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DOCTORAL DISSERTATION

INVESTIGATING UNDERLYING MECHANISMS OF DRIVING IN YOUNG NOVICE DRIVERS WITH AND WITHOUT AN AUTISM SPECTRUM DISORDER

Doctoral dissertation submitted to obtain the degree of
Doctor of Transportation Sciences, to be defended by

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LIST OF ABBREVIATIONS

ADHD	Attention deficit hyperactivity disorder
ASD	Autism spectrum disorders
ASS	Autisme spectrum stoornissen
DSM	Diagnostic and statistical manual of mental of disorders
EBPM	event-based prospective memory
EEG	Electroencephalography/Elektroencefalografie
ERP	Event-relation potential
GDE	Goals for Driver Education
GDL	Graduated Driver Licensing
LCI	Lane change initiation
LCT	Lane change task
MDEV	Mean deviation in the lane change path
PCL	Percentage of correct lane changes
PM	Prospective memory
DAS-PR	Driving Attitude Scale Parent-Report
RT	Routine training
TBPM	Time-based prospective memory
VRDS	Virtual reality driving simulation
VRDST	Virtual reality driving simulation training
VRRS	Virtuele realiteit rijsimulatie
VRRST	Virtuele realiteit rijsimulatie training
WM	Working memory

PREFACE

At the start of my PhD, we planned to investigate risky driving in young novice drivers in a dual-process framework. During those years however interesting opportunities were offered and new research interests were developed. Therefore the current thesis now not only withholds research regarding young novice drivers, but also research investigating underlying mechanisms of distraction in an adult sample (in cooperation with Maastricht University), as well as research investigating young novice drivers with an autism spectrum disorder (ASD) (in cooperation with REVAL/BIOMED and the University of Virginia). I gained a lot of knowledge during this PhD, not only in an academic sense, but also on a personal level. I hope that whoever will read this document will enjoy the diversity in topics as much as I did when I was executing them.

ACKNOWLEDGEMENTS / DANKWOORD

I remember when I was growing up in Diepenbeek that we were very proud that we had our own university. Nevertheless, I had never heard of IMOB until I was in the final year of my psychology studies in Maastricht. IMOB was listed among the list of possible internships. After a talk with Ellen Jongen and Kris Brijs, I decided to start the internship at Diepenbeek in January 2011. Still, I never considered the possibility of starting a PhD until Ellen mentioned the opportunity to continue the research from my internship. I'm grateful that both Ellen and Tom Brijs granted me the opportunity to start my PhD. I also want to thank them for the support they provided me and the knowledge that they shared, and Ellen for the walks and talks during lunch (even on very icy pathways).

During my PhD I was lucky to collaborate with experienced people who were willing to share their expertise. First, I would like to thank Ellen, Fren, Rob, and Alex, for the very enjoyable collaboration on the two EEG chapters. Furthermore, the first part of my PhD wouldn't be possible without the technical assistance of Marc Geraerts and Dirk Roox. For the second part of my PhD I was able to broaden my focus to ASD. In this respect, I want to thank Marleen Vanvuchelen for her support since that time. I also want to thank Daniel Cox for the opportunity of a research stay in Charlottesville, Virginia, at the U.Va, which allowed the inclusion of two additional interesting chapters investigating ASD. I want to thank Matt Moncrief from U.Va, for his support regarding their datasets. Also a big thanks to all my jury members for their support and comments throughout the years.

At the beginning, I knew one colleague very well, my friend Ariane Cuenen that I knew from Maastricht. It was great to be able to share this experience together. During the years I worked at IMOB, I also got to know several other colleagues with whom I could share work and personal experiences. A thanks goes out to all of these colleagues for the talks and laughs we shared. I would like to thank the entire Admin team for their continuous support. And especially Kristel Hertogs, who is a life-saver and travel-agent wrapped in one.

