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Blocking-out auditory distracters while driving: A cognitive strategy to reduce task-demands on the road

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ABSTRACT

The current research examined how drivers handle task-demands induced by listening to the radio while driving. In particular, we explored the traces of a possible cognitive strategy that might be used by drivers to cope with task-demands, namely blocking-out auditory distracters. In Study 1 ($N=15$), participants listened to a radio-broadcast while watching traffic videos on a screen. Based on a recall task asking about what they had listened to, we created baseline scores reflecting the general levels of blocking-out of radio-content when there was no concurrent driving task accompanying the radio-listening. In Study 2 ($N=46$), participants were asked to complete two drives in the simulator: one drive in high-complexity traffic and another in low-complexity traffic. About half of the participants listened to a radio-broadcast while driving, and the other half drove in silence. The radio-listeners were given the same recall task that we had used in Study 1. The results revealed that the participants who drove while listening to the radio (Study 2) recalled less material from the radio-broadcast as compared to the participants who did not drive (Study 1). In addition, the participants who drove while listening to the radio recalled less talk-radio excerpts when driving in high-complexity traffic than when driving in low-complexity traffic. Importantly, listening to the radio did not impair driving performance. Together, these findings indicate that blocking-out radio-content might indeed be a strategy used by drivers to maintain their driving performance.

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1. Introduction

Drivers may engage in various driving-unrelated tasks on the road. These behaviors, which suggest an inclination of multitasking, may vary from eating or drinking to smoking and tuning the radio at the same time (Stutts et al., 2003; Lansdown, 2012). The influence of multitasking on driving behavior has received considerable attention in research, thereby differentiating the secondary tasks based on visual, manual, cognitive or auditory sources of distraction (Ranney et al., 2000). Previous studies especially demonstrated that the visual and manual distracters impose serious demands on drivers and inhibit driving performance; as such these distracters rely on the same mental resources as driving (Horberry et al., 2006; Harbluk et al., 2007). With regard to auditory distracters, however, the results were rather mixed. Some studies showed that auditory distraction has no detrimental effects on driving performance and can be handled quite well by drivers (Wester et al., 2008; Cnossen et al., 2004), while some other studies showed that auditory distracters might actually impair task performance in a similar way

that visual and manual distracters do (Chaparro et al., 2005; Gherri and Eimer, 2010). In the current research, we propose that auditory distracters impose additional demands on the driving task as well, and that drivers are able to handle these demands and still attain a desirable performance level. In addition, we explore the processes that might explain how driving performance is maintained in the prevalence of auditory distracters. More specifically, we suggest that blocking-out auditory distracters by paying less attention to the audio-sources might be a common strategy employed by drivers to handle increased task-demands.

Previous studies on drivers' engagement with other tasks on the road revealed that multitasking is likely to impair primary task performance (McEvoy et al., 2007; Drews et al., 2008; Strayer and Drews, 2003; Consiglio et al., 2003). For instance, several studies documented that the use of a mobile phone or talking to passengers was related to increased crash likelihood and decreased vigilance (Collet et al., 2009; McEvoy et al., 2007; Strayer and Johnston, 2001; McKnight and McKnight, 1993), suggesting that keeping up with a conversation while driving might distract the driver and pose danger on the road. Other types of distracters or secondary tasks that do not involve a conversation were also related to flaws in driving performance. As an example, performing a secondary cognitive task impaired the visual scanning abilities of drivers,

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leading to violations of give-way rules and disregarding the passengers (Anttila and Luoma, 2005). Similar results were obtained for other distracters, including operating the audio-entertainment devices, reading directions, and eating or drinking (Young et al., 2008; Jenness et al., 2002).

One of the most common in-vehicle distracter is listening to music or the radio (Dibben and Williamson, 2007). Then, how would listening to music or the radio influence driving performance? Previous studies suggest that listening to music or the radio had either no-effects or positive effects on driving performance (Ünal et al., 2012; Hatfield and Chamberlain, 2008; Strayer and Johnston, 2001; Wiesensthal et al., 2000; Turner et al., 1996; Fontaine and Schwalm, 1979). For instance, in a simulated driving context, listening to music and talk-radio fragments had no influence on lateral positioning, speed and reactions to hazardous incidents (Hatfield and Chamberlain, 2008). Similarly, listening to the radio was found to have no influence on drivers' performance in a tracking task (Strayer and Johnston, 2001), suggesting that radio-listening can be handled well while driving.

Some other studies, however, indicated that drivers cannot handle music or the radio while driving (Jäncke et al., 1994; Brodsky, 2002; Dalton et al., 2007). As an example, a driving simulator study revealed that participants increased their speed and engaged in more red-light violations while driving along with high tempo music on the background (Brodsky, 2002). It was concluded that depending on some structural properties (e.g., high tempo), music can be a cognitive distracter affecting driving performance negatively. Supporting this argument, North and Hargreaves (1999) reported increases in lap times in the simulator when the listening situation was demanding (i.e., high tempo and high volume music) rather than not demanding (i.e., low tempo and low volume music). Importantly, the authors detected that lap time was the longest when the demands were increased further by coupling high tempo–high volume music with a concurrent task of backward counting. Together, the findings of North and Hargreaves (1999) indicate that the influence of in-vehicle distracters on driving performance rely on the demands induced by those distracters. Then, are we likely to end up with a lowered driving performance when listening to auditory stimuli in demanding situations?

