, Fernandez, & Nelson, 1996). When the cue for a vigilance task is presented in the periphery of the vision and combined with a driving simulation, music increases response time (Hughes, Rudin-Brown, & Young, 2012). This phenomenon is well illustrated by Beh and Hirst's (1999) study, in which participants performed worse with music on a vigilance task only when the music was loud (high-intensity) and they were performing more than one task at the same time, but performed better with music under some simpler circumstances (i.e., a centrally located cue, lower volume music, or concentrating on one task).

Visual complexity, heavy traffic and parked cars pulling out have all been related to increased mental effort (Cantin et al., 2009; de Waard, 1996; Ünal, Steg, and Epstude, 2012). In visually complex environments, such as driving in a city with pedestrians and cars as possible obstacles, music has been found to be detrimental to driving performance as compared to no music (Brodsky, 2002; Hughes, Rudin-Brown, & Young, 2012), although this has not always been the case (Hatfield & Chamberlain, 2008; Ünal, Steg, & Epstude, 2012). Conversely, for less demanding situations or tasks, such as following a car and matching its speed (Ünal, de Waard, Epstude, Steg, 2013), maintaining lane position (Hughes, Rudin-Brown, & Young, 2012), or driving for an extended period of time (Oron-Gilad, Ronen, & Shinar, 2008), music has been shown to either facilitate or have no significant effect on driving indices. In a study on music's effect on mood, van der Zwaag, et al. (2012) manipulated cognitive demand by varying lane width and found a pattern of results consistent with the combination of music and narrow lane width leading to worse performance, although the researchers did not find a significant interaction.

We investigated the music effect under different driving workload conditions in a simulated driving task. The low-workload condition is similar to one previously utilized by Ünal, de Waard, Epstude, Steg (2013). The high-workload condition changed complexity of the environment, event, and the location of the stimulus as in Cantin et al. (2009) and Ünal et al. (2012). However, we maximized the demand conditions of the task by shortening the intervals between events. We predict that drivers will perform better with music under low-workload driving conditions and worse with music under high-workload driving conditions. We expect that as tasks become better-rehearsed, reducing the mental workload required to perform those tasks, the positive effects of music will increase and the negative effects of music will decrease.

METHODS

Participants

165 University of North Florida undergraduate students participated. Forty-seven (27.5%) were male and 118 (71.5%) were female. The median age was 21, with 5 participants over the age of

33 and the oldest participant being 51. One participant's data was entirely excluded from analysis due to extreme number of driving errors.

Procedure

After signing the informed consent, participants were told that they would be asked to fill out several questionnaires during the experiment breaks. They then drove through a ten-minute training run and two twelve-minute test runs (with music vs. without music). Participants were counterbalanced on whether they listened to music during the first or second test run. Those driving without music heard ambient vehicle noises. The "music" condition compresses participants from a larger study comparing the familiarity of vocal music to the participants, and contains both participants who self-selected music and participants for whom music was experimenter-selected (for details, please contact the reviewers). An SPER digital sound level meter (model no. 840028), held 70-80 cm from the speakers, was used to measure sound volume and keep it near or below 70 dB, which is close to most listeners' comfortable level (Turner, Fernandez, & Nelson, 1996). Music was played by a pair of speakers positioned to the left and right of the computer monitor, positioned approximately 70-80 cm from the participant.

Simulation

The driving simulations were programmed using STISIM (Build 2.06.00) software. Driving scenarios were displayed on a 17" Dell monitor from a Dell computer with a Logitech steering wheel and brake/gas pedal attached.

Each driving simulation began with a low-load condition, a visually simple car-following task in open country (approximately six minutes long for the test runs), and followed with a high-load condition, a visually complex metropolitan (city) area that required frequent braking for unexpected peripheral obstacles. Throughout the simulation, participants were asked to obey traffic laws and drive safely. In the car-following task, participants were asked to follow closely behind a lead car, matching its speed while maintaining a safe distance. No speed limit was given for the car-following task, since speed was regulated by the lead car. In the metropolitan area, a speed limit of 40 mph was posted and pointed out in the training run. A siren sounded if participants drove more than three miles over the speed limit. Each metropolitan environment contained at least 1 red light, 4 pedestrians, and 3 parked cars pulling out. Each test run also contained at least one unanticipated task which was not included in any other simulation—either a car running a red light or a dog crossing the street.

Vehicles were programmed to randomly change in appearance but not substantially in size. In the metropolitan area, vehicles were parked in the right-hand lane and a stream of traffic flowed in the opposing lane so that it was difficult to swerve instead of brake when an obstacle appeared. Whether the participant crossed the road edge or center line was also recorded as a way to gauge whether swerving was used as a strategy.