I wouldn't be able to have successfully finished my PhD without support from close friends and family (in-law). Especially mom and dad, who allowed me to start my Psychology studies after I already I obtained my Occupational Therapy degree. I grew up a lot during the past years and a lot has happened, but your parents will always be your parents and I hope to receive their support for many years to come. And finally, the best journey always takes us home. From sharing coffee in the morning to singing songs to the kids before bedtime, these are the little things for which I'm thankful.

EXECUTIVE SUMMARY

The current thesis describes underlying mechanisms of driving behavior in young novice drivers with and without an autism spectrum disorder (ASD).

Part one includes virtual reality driving simulation (VRDS) research that was conducted in order to investigate a dual process theory of risky driving in neuro-typical novice drivers. The dual process theory of risky driving provides a framework for risky driving that considers the imbalance between the development of the social-affective brain and the cognitive control system. This imbalance is caused by a maturational gap between both brain systems (i.e., early developing social-emotional and late developing cognitive brain systems).

In chapter one and two (a and b), we investigated the hypothesis that sufficient cognitive resources are necessary to safely execute the driving task. More specifically, these chapters included detrimental effects of distraction while driving. Distraction can occur at the sensory input (e.g., visual) level, but also at the cognitive level where assistive technology induces working memory (WM) load. Active maintenance of goal-directed behavior in the presence of distraction depends on WM capacity (i.e., Lavie's Load theory), which implies that the performance of people with higher WM capacity may suffer less when distracted. In chapter one we included the interaction between verbal WM load and WM capacity on driving performance to determine whether individuals with higher WM capacity were less affected by verbal WM load, leading to a smaller deterioration of driving performance. It included the target population of interest, young novice drivers, who are presumed to be more susceptible to effects of distraction when compared to more experienced drivers. First, they lack an automaticity in driving skills, therefore, they need to invest more resources into the driving task. Second, their WM capacity is still developing, leaving them with less spare resources to invest in the driving and distracting activities. Third, they are more willing to accept new technologies, inclining them the use these distractive technologies while driving. Driving performance was measured with the lane change task (LCT). Participants drove with and without the distracting task (i.e., resembling hands-free technology) of increasing complexity. Driving performance deteriorated with increasing verbal WM load. Meanwhile, higher WM capacity related to better performance. Finally, participants with higher verbal WM capacity were influenced less by verbal WM load. The negative influence however could not be eliminated completely. These findings entailed that increased WM performance cannot completely eliminate negative effects of distraction among young novice drivers. In chapter two (a and b), we investigated effects of distraction in a specific high-risk environment in a sample of adult drivers. Intersection accidents encompass a significant proportion of fatalities and attention allocation seems to play a key role. Attention allocation depends on an orienting mechanism pending on limited WM capacity. Study 2a investigated WM load effects, induced by a memory task, on spatial and nonspatial orienting processes by analyzing event-related potentials (ERPs) that were measured by electroencephalography (EEG) and behavioral outcomes on a cued attention task. In study b, this attention task was translated to a simulated driving environment, allowing additional measurement of continuous driving (lane-keeping). Typical neurological markers of attention orienting were found, and some were affected by WM load, in both settings. This demonstrates the applicability of EEG markers as neural indicators in the study of visuospatial orienting and distraction also in more realistic task conditions. Study 2b additionally showed that the lane-keeping variability was reduced under high WM load. Meanwhile, WM load led to an increased number of errors in the memory task combined with decreased performance on the simulated attention task. This was indicated by an increased tendency to yield and a smaller ERP response to movement. Distraction while driving at intersections might degrade traffic flow when drivers stop at inappropriate moments. These chapters together indicate that a lack of cognitive resources can degrade driving performance.