In a recent investigation of the influence of a demanding type of listening situation on driving performance, Ünal et al. (2012) showed that listening to loud music significantly increases self-reported mental effort while driving, irrespective of the specific driving conditions and tasks. Interestingly, it was also found that drivers were quite capable of dealing with the demands induced by music, and listening to music did not negatively affect driving performance. In fact, the driving performance of the group listening to music was even better than the driving performance of a no-music group for some driving tasks such as car following. The findings indicated that even if an auditory distracter is very demanding (as observed by consistent increases in mental effort), this does not necessarily translate into impaired driving performance. So, how do drivers preserve their primary task performance in such situations of high demand?

As also shown by North and Hargreaves (1999), drivers are good at adjusting their driving patterns to meet task-demands, by decreasing their speed or increasing the distance with the lead car (Young and Regan, 2007; Törnros and Bolling, 2006; Kubose et al., 2006; Lansdown et al., 2004; Brookhuis et al., 1991). However, drivers may also rely on other kinds of compensation strategies that do not require them to adjust their driving pattern. For instance, instead of regulating their driving behavior, drivers might regulate their allocation of cognitive resources to secondary tasks (Kahneman, 1973; Hockey, 1997). As a result, they might either completely refrain from the secondary task, or start paying attention to it less thoroughly so as to preserve the primary

task performance at a desired level (Hockey, 1997). Some studies provide initial support for this strategy of investing less effort in the secondary task. For instance, during a conversation with a passenger or on a mobile phone, drivers decreased their speech production rates or speech complexities when the demands of the traffic increased (Maciej et al., 2011; Drews et al., 2008; Crundall et al., 2005). Similarly, drivers were found to ignore a driving-unrelated secondary task (i.e., auditory working memory task) more than driving related secondary tasks (i.e., using route finding tools; Cnossen et al., 2004). As such, they prioritized both the driving task and the tasks that are related to driving. In general, these findings suggest that secondary tasks may receive less attention from drivers if they pose threat to driving safety, or if they are irrelevant to the driving task. Can we observe a similar trend while listening to music or the radio in a demanding traffic environment? Would drivers avoid paying attention to the radio in such situations in order to maintain their desired level of driving performance? Or would they still be engaged with the radio and cope with multiple task-demands?

1.1. Current research

In the current research, we propose that drivers who listen to the radio would be able to preserve their driving performance despite the demands induced by the radio. We believe that the maintained driving performance of the radio-listeners will be related to paying less attention to the secondary task of listening to the radio, in order to regulate attentional resources so as to concentrate better on the primary task. We refer to this inclination of paying less attention (either consciously or not) to the secondary task of radio-listening as blocking-out the radio-content. We expect that as a result of blocking-out the content, drivers would recall less material from a radio-broadcast, suggesting a lower secondary task performance while driving.

It may be that blocking-out may also take place in a regular context of listening to the radio, in which listening to the radio is not accompanied by a challenging task or is hardly demanding (e.g., at home). Therefore, in order to be able to draw conclusions on whether the radio-content is indeed blocked-out more when one has to carry out a demanding task (i.e., driving), we first ran a baseline experiment (Study 1). The baseline experiment provided us with a measure that can serve as a reference index showing the regular patterns of blocking-out during radio-listening.

In addition, the demands of a driving task are not stable either, and depend on the traffic environment such as the level of traffic density and the prevalence of conflict situations that one has to negotiate (Stinchcombe and Gagnon, 2010; Horberry et al., 2006; Cnossen et al., 2004; Baldwin and Coyne, 2003; De Waard, 1996). A driver might still have enough cognitive capacity to carry out multiple tasks on the road if the traffic demands are not exceeding his or her potential. In our case for instance, a driver may still pay some attention to a program on the radio when the traffic is calm. When the traffic complexity is higher, however, we expected that drivers would allocate more cognitive resources to the driving task, and would not pay careful attention to a secondary task that is irrelevant for driving safety, like listening to the radio. So, we expected that the inclination to block-out the radio-content would increase even further when the traffic complexity is higher. We tested these assumptions in Study 2.

More specifically, in Study 2, we first checked whether drivers who listened to the radio were able to preserve their driving performance, and perform as well as the drivers who drove in silence. In explaining the mechanism behind the sustained driving performance of radio-listeners, we formulated two hypotheses. First, we hypothesized that individuals who listened to the radio while performing a concurrent driving task would remember less

from a radio-broadcast as compared to individuals who listened to the radio without performing a concurrent driving task. Second, we hypothesized that drivers who listened to the radio would remember less from a radio-broadcast during a drive in high-complexity traffic, while they would remember more from a radio-broadcast during a drive in low-complexity traffic. In other words, we expected that drivers would prioritize the driving task, and would lower their engagement with the radio when the traffic is more demanding.