The initial time-to-contact for pedestrians and for the unexpected events (the dog and the car running the red light) was determined by the simulation software so that the obstacle would cross directly in front of the driver at his or her current speed and heading, while the initial time-to-contact for cars was invariably set at 2.2 seconds. The initial time-to-contact of 2.2 seconds was chosen for the cars pulling out in order to ensure that participants would need to brake to avoid colliding with the car pulling out but would also be able to avoid an accident. A simulated distance of 1000 feet was used as a trigger for the traffic light to change from green to yellow, with 2 seconds passing before the traffic light turned red.

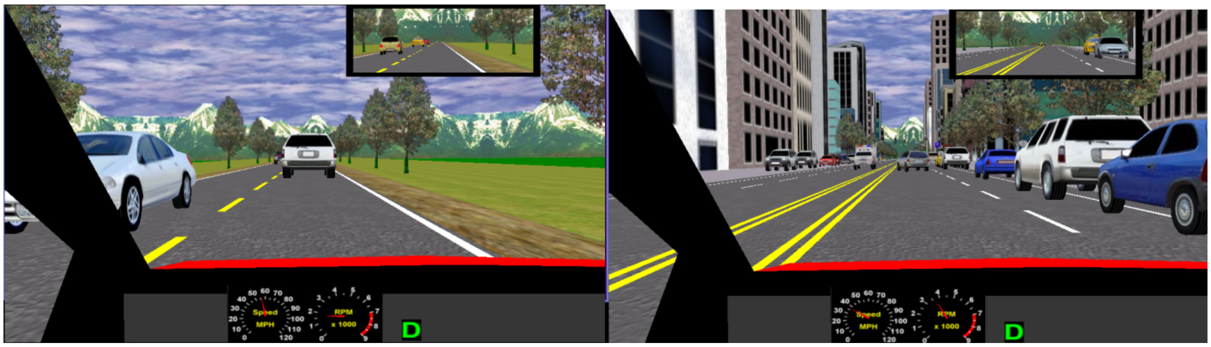

Figure 1. The car-following task (on the right) and city environment (on the left)

For each run, the following variables were measured: number of traffic violations (e.g., speeding, crossing the center line, running a red light), number of collisions, brake response time for each city event, steering variance from the center line for the duration of the car-following task and at intervals in the city portion of the run, average speed, and—for the car-following task—coherence with the lead vehicle (how well the driver matched the changes in speed of the lead vehicle), modulus (whether the driver tended to overcorrect [drive too fast] or undercorrect [drive too slow] in response to the lead vehicle), and delay in response to the lead vehicle (how long it took the driver to respond to the speed changes of the lead car).

RESULTS

Brake response times were coded by subtracting the first brake input after an event began (i.e., after a car or pedestrian began moving or after the traffic light changed to yellow). If there was no response such as described above by the end of the event, no data was coded for that event. All other measurements were recorded by the STISIM simulator.

Outliers were determined for dependent variables on a case-by-case basis, with outliers being defined as any values more than 2.5 standard deviations from the mean. Five participants whose partial data were included in between-subjects analysis (analysis of the unexpected event) did not complete the full experiment and were not included in within-subjects analysis. The tempo of the songs, as provided by Echonest.com, was analyzed and did not have a significant effect on dependent variables.

Effects of Music on Different Tasks

Since only one yellow light was included, tendency to pass this was tested with binary logistic regression. A within-subjects ANCOVA controlling for run order was conducted for all the other measurements (see Table 1). For the car following (low-load) task, participants exhibited significantly less steering variance and car-following delay. For the city run (high-load condition), participants showed no significant difference in steering variance but showed significantly more collisions with cars, significantly more lane excursions and were more likely to attempt to pass the traffic light. Participants are 3.07 times more likely to try to pass the yellow light in the "music" run than in the "without music" run.

