

Does working memory capacity offer protection to driving performance when working memory load increases?

Veerle Ross^{1*}, Ellen M. M. Jongen¹, Weixin Wang¹, Tom Brijs¹, Kris Brijs^{1,2}, Robert A. C. Ruiter³ & Geert Wets¹

¹Hasselt University
Transportation Research Institute (IMOB)
Science Park - Building 5, bus 6
BE-3590 Diepenbeek, Belgium
Phone: +32(0)11 26 91 49
Fax.: +32(0)11 26 91 99
Email: veerle.ross@uhasselt.be

²XIOS University College
Department of Construction Engineering
Campus Diepenbeek – H Building
BE-3590 Diepenbeek, Belgium

³Maastricht University
Department of Work and Social Psychology
Faculty of Psychology and Neuroscience
Universiteitssingel 5, room 3.001
Maastricht, 6200 MD
Netherlands
Phone: +31 43 3882413 /1908
Fax: +31 43 3884211

* Corresponding author

Number of words = 5538

Number of Figures = 2

Number of Tables = 0

Number of words incl. Figures and Tables = 6038

Paper submitted: 1st of August, 2012

ABSTRACT

Distracted driving received increasing attention in the literature due to potential adverse safety outcomes. Especially the use of new in-vehicle technologies created situations in which driving is often combined with other tasks. However, operating in-vehicle technology induces working memory load (WM load) and therefore the working memory capacity (WM capacity) of the driver is not only devoted to the primary task of driving. WM capacity consists of different subtypes (visuospatial and verbal). This study investigated if, and how, these types relate to the influence of WM load on driving performance, as measured by a lane changing task (LCT). Young novice drivers (n= 51, age= 17-25), with minimum 20 hours of practice and no more than two years of driving experience, participated in the experiment. Each participant completed two WM capacity tasks, tapping into either visuospatial or verbal WM capacity. The LCT was performed under baseline conditions and in combination with three levels of increasing WM load, induced by an auditory-verbal response N-back. Dependent measures of interest were mean deviation in the lane change path (MDEV), percentage of correct lane changes (PCL), and lane change initiation (LCI). Results showed that with increasing distraction performance on each measure deteriorated. Furthermore, higher WM capacity was related to better LCT performance, but this relation differed per WM capacity measure. More important, for PCL, young novice drivers with high verbal WM capacities were less influenced by distraction. Discarding distraction, in combination with WM capacity training, is proposed as the best solution for minimizing crash risks.

1 INTRODUCTION

2
3 “Distraction occurs when a driver is delayed in the recognition of information needed to safely
4 accomplish the driving task because some event, activity, object, or person within or outside the
5 vehicle compels or induces the driver to shift attention away from the driving task. The presence of a
6 triggering event distinguishes a distracted driver from one who is simply inattentive or lost in
7 thought.” (1). Distracted driving has received increasing attention in the literature due to potential
8 adverse safety outcomes. At least 25% of the car crashes in the United States can be related to some
9 form of driver distraction (1,2). Furthermore, distracted driving is a worldwide problem (3).
10 Especially the use of cell-phones and new in-vehicle technologies created a situation in which driving
11 is often combined with other tasks. One often posed solution is hands-free technology (e.g. hands-free
12 cell phones). This technology should decrease the impact of secondary tasks on driving since it does
13 not require shifting visual attention away from the roadway, nor does it require manual adjustments of
14 settings (4,5). Nonetheless, engaging in activities such as hands-free phoning also disrupts driving
15 performance (6,7). Distraction occurs because people are limited in the capacities they can devote to
16 ongoing activities. They are only able to process a limited amount of information at the same time and
17 are restricted in the amount of actions that they can perform simultaneously (8,9,10,11). An important
18 moderator of dual-tasking is working memory capacity (WM capacity). WM capacity allows one to
19 keep information active in the mind while being able to manipulate it, in order to guide goal-directed
20 behavior (12,13). WM capacity therefore supports the ability to resist distraction by irrelevant stimuli
21 (14). Different subtypes of WM capacity can be distinguished, i.e. visuospatial and verbal WM
22 capacity. Visuospatial WM capacity (VSWM) is responsible for processing and storing of visual and
23 spatial information, verbal WM capacity (VWM) is responsible for processing and storing of auditory
24 and verbal information (15,16). Both types of processing occupy WM capacity and therefore induce
25 working memory load (WM load), which draws attention away from the primary driving task. This,
26 by WM load induced distraction then leads to degraded driving performance (17,18,19). For instance,
27 Just et al. (2008) found, using fMRI, that combining language comprehension and driving decayed
28 driving performance because cognitive resources were occupied. This effect held even when it did not
29 require holding or dialing the phone (7).