2. Study 1

Study 1 aimed to find out how much of radio-content is being blocked-out and remained unattended in a regular context of listening. This way, we created a reference index to be used in Study 2, so that we would be able to compare whether the tendency to block-out the radio-content differs when one is busy with driving rather than solely listening to the radio. We used the same radio-content and a similar procedure of radio-listening in both studies, as explained in Section 2.1.3.

2.1. Method

2.1.1. Participants

Fifteen students (11 females and 4 males) of the Psychology Department of the University of Groningen participated in the first study. The participants had a mean age of 21.20 ($SD = 8.20$). None of them reported having any hearing deficiencies.

2.1.2. Research design and procedure

Upon arrival, participants were instructed that they would watch a series of traffic videos during the course of the experiment. The use of the videos was both a cover to mask the real purpose of the study, as well as a visual stimulation to prevent participants from daydreaming while listening to the radio-program. The video-footage reflecting a Dutch traffic environment was from a Dutch TV program called the *De Bijrijder* ('Co-driver', *TV Noord*, 2011). The videos were all captured inside of a vehicle from a co-driver's perspective, depicting regular city and intercity driving situations in the Netherlands. The videos were projected on a big screen, and were played in mute to make sure that the sounds in the original video recordings would not interfere with the radio-broadcast.

We told the participants that we were trying to create a situation similar to real-life driving, and therefore a radio-broadcast consisting of talk-radio excerpts, commercials and music excerpts would accompany the videos. At this point, we asked the participants to fill in a short scale and indicate their top-three music genre, so that we were able to play the music excerpts from their favorite genres during the experiment (see Section 2.1.3) as to ensure that any failures in recall of the music excerpts would not be attributed to unfamiliarity with the music or disliking the music.

In real-life, people's attention to radio-programs might differ during the course of a radio-program. Listeners might block-out some of the radio-content while they might pay careful attention to some other content. We wanted our experiment to reflect real-life experiences as much as possible, and therefore did not communicate the radio-content recall as an explicit task. Instead, we instructed the participants that they could be asked some questions about the radio-program afterwards. This methodology ensured that participants would be aware of the possibility of a recall task after the experiment, while they would still be free to decide on the extent to which they pay attention to the content.

The volume of the radio was moderate with a sound level of approximately 75 dB throughout the experiment. After watching the video clips and listening to the radio-program, participants were given the questionnaires and check-lists for the recall task

(see Section 2.1.4). At the end of the recall task, participants rated whether they actively tried to keep the radio-content in mind, on a 6 point Likert-type scale (1 = not at all, 6 = all the times). We found that participants did not try to actively encode the radio-content into memory ($M = 2.79$, $SD = 1.42$). This suggests that we were successful in creating a radio-listening situation that is close to real-life experiences, and that the results of this study can be used as a reference point for general indices of blocking-out radio-content.

2.1.3. Radio-broadcast

We created seven radio-broadcasts that were 40 min long each, and consisting of talk-radio excerpts (i.e., a DJ interviewing guests), commercials and music excerpts. The commercials and talk-radio excerpts were all the same in the different radio-programs. The programs differed only in terms of the music genre that was played, so that every participant listened to his or her preferred type of music during the experiment.

The radio-programs included seven talk-radio excerpts recorded from Dutch radio-stations in the months preceding the study that covered a broad range of topics, from politics to world cuisine, and lasted about 16 min. Besides, a total of 41 commercials were randomly recorded from the Dutch radio stations as well. The total length of the commercials was 14 min.

In choosing the music genres that were listened to in different radio-programs, we used the classification of *Rentfrow and Gosling (2003)*. The genres we selected were rock, electronic, funk/soul, pop, jazz/blues and chill/dance. In addition, we created a radio-program that played Dutch music only. We used music websites (i.e., Last FM) and Top-100 charts on the web to select artists and bands that are representative and prototypical of each genre, and created short music excerpts from each song (by selecting a fragment of the song that is widely known such as the chorus) that lasted between 29 and 35 s each. We selected a total of 30 music excerpts for each genre, which lasted about 15 min in total. At the end of the experiment, participants were asked to indicate how many songs they could sing along on a 7-point Likert type scale (1 = none, 7 = all; $M = 5.87$, $SD = 1.06$), which revealed a high familiarity with the music broadcasted.

In Study 2, participants would be asked to complete two simulated drives (see Section 3.1.2), so the radio-broadcast would be presented in two parts. We broadcasted the radio-content in two parts in Study 1 as well, since we wanted both studies to be structurally similar in procedures related to radio-listening. Participants listened to the talk-radio excerpts, commercials and music excerpts as blocks in each part. So, when one type of audio stimulus has ended, the other was broadcasted. The order within music excerpts, commercials and talk-radio excerpts in each block was the same across participants. The presentation order of the first part and the second part of the radio-broadcast was kept constant across participants too. However, we counterbalanced the presentation order of music and commercials/talk-radio in each block. Therefore, in half of the cases, the radio-program started with music excerpts, and in the other half it started with commercials/talk-radio excerpts.

2.1.4. Dependent measure: percentage of recalled radio-content

We tracked how much of the talk-radio excerpts, commercials and music excerpts had been recalled. For the talk-radio excerpts, participants were asked to answer some questions tapping on the topics discussed during the interviews. The questions were constructed in such a way that they always had only one correct answer, with no room for ambiguity. For each block of talk-radio excerpts either in the first or second part of the radio-program, we counted the number of correct answers. Then we converted the total number of correct answers into percentage scores, reflecting the amount of talk-radio excerpts that were recalled in the first and second part of the radio-program.