Table 1. Estimated marginal means of driving variables as a function of music and run order

Part of Simulation	Variable	Run 1		Run 2	
Overall		With Music	Without Music	With Music	Without Music
Part One:	Mean Speed***	35.24 (.16)	34.90 (.16)	35.67 (.17)	35.55 (.17)
Car-following	Car-Following Variance***	.94 (.03)	.93 (.03)	.86 (.03)	.92 (.03)
(low-load)	Car-Following Modulus	1.11 (.01)	1.07 (.01)	1.08 (.01)	1.09 (.01)
	Car-Following Delay***	1.70 (.11)	2.28 (.11)	1.81 (.11)	2.19 (.11)
	Car-Following Coherence	.81 (.01)	.81 (.01)	.83 (.01)	.80 (.01)
Part Two:	# Collisions (Cars)***	.71 (.08)	.5 (.08)	.11 (.08)	.19 (.08)
City	# Collisions (Pedestrians)	.77 (.10)	.51 (.10)	.57 (.10)	.76 (.10)
(high-load)	City Variance	.85 (.02)	.86 (.02)	.84 (.02)	.85 (.02)
	Lane Excursions***	2.15 (.23)	1.68 (.22)	1.15 (.23)	1.71 (.23)
	Minimum T2C**	.64 (.03)	.65 (.03)	.72 (.03)	.69 (.03)
	Pedestrian Brake Time	1.14 (.03)	1.07 (.03)	1.02 (.03)	1.13 (.03)
	Traffic Light**	.15 (.03)	.05 (.03)	.06 (.03)	.03 (.03)
	Unexpected Event Brake Time	2.60 (.05)	2.58 (.05)	1.47 (.03)	1.53 (.03)

Effects of Practice

A mixed ANOVA was conducted with music/without music as within-subject variables and run order as between-subject. There is also an interaction between run order and music/without music on driving performance (see Table 1). This interaction was not anticipated. However, it confirms the expectation that drivers would perform better with more practice (i.e. when the task has become less cognitively taxing. Drivers evinced more desirable performance *with music* on the second run than on the first run for the variables of car-following modulus, $F(1, 308) = 4.73$, $p < .05$, number of collisions with pedestrians, $F(1, 317) = 4.01$, $p < .05$, number of lane excursions, $F(1, 311) = 5.11$, $p < .05$, and pedestrian brake time, $F(1, 267) = .9.54$, $p < .01$. There is also a trend towards this same type of interaction for car-following coherence, $F(1, 309) = 3.12$, $p < .1$ and number of collisions with cars, $F(1, 317) = 3.63$, $p < .1$. The unexpected event was tested using one-way ANOVAs with music/without music as a between-subject variable for each run. The unexpected event only shows a difference for the second run, where there is a trend for drivers to exhibit a faster reaction time with music, $F(1, 145) = 3.17$, $p < .1$.

DISCUSSION

The current study replicates the findings of Ünal Steg and Epstude (2012), with improvements shown for car-following delay and time-to-contact for cars pulling out with music. However, additional variables also replicate Brodsky's (2002) finding that music (especially high-tempo music) leads to more passed traffic lights, more collisions with other cars, and more lane crossings. Furthermore, either no effect or positive main effects of music were found for the low mental workload (car-following) condition, while—with one exception—either no effect or negative main effects of music were found for the high mental workload (city) condition. This suggests that part of the differences found in previous research may be due to the situation—that is, whether the scenario presented tended to impose high- or low-mental workload. The effect of music on driving performance is a function of the complexity of the current driving situation. This may explain the differences between previous results.

The current study furthered these results by finding that, with practice, participants performed better with music. Uniformly, when an interaction between music and run order was found, if music appeared to be detrimental in the first run, its effects became either facilitative or negligible in the second run, and if music appeared to have no effect in the first run, its effects appeared facilitative in the second run. At least a trend for this sort of interaction was found for all dependent variables for which music appeared to have a detrimental effect except attempts to pass the traffic light. This interaction may alternatively be explained as a carryover effect of mood induced by music. In their study, Ünal Steg and Epstude (2012) found that mental effort mediated music's positive effects on the standard deviation of speed in their car-following task but masked music's positive effects on time-to-contact with a parked car pulling out (that is, the results became more significant when mental effort was controlled for). The current study contained a series of obstacles for the high-load condition, requiring more effortful vigilance, and found overall negative effects of music for this condition. Ünal Steg and Epstude's overall finding in regards to music increasing time-to-contact was also found, but this was due entirely to music's effects in the second run, when participants had more practice. As such, it seems that under circumstances of very high external mental workload, the costs of music while driving may outweigh its benefits.

Research has already been published on music's effects on driving in regards to mental workload, arousal, tiredness, boredom, and mood. Further research regarding under which circumstances each of these variables becomes important should be of interest, especially in regards to whether drivers already consciously or unconsciously self-regulate whether they listen to music and what type of music they listen to depending on their circumstances. As the cognitive burden of driving should lessen with practice, further research might contrast newly-licensed and less experienced drivers, such as those studied by Brodsky and Slor (2013), with better-experienced drivers.

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