30 Although drivers of all ages will be affected by distraction, young novice drivers are thought
31 to be especially susceptible. Many aspects of driving become automated over time with increasing
32 driving experience. Novice drivers, however, have low experience levels and therefore often lack the
33 skills needed to operate a vehicle while devoting minimal attention to the driving task (2). Because
34 driving is not automated in the same way as with experienced drivers, novice drivers will probably
35 need to devote more WM capacity to the driving task itself. Meanwhile, the WM capacity of young
36 drivers is even more limited in comparison to older drivers. WM capacity only begins to take on adult
37 form in late adolescence due to the fact that this development of WM capacity depends on the
38 maturation of the prefrontal cortex (PFC) and parietal lobes which starts at the age of 11 (20).
39 Because of low practice levels and their developing WM capacity young novice drivers lack spare
40 WM capacity to devote to secondary tasks. When they do perform simultaneous tasks their
41 performance on both tasks is likely to degrade (2,21,22,23). For instance, text messaging during a
42 driving simulation caused a detrimental effect on several critical driving measures (24). An
43 investigation by NHTSA indeed found that the age group below 20 had the largest proportion of
44 distracted drivers, about 16%, on fatal crashes (25). Lastly, despite their limitations, they are more
45 willing to accept and use new technologies in comparison with older drivers (21) and also perceive
46 less risk in using such technologies (26).

47 While previous studies already established degrading effects of WM load on driving
48 performance (17,18,27), they did not include a link with WM capacity. This study was aimed to
49 investigate, for young novice drivers, the relation between driving performance, WM load and
50 different WM capacity types (VSWM and VWM). Driving performance was measured with the Lane

change task (LCT), a simple, efficient and low-cost tool used in distraction studies to investigate the effect of visuospatial and WM load on driving performance (19,26,27). Use of the LCT allowed the selection of dependent measures, already postulated to be susceptible for WM load, to be investigated further by including WM capacity. WM load was induced by an auditory-verbal response N-back WM task. This induces load on VWM by requiring one to maintain and manipulate information in memory. It resembles distracting tasks such as cell phone conversations or interacting with auditory in-vehicle devices because it draws on many of the same cognitive resources (28). VSWM and VWM were assessed with two separate tasks (15) in order to determine if young novice drivers with a high VSWM and/or VWM capacity show superior LCT performance in comparison to those with low capacity. Driving performance relies heavily on visuospatial abilities. Therefore, VSWM was expected to be highly related to baseline LCT performance. However, when combined with increasing levels of auditory-verbal WM load, VWM would likely become more important in order to handle this distraction. Last, and most important, this study investigated if the expected degrading effects of WM load on driving performance differ for participants with low and high WM capacity. Would participants with high WM capacity be less influenced by increasing WM load so that their LCT performance was less degraded?

METHODS

Participants

A group of 51 young novice drivers (27 females) between 17 and 25 years (mean= 19.42; SD= 1.77) with either a learners permit and minimum 20 hours driving experience (mean months license= 8.38, SD= 5.06), or a permanent license and maximum two years of license possession (mean months license= 11.16, SD= 7.68).

Lane Change Task (LCT)

The LCT Sim v1.2, developed by Daimler AG, consisted of three-km road tracks with 18 lane change signs. Participants were instructed to perform lane-change maneuvers in the direction indicated by the sign (Fig. 1), while maintaining a constant speed of 60 km/hour. Mean distance between signs was 150m, resulting in a mean duration of nine seconds between lane changes. One track can be completed in approximately 180 seconds (29). Participants used a force-feedback steering wheel to control the simulation. Meanwhile, simulated vehicle engine sounds made the driving situation more realistic. The LCT consisted of six tracks. The first two were training tracks to enable the subject to familiarize with the task and did not include WM load. The third served as a baseline (i.e. without WM load) measurement. Tracks four to six were combined with the auditory-verbal N-back increasing complexity. The three LCT-N-back combinations were counterbalanced among participants.