For the music excerpts and commercials, participants were given check-lists with brand names and names of artists or songs. For commercials, the list consisted of 99 brand names in alphabetical order, 41 of which were the brands that were broadcasted during the radio-program. For recall of the music, the lists consisted of names of 90 artists or songs in alphabetical order, 30 of which were the names of the artists or songs that they had been listening to during the radio-program. Participants were instructed to circle the brand names or names of the artists or songs that they recalled from the radio-program on the lists. We counted the number of correct items, and again computed percentage scores indicating the amount of commercials and music excerpts that were recalled in the first and second part of the radio-program. For each type of audio stimuli, we also checked whether time lag had any influence on recall of the radio-content, such as recalling less material from the first part as compared to the second part which was heard just before the recall task.

2.2. Results

We found that participants recalled the topic of more than half of the talk-radio excerpts they had listened to in the first and second part of the radio-program; $M = 55.91$ ($SD = 16.78$) and $M = 60.59$ ($SD = 16.75$), respectively. A repeated measures analysis revealed that the percentage of recalled talk-radio excerpts in the first part was not significantly different from the percentage of recalled talk-radio excerpts in the second part, indicating that time lag did not influence the recall performance, $F(1, 14) = 1.15$, $p > .05$, partial $\eta^2 = 0.08$. Participants recalled less than half of the commercials that they had listened to in the first and second part of the radio-program; $M = 38.25$ ($SD = 18.17$) and $M = 41.81$ ($SD = 16.94$), respectively. A repeated measures analysis revealed that, again time lag did not affect the recall performance, $F < 1$, n.s., partial $\eta^2 = 0.05$. Finally, we found that participants recalled about half of the music excerpts they had listened to in the first and second part of the radio-program; $M = 54.22$ ($SD = 23.21$) and $M = 47.56$ ($SD = 17.43$), respectively. A third repeated measures analysis revealed that the percentage of music excerpts recalled from the first part was not significantly different from the percentage of music excerpts recalled from the second part, $F(1, 14) = 1.72$, $p > .05$, partial $\eta^2 = 0.11$.

As time lag had no influence on the recall of the radio-content, we created our reference index by averaging the scores we had calculated for the first and second parts of the different radio-contents. So, we had single percentage scores depicting the recall performance for each type of audio stimuli (talk-radio excerpts, commercials and music excerpts), instead of having separate percentage scores for the first and second parts.

3. Study 2

In Study 2, we examined the extent to which drivers pay attention to the radio-content while driving, and especially in traffic environments with high or low-complexity. To test our first hypothesis, we examined how much of the radio-content had been recalled when the radio-listening was accompanied by a driving task (i.e., Study 2), as compared to when it was not accompanied by a driving task (i.e., Study 1). To test our second hypothesis, we examined how much of the radio-content has been recalled by drivers from a drive that took place in high-complexity traffic as compared to a drive that took place in low-complexity traffic. Prior to testing our hypotheses, we wanted to confirm whether our initial idea of drivers' prioritizing the driving task while listening to the radio would hold true. So, we first checked whether radio-listeners performed as well as the drivers who drove in silence in Study 2.

3.1. Method

3.1.1. Participants

Fifty students of the Psychology Department at the University of Groningen participated in the study. Four of the students were excluded from data analysis due to either simulation sickness or not being native Dutch-speakers. The remaining 46 participants (25 female) had an age range of 18–29, with a mean age of 21.83 ($SD = 2.44$). Participants' mean mileage covered in the year preceding the study was 4308 km ($SD = 6125$). None of the participants reported having hearing deficiencies.

3.1.2. Research design and procedure

The study employed a 2 (auditory distraction: listening to the radio or no-radio) $\times$ 2 (traffic complexity: low and high) mixed subjects design with repeated measures on the second factor. Participants were randomly assigned to the radio or no-radio conditions.¹

We instructed the radio group participants to drive in the simulator with the radio playing on the background. As in Study 1, we instructed them that they might be asked to answer some questions about the radio-content afterwards. Then, we asked them to indicate their top-three genres of music in order to play the preferred genre of music for each participant.

Prior to the simulated drive, all the participants completed a training session in the simulator. The experimental simulated drive composed of two parts. One part involved driving in a low-complexity traffic setting and the other part involved driving in a high-complexity traffic setting. Complexity of the driving environment was manipulated by the traffic density of the oncoming traffic and the number of critical incidents occurring on the road (see Section 3.1.5). Participants listened to the same radio-broadcast that we used in Study 1 and with the same amplitude of 75 dB. Along with the counterbalancing procedure regarding the presentation order of the radio-content (as explained in Section 2.1.3), we also counterbalanced the order of starting to drive in low or high-complexity traffic settings. The greater number of counterbalancing in the radio group created the necessity to employ a larger sample for the radio group than for the no-radio group. Therefore the sample size of the no-radio group was approximately half of the sample size of the radio group ($n = 14$ and $n = 32$, respectively). As sample size differs across both groups, we assumed that the variance within groups is unequal in the relevant tests.