In chapter 3 and 4, we investigated how the interplay of cognitive with social-emotional mechanisms influences risky driving in young novice drivers. In chapter 3, we investigated whether decreased cognitive control, reflected in inhibitory control and WM performance, may partially explain risky driving in young novice drivers. Several driving measures were analyzed and it was indeed found that cognitive control relates to risky driving. The relation however was not always in the same direction. Better inhibitory control and verbal WM capacity were associated with better lane-keeping. Inhibitory control, but not WM, was also related with better hazard-handling as reflected in the detection of, reaction to, and crashes with road hazards. Better visuospatial WM capacity however related to increased risky driving, as reflected in yellow-light running and the following distance inside the city center. In chapter 4, we tested the dual process theory of risky driving by including peer passengers. Cognitive control was included by measuring inhibitory control. Driving performance measures were classified based on a driver-error model. Key findings of the study were: 1) risky driving increased in the presence of peer passengers in case of red light running (violation); 2) the risk-increasing effect on speeding (violation) was moderated (lowered) by (increased) inhibitory control; 3) distractive effects were reflected in reduced lane-keeping variability; 4) protective effects occurred for amber light running and hazard handling (cognition and decision making). Chapters three and four have important practical implications as insights coming from research on cognitive development can be applied to programs aimed at reducing injury risk for adolescents and young adults, such as GDL (Graduated Driver Licensing). Furthermore, the results apply to cognitive control training, which is based on the assumption that improved cognitive control leads to increased behavioral control and therefore decreased risky behavior. The current results indicate that more research is necessary to be able to determine the usefulness of cognitive training as 1) the relation with risky driving is not always negative, and 2) inhibitory control only moderated the effect of peer passengers on one driving measure (speeding).

Part two of the thesis includes a questionnaire and VRDS to investigate driving in young novice drivers with ASD, a population that may experience additional problems when learning how to drive/while driving due to associated cognitive dysfunctions.

In chapter five, we surveyed driver instructors. Several questions queried advice for teaching youth with ASD on how to drive, and for improving current driving education to better fit the needs of youth with ASD. Flemish driver instructors who encountered learner drivers with ASD acknowledged potential problems. Furthermore, respondents were asked to indicate whether specific characteristics often associated with ASD, have an impact on driving ability. Advice for teaching youth with ASD to drive mainly focused on a need for structure, clarity, visual demonstration, practice, repetition and an individualized approach. Results however also showed that the relation between ASD and driving performance might not always be negative but can be positive (e.g., rule-bound) too. The results also entail some practical implications. For instance, financial aids and driver instructor courses might improve the accessibility of driving lessons for youth with ASD. Furthermore, although not specifically queried, driver instructors indicated driving simulation as a means to familiarize ASD learner drivers with driving. In chapter six, we followed up on this issue as it consists of a preliminary investigation of the usefulness of virtual reality driving simulation training (VRDST) to improve both driving ability and cognitive control of US young novice drivers. It was found that VRDST indeed was able to improve those abilities. Different VRDST conditions (i.e., human feedback, automated feedback, automated feedback + eye tracking) however showed different results. Interestingly, human and automated feedback demonstrated improvement over on-road routine training (RT) alone in terms of speed and steering control. The results therefore provided initial support for the usefulness of VRDS to improve driving abilities in young novice drivers with ASD. Additional research however is warranted. In chapter seven, we extended on this research by investigating attitudes towards driving as an indication of apprehensive driving in in young novice drivers with ASD. The background for this study is provided by studies where it has already been found that people with ASD prefer other modes of transportation even after they have obtained their license, and that ASD comes with an increased risk for anxiety disorders. The study included a questionnaire probing for parent ratings. Additionally, it investigated whether VRDST could alleviate driving apprehension. Apprehension is defined by worry, a concern for the future, and verbal rumination about negative expectations and fears. The results showed that young novice ASD drivers showed more negative and less positive attitudes towards driving compared to a neuro-typical young novice driver control group, indicating apprehensive driving, which could interfere with safe driving. Training in the safe VRDS environment, however, resulted in improved attitudes toward driving, providing additional support for the usefulness of VRDST for young novice drivers with ASD.

NEDERLANDSTALIGE SAMENVATTING

De huidige thesis bekijkt onderliggende mechanismen van het rijgedrag van jonge beginnende bestuurders met en zonder een autisme spectrum stoornis (ASS).