FIGURE 1 Simulated three-lane road

Auditory-Verbal Response N-back

This task was adapted from Mehler et al. (2011) (30). Numeric values ranging from zero to nine were presented to the subject. The time interval between stimuli was 2.25s. The task included three complexity levels which were counterbalanced among participants. The 0-back was low-level; the participant, whilst carrying out the LCT, had to repeat out loud each number immediately after it was presented. For the 1-back, the subject was required to recall and repeat out loud the number that was presented just before the last number they heard, (i.e. one stimulus back). For the 2-back, participants were required to recall and repeat out loud the number that was presented two numbers before the last number they heard. The auditory-verbal nature of the task allowed WM load to be systematically varied without conflicting with manual control or visual processing of the LCT (31).

Working Memory Capacity Tasks

Visuospatial WM capacity: Visuospatial Span (VS)

In the VS, a 4-by-4 grid was presented on screen and a certain number of squares in the grid would sequentially and randomly turn blue. Participants were instructed to reproduce the sequence in the correct order by clicking on the squares that had changed color by use of a computer mouse. Initially, the task involved a sequence of three items. When participants correctly reproduced the sequences on two consecutive trials, one item was added to the sequence on the next trial. When participants were not able to correctly reproduce sequences on two consecutive trials, the task stopped (32).

Verbal WM capacity: Letter Span (LS)

In the LS, a series of letters was sequentially presented on screen in a circular manner. Together with each letter an arm lighted up that was connected with a central circle. After presentation of the complete letter set, one of the arms from this circle was presented in red and participants had to use the keyboard to indicate which letter was previously connected to this arm. Task sequence was the same as for the previous VS (32).

Procedure

Upon arrival, participant signed an informed consent. The WM load was trained starting from simple to complex. The subject then performed six LCT tracks. Participants were instructed to change lanes as soon as the information on the sign was visible. This change should be deliberate, abrupt and efficient, with the change executed before the sign. Participants were reminded of the importance of both tasks and were asked to balance efforts between both. Participants then completed two WM capacity tasks starting with the visuospatial span and following with the letter span.

DATA COLLECTION

Lane Change Task (LCT)

Dependent measures, known to be influenced by WM load, were derived from existing literature (19,33).

- Mean deviation in lane change path (MDEV): deviation between the position of the normative model and the actual driven course (Fig. 2). This measure covers several aspect of LCT

performance which can result in an increased deviation: perception (i.e. late perception of the sign or missing a sign), maneuvering quality (i.e. slow lane changes) and lane keeping quality. The normative model was based on baseline level of the participant.

- Lane change initiation (LCI): the start of the initiation was defined as the first instant that the steering wheel angle was greater than, or equal to, 3 degrees when required to move by one lane position; or 6 degrees when required to move by two lane positions. A steering event was only recorded if the driver steered in the proper direction. The distance travelled from the beginning of the segment, when the road sign appears, to the initiation was computed for each of the 18 segments and averaged. This measure was used to assess late detection of command signs.
- Percentage of correct lane changes (PCL): the number of correct lane changes that occurred until 40m after the sign. This measure was used to identify cases where signs are missed or incorrectly responded to.

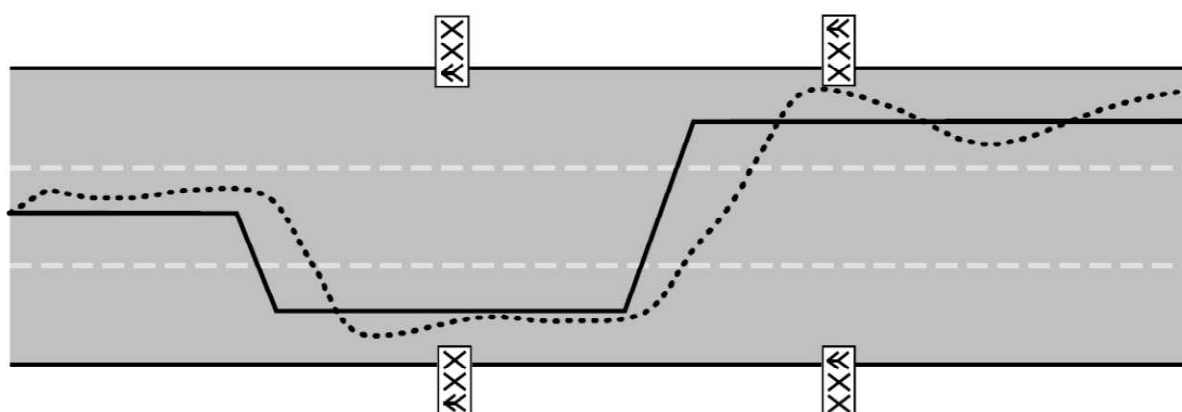


FIGURE 2 Comparison of normative model and driving data

Auditory-Verbal Response N-back

Performance on the WM load task was calculated as the error rate per LCT track and was used as a check for the increasing complexity of WM load levels.