All participants drove in both the high and low-complexity traffic. At the end of each ride, participants evaluated the completed ride in terms of complexity. After the simulated drives, the radio group participants were immediately given the recall task in which they answered questions asking about what they have listened to while driving. They also indicated to what extent they were able to sing along with the music excerpts, which revealed a moderate familiarity with the music broadcasted ($M = 5.09$, $SD = 1.51$).² All the participants also filled in some additional questionnaires asking about demographic and driving related characteristics.

¹ As we randomly assigned the participants to radio and no-radio groups, we did not have control over the gender or age distribution in the samples of the groups. Investigation of the gender distribution of the two samples revealed that the radio group included slightly more females (62.5%), while the no-radio group included more males (64.3%). We did not find any significant differences in age; $F(1, 44) = 2.37$, n.s.), and annual mileage reported for the year preceding the study across the groups ($F < 1$, n.s.), meaning that the driving experience of the radio and no-radio groups were similar.

² The comparison of the music familiarity ratings in Study 1 and Study 2 indicated a marginally significant difference between the two samples $F(1, 46) = 3.17$; $p = .08$, meaning that familiarity with the music excerpts was higher in Study 1 than in Study 2.

3.1.3. Manipulation check

In order to carry out manipulation checks for traffic complexity, we developed a short scale to be filled in after each drive in the simulator. The scale consisted of 14 adjectives describing the complexity of a driving situation (e.g., demanding, monotonous, risky, tiring and boring). Participants indicated to what extent the adjectives reflected the traffic environment that they have just been to by using a Likert type scale from 1 (strongly disagree) to 7 (strongly agree). A reliability analysis showed that the scale had a high internal consistency (Cronbach's $\alpha = .86$). Therefore, mean scores were computed for participants' evaluations of the low and high-complexity traffic environments, respectively, with a higher mean reflecting a higher perceived complexity of the traffic environment.

3.1.4. Dependent measure: percentage of recalled radio-content

We calculated the percentage of recalled radio-content following the same procedure as in Study 1 (see Section 2.1.4).

3.1.5. Dependent measures: driving parameters

We used the driving simulator of University of Groningen (STSoftware) which consists of a fixed-base driving console surrounded by three LCD screens, providing a 180° field of view of the driving environment. The simulator had all the usual equipment for car-control, and responses were recorded in the database at a sample rate of 10 Hz.

For the current study we designed two different simulated worlds, being either high or low in traffic complexity. The worlds included the same driving route that consisted of urban and rural areas. The urban and rural areas both consisted of a single carriageway with two lanes, with a lane width of 3 m. The speed limit was 50 km/h in urban areas, and 80 km/h in rural areas. It took the participants 15–20 min to complete each part, depending on their speed. In high-complexity traffic, we had the following critical incidents: 1. car emerging from the right (5 times); 2. car approaching from left and violating the give-way rule (3 times); 3. gap acceptance at an intersection; 4. gap acceptance at a T-junction; 5. parked car driving off a parking lot (2 times). In low-complexity traffic, we only had the incidents of gap acceptance at an intersection and parked car driving off a parking lot. By means of critical events occurring in high and low-complexity traffic, we were able to measure a variety of performance indicators, such as time-to-contact or brake-response to hazards. Appendix A provides a detailed description of all the critical events and performance indicators included in our study.

3.2. Results

3.2.1. Manipulation check for traffic complexity

Results of a mixed-model ANOVA, with low and high-complexity traffic as the within-subjects factor, and with listening to the radio as the between-groups factor revealed that there was a main effect of traffic complexity on participants' ratings of low and high-complexity traffic situations, $F(1, 44) = 85.65$, $p < .001$, partial $\eta^2 = 0.66$. As expected participants rated the low-complexity drive ($M = 3.11$, $SD = 0.75$) as lower in traffic complexity than the high-complexity drive ($M = 4.46$, $SD = 0.87$). There was no main effect of radio-listening on ratings of traffic complexity, $F < 1$, n.s., partial $\eta^2 = .001$. The interaction of listening to the radio and driving in low and high-complexity traffic was not significant either, $F < 1$, n.s., partial $\eta^2 = .006$. Therefore, regardless of the presence of the radio on the background, participants indeed evaluated the high-complexity traffic as more complex than the low-complexity traffic, suggesting that our manipulation of traffic complexity was successful.

3.2.2. The influence of listening to the radio on driving performance

In order to check our initial expectation regarding no impairment in driving performance while listening to the radio, we used multivariate analysis of variance (MANOVA) and compared the driving performance of the radio and no-radio groups in low and high-complexity traffic settings. As described in Section 3.1.5, we had a number of critical incidents and several driving performance indicators for each critical incident (see Appendix A). In multivariate statistics, it is advised to include no more than 10 dependent variables in MANOVA if the sample size is not large (Stevens, 1980). Due to the small sample size, we were not able to run an overall MANOVA with all the dependent variables. Instead we ran MANOVAs for each critical incident and their subsequent indicators.