Working Memory Capacity Tasks

Visuospatial & Letter Span

For the VS and LS, the number of items in the sequence that could be correctly reproduced (i.e. the level that was reached) was used as the outcome measure, with a higher level indicating a better WM capacity (32).

DATA ANALYSES

Exploratory analyses were conducted to identify outliers per WM load level, and per dependent measure, in order to be removed from the analyses. Repeated measures ANOVA on the secondary task was conducted to test if the distraction was effective (i.e. more N-back errors with increasing complexity). Repeated measures ANCOVA were conducted in order to assess: 1) if the WM load was effective in causing distraction, 2) if WM capacity was related to better LCT performance, 3) to shed more light on the specific relational patterns for different WM capacity types. More specifically, was

VSWM most related to baseline and VWM most to higher levels of WM load, 4) to determine if there was an interaction between WM load and WM to investigate if participants with high WM capacity were less negatively influenced by WM load. Separate models were analyzed for every dependent measure and included both VSWM and VWM. When VSWM and/or VWM were not significant, it was removed from the model. Greenhouse-Geisser was used to correct for sphericity violations, Bonferroni correction was used for pairwise comparisons of mean differences (MDs) between performance levels in order to correct for familywise error.

RESULTS

Secondary Task Data

As expected, the increasing complexity of WM load was effective, with more errors being made in the more difficult levels ($F(2,86) = 147.2$, $p < .0005$; means: 0-back = 0%, 1-back = 11.04%, 2-back = 45.11%).

Repeated Measures ANCOVA

MDEV degraded with increasing N-back levels since the main effect of WM load on MDEV was significant ($F(2.1,99.3) = 51.3$, $p < .0005$). MDs between levels showed there was no significant difference between baseline and 0-back (mean difference (MD) = -.02, $p = .841$) performance, the 0- vs. 1-back (MD = -.14) and 1- vs. 2-back (MD = -.13) did show significant differences ($p < .0005$). There was a main effect of VSWM ($F(1,47) = 4.4$, $p = .041$, $r = -.454$) and VWM ($F(1,47) = 5.5$, $p = .024$, $r = -.472$) indicating that participants with higher verbal and visual WM capacity showed less deviation from the normative path. Parameter estimates showed VSWM to be a significant predictor of baseline and 0-back level ($p < .05$). VWM was a significant predictor for 0- and 1-back performance ($p < .05$). The interaction effect with WM load was not significant for VSWM, or VWM. The MDEV of participants with higher VSWM and VWM was thus not significantly less affected by increasing WM load complexity. In sum, MDEV degraded between 0-, 1- and 2-back levels. Participants with higher WM capacity showed less overall deviation from the normative path. VSWM predicted LCT performance, as assessed by MDEV, under baseline and lower levels of WM load while VWM predicted performance at lower and intermediate levels. Nonetheless, participants with high WM capacity were not significantly less influenced by increasing WM load.

The initial model of LCI, including VSWM and VWM, did not reveal a significant main effect of VSWM on LCI ($F(1,48) = .1$, $p = .94$, $r = -.201$). A new model, only including VWM, was analysed. Participants initiated lane changes more slowly with increasing N-back complexity level, WM load main effect on LCI was significant ($F(2.29,112.32) = 80.1$, $p < .0005$). MDs were significant across for baseline vs. 0-back (MD = -.9, $p < .0005$) and 0- vs. 1-back (MD = -1.52, $p < .0005$), and 1- vs. 2-back levels (MD = -.78, $p = .009$). VWM main effect was significant ($F(1,49) = 7.2$, $p = .01$, $r = -.358$) thus participants with higher VWM displayed lower LCI values. Parameter estimates showed that VWM predicted baseline LCI marginally ($p = .51$). VWM did significantly predict 0-back ($p < .05$) and 1-back LCI ($p < .01$), but did not significantly predict 2-back ($p = .1$) LCI performance. The interaction effect was not significant and thus LCI of participants with higher VWM was not significantly less affected by increasing WM load complexity. In sum, LCI degraded between baseline, 0-, 1- and 2-back WM load. Participants with higher VWM capacity had smaller overall LCI values. VWM predicted LCT performance, as assessed by LCI, under lower and intermediate levels of WM load. Again, high WM capacity participants were not significantly less influenced by increasing WM load.

Participants made more erroneous lane changes with increasing N-back complexity since the WM load main effect on PCL was significant ($F(1.7,64.58) = 22.5$, $p < .0005$). MDs showed there was no significant difference between baseline and 0-back (MD = .41%, $p = .646$) performance. The 0- vs.

1-back ($MD = 1.9\%$, $p = .009$) and 1- vs. 2-back ($MD = 2.58\%$, $p = .010$) did show significant differences. VSWM had a significant main effect ($F(1,38) = 5.3$, $p = .027$, $r = .464$), participants with a higher VSWM capacity overall made less erroneous lane changes. VSWM was a significant predictor for baseline ($p < .01$) and 0-back WM load level ($p < .0005$). The interaction effect was not significant so participants with high VSWM were not significantly less affected by increasing WM load. VWM did not show a significant main effect ($F(1,38) = 1.5$, $p = .235$). VWM also was no significant predictor for any of the WM load levels; although with increasing complexity of WM load the significance level did show a trend towards .05. The interaction between WM load and VWM was significant ($F(1.7,64.58) = 4.7$, $p = 0.017$). This suggests that, for PCL, participants with higher VWM were differently influenced by increasing WM load in comparison to those with lower VWM. Separate analyses per low and high VWM groups indicated that both were affected by WM load. F-values however, were larger for the low VWM group (low ($F(2.11,48.52) = 11.2$, $p < .0005$)) in comparison to high VWM ($F(2.33,58.19) = 8.1$, $p < .0005$). MDs indicated that the MD between 0- and 1-back differed significantly for both groups, but it was larger for low VWM ($MD_{low} = 3.71\%$, $p = .049$; $MD_{high} = 1.50\%$, $p = .033$). Even though not significant, remaining MDs for the low VWM capacity group were also larger in comparison with the high VWM group (baseline vs. 0-back ($MD_{low} = -.46\%$, $p = 1$; $MD_{high} = 0\%$, $p = 1$); 1-back vs. 2-back ($MD_{low} = 2.78\%$, $p = .375$; $MD_{high} = 1.28\%$, $p = .499$)). These MDs indicate that the amount of correct lane changes were less reduced for participants with high VWM. In sum, PCL degraded between 0-, 1- and 2-back WM load. VSWM was related to PCL performance and mainly predicted baseline and lower WM load levels. Participants with high VSWM, however, were not less influenced by increasing WM load. Separate analyses for low and high VWM participants showed that the PCL of participants in the higher VWM group was less affected by increasing WM load.

DISCUSSION

The goal of this research was to investigate the relation between by WM load induced distraction, driving performance and WM capacity. While previous studies already established degrading effects of WM load on driving performance (17,18,27), they did not include a link with WM capacity. This study was aimed to investigate if, for young novice drivers, the expected degrading effects of WM load differed for participants with low and high WM capacity. Thus for investigating if high WM, in comparison with low WM capacity, capacity related to better LCT performance. Furthermore, since the LCT relies heavily on visuospatial processing, VSWM was expected to relate most to LCT baseline performance. When combined with increasing levels of auditory-verbal load, VWM would likely be deployed to cope with the distraction and for those levels VWM would relate more strongly with LCT performance. Last but not most important, this study examined whether young novice drivers with high WM capacity were influenced by increasing WM load, in that their performance degraded less as for those with low WM capacity.

As expected, WM load degraded LCT performance for the selected dependent measures (i.e. MDEV, LCI and PCL) (19,33). This replicates previous findings that distraction, as induced by WM load, affects the normative model (27), as well as detection and response selection (19). Since distracting tasks such as cell phone conversations or interacting with auditory in-vehicle devices, like the current WM load, imply storage and manipulation of information (28), these tasks will cause similar effects on driving performance. This indeed has been found, for instance, younger and older drivers doubled their engagement in rear-end collisions when using hands-free cell phones during simulated driving (34).