The results of the MANOVA analyses revealed no influence of radio-listening on driving performance during critical incidents in high-complexity and low-complexity traffic (F values ranging from 0.32 to 2.14, all being non-significant at $p < .05$; partial η^2 s ranging from 0.02 to 0.17). So, as expected, the results suggested that the driving performance of the radio group was not different than the driving performance of the no-radio group.

3.2.3. Paying attention to the radio-content while driving vs. not driving

In order to check whether people recall less from a radio-broadcast when listening to the radio was accompanied by driving (Study 2) vs. not (Study 1), a one-way ANOVA was run. In other words, we compared the percentages of recalled radio-content we obtained in Study 2 with the reference index created in Study 1 (see Section 2.2). Prior to the ANOVA, we first checked the sample characteristics of Study 1 and Study 2. The mean age of the sample we employed in Study 1 was not significantly different from the mean age of the sample we employed in Study 2, $F < 1$, n.s. In addition, in both of the studies, the percentage of females was higher than the percentage of males (73.3% in Study 1 and 62.5% in Study 2), meaning that the sample characteristics of the studies were similar, and not likely to confound the findings.

As seen in Table 1, there were significant differences between the two samples in terms of how much has been recalled after the radio-broadcast. The percentage of recalled radio material was consistently lower when listening to the radio was accompanied by driving (Study 2) than when it was not accompanied by driving (Study 1). Importantly, this applied to all types of radio-content. In general, the findings on lower percentages of recall in Study 2 (driving and listening to the radio) support our first hypothesis that participants would prioritize the primary task of driving and pay less attention to the secondary task of listening to the radio.

3.2.4. Paying attention to the radio-content while driving in low and high-complexity traffic settings

In order to check whether participants who had the driving task paid attention to the radio-content differently based on the level of traffic complexity, we ran mixed-model ANOVAs, with the percentage of recall of the radio-content in high and low-complexity driving as the within-subjects factor, and with the order of starting the simulated driving session in a high-complexity or low-complexity traffic as the between-groups factor.³

The results of the first mixed-model ANOVA revealed a main effect of traffic complexity on the percentage of talk-radio excerpts recalled, $F(1, 30) = 6.77$, $p < .05$, partial $\eta^2 = 0.18$. In line with our

³ When gender was used as a between-groups factor in the mixed-model ANOVAs, it revealed no effects on the percentage of radio-content recalled (F values ranging from 0.22 to 0.64, all being non-significant at $p < .05$).

Table 1

Comparing the radio (no-driving) and radio and driving groups based on the percentage of radio-content recalled.

	df	Radio and driving (n = 32) Mean	Radio (no-driving) (n = 15) Mean	F	p	Partial η^2
1. Recall % in high-complexity situation vs. no-driving						
Talk-radio		34.04	58.25	29.79	.000	.40
Commercials		29.01	40.03	5.94	.019	.12
Music		36.14	50.89	5.68	.021	.11
Between groups	1					
2. Recall % in low-complexity situation vs. no-driving						
Talk-radio		43.59	58.25	5.81	.020	.11
Commercials		26.76	40.03	6.94	.012	.13
Music		32.11	50.89	9.90	.003	.18
Within groups	45					

Note. Within the radio and no-driving condition (Study 1), we had single scores for the recall of talk-radio excerpts, commercials and music excerpts. So, the recall percentages are the same in each set, reflecting the baseline recall performance when there was no-driving task.

second hypothesis, the percentage of talk-radio excerpts recalled was lower when participants had been driving in the high-complexity traffic setting ($M = 34.04$, $SD = 14.03$) as compared to the low-complexity traffic setting ($M = 43.59$, $SD = 21.29$). There was no main effect of order of starting to drive in high-complexity or low-complexity traffic on percentage of recall ($F(1, 30) = 1.60$, $p = .22$, partial $\eta^2 = 0.05$). Importantly, the interaction of traffic complexity and order of starting to drive in high or low-complexity traffic did not have a significant effect on the percentage of talk-radio excerpts recalled either, $F(1, 30) = 1.99$, $p = .17$, partial $\eta^2 = 0.06$. So, the higher percentage of recall during the low-complexity traffic was not due to time lag (see Fig. 1).

The results of the second mixed-model ANOVA revealed that the recall percentage for the brand names heard during a drive in high-complexity traffic ($M = 29.01$, $SD = 13.92$) was not significantly different from the recall percentage of brand names heard during a drive in low-complexity traffic ($M = 26.76$, $SD = 16.33$), $F < 1$, n.s., partial $\eta^2 = 0.03$. So, our second hypothesis regarding a lower percentage of recall from a drive in high-complexity traffic was not confirmed for commercials. There was a significant main effect of order of starting the simulated driving with high or low-complexity traffic on recall percentages, $F(1, 30) = 6.13$, $p < .05$, partial $\eta^2 = 0.17$. Percentage of brand names recalled was higher when the first drive took place in high-complexity traffic ($M = 32.46$, $SE = 2.79$) than in low-complexity traffic ($M = 21.99$, $SE = 3.17$). There was no interaction effect of order and complexity of the traffic on the percentage of brand names recalled; $F < 1$, n.s., partial $\eta^2 = 0.03$ Fig. 2.