WM capacity had a significant influence on baseline driving performance, as well as driving performance when distracted by WM load. This replicates and extends previous research which related WM capacity to LCT performance (i.e. measured by MDEV and lateral position) while counting backwards (35). This study, however, did not include detection (i.e. LCI) and response

selection (i.e. PCL) measures nor did it include varying WM load levels. Results from this study indicated that participants with higher WM capacity showed less overall deviation from the normative path, and results also indicated that they initiated lane changes faster and made more correct lane changes. In more detail, those with high VSWM displayed better LCT performance, as measured by MDEV and PCL. Participants with high VWM displayed better LCT performance, as measured by MDEV, LCI and PCL. The exclusive relation between VWM and LCI was probably caused by the fact that the relation is averaged among levels and the WM load itself is an auditory-verbal task.

In addition to the relation between WM capacity and LCT performance, this study investigated specific relational patterns for VSWM and VWM with driving performance under different levels of WM load. Unlike VSWM, VWM was related to driving performance under increasing complexity WM load. This effect was expected due to the verbal-auditory nature of the secondary task. It adds to existing literature describing WM load effects on driving performance (4,14,18) by showing the involvement of WM capacity, more specifically VWM, in dealing with distraction induced by verbal-auditory WM load. Even though the task did not require extra VSWM capacity, VWM was increasingly loaded and performance degraded.

Most important, young novice drivers with higher WM capacity were better able to devote attention to one aspect of the primary task of driving. This study was the first to find that for one driving parameter (i.e. PCL, response selection) participants with higher VWM were less influenced by increasing WM load complexity in comparison with lower VWM. Thus, even though they also made more erroneous lane changes with increasing complexity levels, their performance degrade in a lesser manner. This finding coincides with theories and findings that the availability of more WM capacity leaves room for greater abilities to use attention for avoiding distraction (14,36).

LIMITATIONS

Questions could be raised concerning the transfer of LCT task driving performance to real-life driving. LCT only requires lane changes over a constant time period; no other driving conditions are included. Furthermore, the instruction to change lanes in a deliberate manner may not resemble daily driving conditions. However, the LCT has been proven a valid way for measuring distraction effects (19,27). Furthermore, the lane keeping and detection measures do resemble necessary functions for real-life driving. Nonetheless, further research should be able to address additional driving parameters in order to gain a more complete image of the above described relations between WM capacity and driving performance. Driving simulator, or on-road driving, studies could allow investigation of other driving parameters which cannot be investigated with the LCT. For instance, it would be interesting to investigate if other driving parameters that withhold response selection, such as reacting to slowing vehicles, would show the same interaction with VWM when loaded with auditory-verbal WM capacity tasks. A possible question could be if people with a high VWM capacity collide less with slow vehicles in a in a driving simulation?

RECOMMENDATIONS

The found relationship between WM and driving performance allows for some practical inferences. First of all, training WM capacity could lead to overall better driving performance. More important, it might even, at least for some driving parameters, lead to superior coping with distraction. Training of cognitive control functions, such as WM, to transfer to daily life activities has become popular in the last years. For instance, training WM with a visuospatial N-back task improved simulated driving performance in older adults (37). The additional WM capacity developed during training could be devoted to focusing attention at the primary task of driving and diverting if from distraction activities.

Training therefore might compensate some of the before mentioned causes for the susceptibility of young novice drivers for distraction (i.e. low driving experience and less developed WM capacity).

A practical application could be to use WM capacity (e.g. VS and LS) to screen young novice drivers for the necessity of training. This WM capacity training could be included in drivers learning programs. For instance, a graduated driver licensing (GDL) system already withholds several restrictions for adolescents who are learning how to drive (e.g. limiting nighttime driving and transport of passengers) (38). A possible addition could be a mandatory screening in order to assess whether WM capacity training is necessary. Another option is including such training for every adolescent who wants to obtain his/her license.

Nonetheless, the degrading effect of distraction by WM load in this study, for both high and low WM capacity participants, clearly indicates the need to try to eliminate distraction as much as possible. Especially when dealing with young novice drivers since they are more susceptible to distraction related crashes and are more willing to accept risks accompanying hand-free technology (21). From this point of view, encouragement of new technologies as the MyKey® system from Ford, which for instance allows parents to limit audio volume (39), is necessary in order to minimize crash risks due to distraction among young novice drivers.

ACKNOWLEDGEMENTS

The authors would like to thank would like to thank Stefan Mattes and Denis Boucher for their assistance concerning LCT analyses. They would also like to thank Bruce Mehler, Bryan Reimer & Jeffery A. Dusek for providing materials for the auditory-verbal N-back. Lastly, they would also like to thank Katrijn Houben and Michiel Vestjens for providing the visuospatial and letter span tasks.

REFERENCES

- [1] Blanco, M., W. J. Biever, J. P. Gallagher and T. A. Dingus, "The impact of secondary task cognitive processing demand on driving performance," *Accident Analysis and Prevention*, vol. 38, p. 895–906, 2006.
- [2] Young, K., and M. Regan, "Driver distraction: A review of the literature," in *Distracted driving*, Sydney, NSW: Australasian College of Road Safety, 2007, pp. 379-405.
- [3] Stutts, J., D. Reinfurt, L. Staplin and E. Rodgman, "The role driver distraction in traffic crashes," AAA Foundation for Traffic Safety, Washington, DC, 2001.
- [4] Neyens, D. M., and L. N. Boyle, "The effect of distractions on the crash types of teenage drivers," *Accident Analysis and Prevention*, vol. 39, p. 206–212, 2007.
- [5] Fofanova, J., and M. Vollrath, "Distraction while driving: The case of older drivers," *Transportation Research Part F*, vol. 14, p. 638–648, 2011.
- [6] Hosking, S., K. Young and M. Regan, "The effects of text messaging on young novice driver performance," in *Distracted driving*, Sydney, NSW: Australasian College of Road Safety, 2007, pp. 155-187.
- [7] Harbluk, J. L., Y. I. Noy, P. L. Trbovich and M. Eizenman, "An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance," *Accident Analysis and Prevention*, vol. 39, p. 372–379, 2007.
- [8] Maciej, J., and M. Vollrath, "Comparison of manual vs. speech-based interaction with in-vehicle information systems," *Accident Analysis & Prevention*, vol. 41, no. 5, p. 924–930, 2009.
- [9] Just, M. A., T. A. Keller and J. Cynkar, "A decrease in brain activation associated with driving when listening to someone speak," *Brain Research*, vol. 1205, pp. 70-80, 2008.

- [10] Nunes, L., and M. A. Recarte, "Cognitive demands of hands-free-phone conversation while driving," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 5, no. 2, p. 133–144, 2002.
- [11] Rosenbloom, T., "Driving performance while using cell phones: an observational study," *Journal of Safety Research*, vol. 37, no. 2, p. 207–212, 2006.
- [12] Regan, M. A., J. D. Lee and K. L. (. Young, *Driver Distraction: Theory, Effects, and Mitigation*, Boca Raton FL: Taylor & Francis Group, 2009.
- [13] Castro, C., *Human Factors of Visual and Cognitive Performance in Driving*, Boca Raton: Taylor & Francis Group, 2009.
- [14] Buckner, R. L., "Memory and Executive Function in Aging and AD: Multiple Factors that Cause Decline and Reserve Factors that Compensate," *Neuron*, vol. 44, p. 195–208, 2004.
- [15] O'Hearn, K., M. Asato, S. Ordaz and B. Luna, "Neurodevelopment and executive function in autism," *Development and Psychopathology*, vol. 20, p. 1103–1132, 2008.
- [16] de Fockert, J. W., G. Rees, C. D. Frith and N. Lavie, "The Role of Working Memory in Visual Selective Attention," *Science*, vol. 291, pp. 1803-1805, 2001.
- [17] Engström, J. and G. Markkula, "Effects of visual and cognitive distraction on lane change test performance," in *PROCEEDINGS of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Stevenson, Washington, 2007.
- [18] Engström, J., E. Johansson and J. Östlund, "Effects of visual and cognitive load in real and simulated motorway driving," *Transportation Research Part F* 8, p. 97–120, 2005.
- [19] Harbluk, J. L., P. C. Burns, M. Lochner and P. L. Trbovich, "Using the lane-change test (LCT) to assess distraction: tests of visual-manual and speech-based operation of navigation system interfaces," in *PROCEEDINGS of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Stevenson, Washington, 2007.
- [20] Shinar, D., *Traffic safety and human behavior*, 1st edition ed., Amsterdam: Elsevier, 2007.
- [21] Underwood, G., "Visual attention and the transition from novice to advanced driver," *Ergonomics*, vol. 50, no. 8, p. 1235–1249, 2007.
- [22] De Luca, C. R. and R. J. Leventer, "Developmental trajectories of executive functions across the lifespan," in *Executive functions and the frontal lobes*, New York, Taylor & Francis group, 2008, pp. 23-56.
- [23] Mehler, B., B. Reimer, J. F. Coughlin and J. A. Dusek, "Impact of Incremental Increases in Cognitive Workload on Physiological Arousal and Performance in Young Adult Drivers," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2138, pp. 6-12, 2009.
- [24] Wager, T. D. and E. E. Smith, "Neuroimaging studies of working memory: A Meta-Analysis," *Cognitive, Affective, & Behavioral Neuroscience*, vol. 3, no. 4, pp. 255-274, 2003.
- [25] Mehler, B., B. Reimer and J. F. Coughlin, "Sensitivity of Physiological Measures for Detecting Systematic Variations in Cognitive Demand From a Working Memory Task: An On-Road Study Across Three Age Groups," *Human Factors*, vol. 54, no. 3, pp. 396-412, 2012.
- [26] Stutts, J., J. Feaganes, D. Reinfurt, E. Rodgman, C. Hamlett, K. Gish, Staplin and L., "Driver's exposure to distractions in their natural driving environment," *Accident Analysis & Prevention*, vol. 37, no. 6, p. 1093–1101, 2005.
- [27] Young, K. L., and M. G. Lenné, "Driver engagement in distracting activities and the strategies used to minimise risk," *Safety Science*, vol. 48, p. 326–332, 2010.
- [28] Bherer, L., A. F. Kramer, M. S. Peterson, S. Colcombe, K. Erickson and E. Becic, "Training Effects on Dual-Task Performance: Are There Age-Related Differences in Plasticity of Attentional Control?," *Psychology and Aging*, vol. 20, no. 4, p. 695–709, 2005.