In terms of music excerpts, results revealed that there was no main effect of traffic complexity on the percentage of music excerpts recalled, $F(1, 30) = 2.07$, $p = .16$, partial $\eta^2 = 0.07$. So, the

percentage of music excerpts recalled from a drive in high-complexity traffic ($M = 36.14$, $SD = 20.53$) was not significantly different from the percentage of music excerpts recalled from a drive in low-complexity traffic ($M = 32.11$, $SD = 19.54$). There were no significant main effect of order, and also no significant interaction effect, both F s < 1 , n.s., and both partial $\eta^2 < 0.01$. So, our second hypothesis regarding the lower recall performance from a drive in high-complexity traffic was not confirmed for music excerpts.

4. Discussion

In the current paper, we explored how drivers are able to maintain their driving performance while listening to the radio. In other words, we were interested in the mechanisms by which drivers cope with the distractions induced by a secondary task. We proposed that performing lower on the secondary task by blocking-out of radio-content might be an effective strategy employed by drivers to reduce task-demands resulting from driving and radio-listening. We formulated two hypotheses to examine whether task-demands influence the way people pay attention to the radio. First, we hypothesized that the radio-content would be recalled less when radio-listening was accompanied by driving as compared to a situation in which radio-listening was not accompanied by driving, and thus, was hardly demanding. Second, we hypothesized that drivers in the radio-listening condition would recall less information from a radio-broadcast during a drive in high-complexity traffic than during a drive in low-complexity traffic.

Prior to testing our hypotheses, we first confirmed that driving performance was indeed maintained by drivers while listening to the radio. In line with previous studies, we found that listening to

Fig. 1. Percentage of talk-radio excerpts recalled during driving in high-complexity vs. low-complexity traffic for drivers who listened to the radio.

Fig. 2. Percentage of brand names recalled during driving in high-complexity vs. low-complexity traffic for drivers who listened to the radio.

music or the radio was not detrimental for driving performance (Ünal et al., 2012; Hatfield and Chamberlain, 2008; Strayer and Johnston, 2001; Turner et al., 1996). Then, how did radio-listeners sustain their driving performance? Did they down regulate their allocation of attention to the secondary task of radio-listening, so as to prioritize the main task of driving?

Our findings tapping on the differences between the recalled radio-content in Study 2 (radio-listening and driving) and Study 1 (radio-listening without driving) indicated that the driving task was indeed prioritized by our participants. As expected, participants with a driving task recalled less material from the radio-broadcast as compared to the participants who did not drive while listening to the radio. Importantly, this applied to all types of radio-content that we had used (namely talk-radio excerpts, commercials, and music excerpts). Therefore, our first hypothesis regarding lower rates of recall of the radio-content due to driving was fully confirmed, meaning that the demands coming along with driving led to focusing less on the radio.

What about the situations in which the external demands are even higher due to traffic complexity? Is it likely that the radio-content would be blocked-out further in those situations while driving? We examined this issue by comparing what has been recalled from the radio-content during driving in busy and calm traffic settings. Our second hypothesis, regarding a lower level of recall of the radio-content during high-complexity traffic, was confirmed for only the talk-radio excerpts. As expected, drivers in the radio-listening condition tended to pay less attention to the talk-radio excerpts when the traffic demands were high. In terms of the commercials and music excerpts, recall of the radio-content did not differ based on traffic complexity manipulation.

Participants in Study 2 were slightly less familiar with the music excerpts that they had listened to as compared to the participants in Study 1. So, a lower familiarity with music might have led to a poorer recall of music excerpts in Study 2, regardless of the traffic complexity. In addition, memory processes might be functioning differently for music than for speech. For instance, there is evidence suggesting that lay listeners are quite good at reproducing the tempo of a song from memory with great accuracy (Levetin and Cook, 1996). Therefore, it is possible that people encode music fragments not based on song names, but based on more abstract features like its tempo or rhythm. Investigating the specific processes behind the retention of different audio-stimuli is beyond the scope of the current paper. However, it is of interest to replicate the current studies by using a different method to measure music memory, such as using a recognition task by playing instrumental versions of the excerpts to stimulate the retrieval of the abstract features of music (see Strayer et al., 2003, for a similar procedure applied to a visual task).

An alternative explanation for the lower recall percentages in Study 2 might be related to faster memory decay due to an increase in cognitive load of the participants while driving. That is, participants in Study 2 could have attended the radio-content to the same extent as the participants in Study 1, but were not able to consolidate the information. We believe that this argument would be plausible if we had used a free recall task. However, we provided the participants with recall cues (i.e., presenting the brand names, artist names, and the topics discussed in talk-radio excerpts), and then measured how much they remembered, which makes it more likely that the lower recall rates are indeed related to paying less attention to the radio-broadcast. That is because the recall cues would have triggered any information that had been attended but cannot be accessed due to memory decay. Still, the competing explanation regarding the influence of cognitive load on memory processes rather than attentional processes can be tested by future research, in order to have conclusive

findings on blocking-out as a compensatory strategy while driving.