- 1 [29] Koppenol-Gonzalez, G. V., S. Bouwmeester and J. K. Vermunt, "The development of verbal
2 and visual working memory processes: a latent variable approach," *Journal of Experimental*
3 *Child Psychology*, vol. 111, no. 3, pp. 439-54, 2012.
- 4 [30] Mehler, B., B. Reimer and J. A. Dusek, "MIT AgeLab delayed digit recall task (nback)," *Massachusetts Institute of Technology*, Cambridge, MA, 2011.
- 5 [31] Houben, K., R. W. Wiers and A. Jansen, "Getting a grip on drinking behavior: Training
6 working memory to reduce alcohol abuse," *Psychological Science*, 2011.
- 7 [32] Cassavaugh, N. D. and A. F. Kramer, "Transfer of computer-based training to simulated
8 driving in older adults," *Applied Ergonomics*, vol. 40, p. 943–952, 2009.
- 9 [33] Masten, S. V., R. D. Foss and S. W. Marshall, "Graduated Driver Licensing and Fatal Crashes
10 Involving 16- to 19-Year-Old Drivers," *JAMA*, vol. 306, no. 10, pp. 1098-1103, 2011.
- 11 [34] Mattes, S. "The lane-change-task as a tool for driver distraction evaluation," in *Annual Spring*
12 *Conference of the GfA/17th Annual Conference of the International-Society-for-*
13 *Occupational-Ergonomics-and-Safety (ISOES)*, Munich, 2003.
- 14 [35] International Organization for Standardization, "www.infovusam.sk," 2007. [Online].
15 Available: www.infovusam.sk/pdf/.../ISO_DIS_26022.pdf. [Accessed 13 June 2012].
- 16 [36] Ford, "MEDIA.FORD.COM," Ford, [Online]. Available:
17 http://media.ford.com/article_display.cfm?article_id=29172. [Accessed 29 July 2012].
- 18 [37] Mäntylä, T., M. J. Karlsson and M. Marklund, "Executive Control Functions in Simulated
19 Driving," *Applied neuropsychology*, vol. 16, pp. 11-18, 2009.
- 20 [38] Engle, R. W., "Working Memory Capacity as Executive Attention," *Current Directions in*
21 *Psychological Science*, vol. 11, p. 19–23, 2002.
- 22 [39] Strayer, D. L. and F. A. Drews, "Profiles in Driver Distraction: Effects of Cell Phone
23 Conversations on Younger and Older Drivers," *Human factors*, vol. 64, no. 4, p. 640–649,
24 2004.
- 25