Previous literature has pointed out that a lower performance level in secondary tasks was suggestive of a high cognitive load while driving, and was used as an indication of increased mental effort (Cnossen et al., 2000; De Waard, 1996). In such situations, drivers either give up on the secondary task or start paying attention to the secondary task in a controlled manner as not to risk their driving performance (Schömig et al., 2011; Hockey, 1997). Our findings provided further evidence to the literature by showing that in the case of listening to the radio, primary task performance can be maintained by regulating one's attention allocation to the radio. This was especially clear by our finding tapping on a higher inclination to block-out the talk-radio excerpts during high-complexity traffic. More research is needed to understand whether drivers employ this strategy consciously or not, in order to explore the mechanism further.

We would also like to note that there might be individual differences in employing cognitive strategies while multitasking in the car. For instance, there might be differences between younger and older drivers in terms of how they deal with distracters or secondary tasks, especially in demanding traffic conditions (Cantin et al., 2009; Chaparro et al., 2005). We had a sample of young drivers with moderate levels of driving experience, and our results showed that they paid less attention to the radio as compared to participants who did not have the concurrent driving task. It would be interesting to explore whether our results can be replicated in different samples, such as in samples with varying experience levels or among older drivers.

Lastly, in the current studies, we had to use the same radio-broadcast in a predetermined sequence in order to have sufficient control over the presentation of the audio-stimuli, while this procedure did not fully reflect a normal radio-listening situation. So, it is possible that participants' engagement with the radio-program was lower than what is expected to be in real-life. Future studies could examine the effects of higher engagement radio-listening situations to further enhance our understanding of how blocking-out works in real-life driving situations.

5. Conclusions

In the majority of the studies, scholars associated radio-listening with nonnegative experiences while driving (Hatfield and Chamberlain, 2008; Strayer and Johnston, 2001). Yet, little is known about how drivers maintain their driving performance while listening to the radio. The current research was one of the first that explored the mechanisms that enable drivers to maintain their driving performance while listening to the radio. First, we showed that individuals recall less material from a radio-program when driving as compared to when not driving. This implies that drivers might be paying less attention on the radio. Second, our findings on poorer recall of the talk-radio excerpts when the traffic complexity was higher gave further support to the argument that drivers are able to regulate their cognitive resources based on the demands induced by the traffic environment. As a result, driving performance is maintained at a safe level. However, this should not be interpreted as radio being an undemanding type of auditory stimulus on the road. Rather, our results indicated that drivers employ cognitive strategies (i.e., blocking-out the radio) to deal with the mental load they experience due to driving with the radio on the background. The practical implication of our findings is that these strategies seem to be working quite fine, and drivers are able to prioritize the driving task, securing their driving performance constantly.

Appendix A. Description of critical driving situations and relevant performance indicators

In high-complexity traffic

1. *Car emerging from the right (5 times)*: This scenario mirrored a hazardous driving incident in which another car unexpectedly emerged from a merging road to the right of the driver. The following performance indicators were used:

1.1. Maximum deceleration: The greatest deceleration value in m/s. Higher values of maximum deceleration indicate harder brake-responses.

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

1.3. Maximum brake: The brake pedal position as a percentage from 0 to 100.

2. *Car approaching from the left and violating the give-way rule (3 times)*: This scenario mirrored a hazardous driving incident in which another car approached from a merging road to the left of the driver. Although the driver had the right to pass through the intersection first, the other car did not stop, violating the give-way rule. The performance indicators were the same as the car emerging from the right scenario.

3. *Gap acceptance at an intersection*: This scenario depicted a situation in which the participant had to cross an intersection where there were cars coming from left and right. The gap between the oncoming cars increases at a certain frequency. We were interested in the gap that the driver chooses to cross the intersection. The performance indicators for the situation were:

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

3.2. Distance to cars that are approaching: It correlates with accepted gap time, and indicates of the distance between the two oncoming cars.

4. *Car driving off from a parking lot (2 times)*: In this critical situation, a parked car unexpectedly drove off from a parking lot, and cut into the driver's way when the driver was passing. The driver was expected to brake immediately in order to avoid a collision. The following performance indicators were recorded:

4.1. Maximum deceleration (see number 1.1).

4.2. Maximum brake (see number 1.3).

4.3. Time to contact: The time in seconds that would lead to a collision to the first object in the same lane as the participant. It is calculated from the moment that the object appears on the road, which is the parked car driving off in this scenario.

5. *Gap acceptance at a T-junction*: The driver had to turn left at a T-junction in which there was oncoming traffic. The gap between the oncoming cars increased with a certain frequency. We were interested in the gap at which the driver chose to turn left. The performance indicators for the situation were the same as for the gap acceptance at an intersection scenario.

6. *Oncoming car overtakes*: The scenario was again mirroring a hazardous situation in which a car in the opposite lane overtakes another car, and suddenly appears on driver's own lane. The driver was expected to insert brake in order to be able to stop on time and avoid a possible head-on-crash with the overtaking car. The following performance indicators were recorded:

6.1. Length of the brake time: The time in seconds that is reflecting the length of using the brake pedal to decelerate.

6.2. Maximum brake (see number 1.3).

6.3. Time-to-contact (see number 4.3).

In low-complexity traffic

1. Gap acceptance at an intersection: see number 3.

2. Car driving off from a parking lot: see number 4.

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