Het eerste gedeelte van de thesis bevat onderzoek op basis van virtuele realiteit rijsimulatie (VRRS) dat werd uitgevoerd met het oog op toetsing van de validiteit van een duale proces theorie van risicovol rijgedrag in neuro-typische jonge beginnende bestuurders. De duale proces theorie van risicovol rijgedrag biedt een kader voor risicovol rijgedrag door te kijken naar het gebrek aan evenwicht tussen de ontwikkeling van het sociaal-affectieve en het cognitieve controlerende hersensysteem. Deze disbalans wordt veroorzaakt door een kloof in de ontwikkeling tussen beide systemen (d.w.z., vroege ontwikkeling van het sociaal-emotionele en late ontwikkeling van het cognitieve hersensysteem).

In hoofdstuk één en twee (a en b) onderzochten we de hypothese dat er voldoende cognitieve capaciteit nodig is om de rijtaak veilig uit te voeren. In het bijzonder werd het negatieve effect van afleiding tijdens het rijden aangetoond. Afleiding kan op het zintuiglijke niveau optreden (bijv., visueel), maar ook op het cognitieve niveau, waar bijvoorbeeld ondersteunende technologie het werkgeheugen (WG) belast. Het uitvoeren van doelgericht gedrag tijdens afleiding is afhankelijk van beschikbare WG capaciteit (zie ook, Lavie's belastings theorie), waaruit men kan afleiden dat mensen met een hogere WG capaciteit minder lijden onder prestatieverlies bij afleiding. In hoofdstuk één onderzochten we de interactie tussen verbale WG belasting en capaciteit om te bepalen of de rijprestatie van individuen met een hogere WG capaciteit minder negatief beïnvloed wordt door verbale WG belasting. De studie richtte zich op jonge beginnende bestuurders. Deze worden verondersteld nog vatbaarder te zijn voor de effecten van afleiding in vergelijk met meer ervaren bestuurders. Hiervoor zijn verschillende verklaringen mogelijk. Allereerst is hun rijvaardigheid nog niet voldoende geautomatiseerd. Daardoor moeten ze meer WG capaciteit in de rijtaak investeren. Daarnaast is hun WG capaciteit nog in ontwikkeling, waardoor ze minder capaciteit over hebben om te investeren in de afleidende activiteiten naast de rijtaak. Ten slotte zijn zij meer bereid om nieuwe technologieën te aanvaarden, waardoor zij eerder geneigd zijn deze afleidende technologie ook achter het stuur te gebruiken. Rijprestaties werden gemeten met de baanvakwisseltaak. Deelnemers reden met en zonder de afleidende taak (d.w.z., gelijkend op handenvrije technologie) van toenemende complexiteit. Rijprestaties verslechterden met toenemende verbale WG belasting. Een hogere WG capaciteit werd gerelateerd aan betere prestaties. Daarnaast, werden de deelnemers met een hogere WG capaciteit minder beïnvloed door WG belasting, ook al bleef er sprake van een negatieve invloed op de rijprestatie. Deze bevindingen tonen aan dat een verhoogde WG capaciteit niet voldoende is om negatieve effecten van afleiding tegen te gaan. In hoofdstuk twee (a en b) onderzochten we effecten van afleiding in een specifieke risicovolle omgeving bij volwassen bestuurders. Een aanzienlijk deel van de verkeersdoden komt om bij kruispuntongevallen. Het richten van de aandacht speelt hierbij waarschijnlijk een belangrijke rol. Het richten van aandacht is afhankelijk van een oriënterend mechanisme dat afhangt van de beperkte werkgeheugencapaciteit. Studie 2a onderzocht het effect van WG belasting, veroorzaakt door een geheugentaak, op ruimtelijke en niet-ruimtelijke oriëntatieprocessen door event-gerelateerde potentialen (ERP), die door elektroencefalografie (EEG) gemeten werden, en gedragsmatige uitkomsten op een teken-gerichte (d.w.z., een pijl) aandachtstaak te onderzoeken. In studie b, werd deze aandachtstaak vertaald naar een gesimuleerde rijomgeving, waardoor er een bijkomende continue rijparameter (baanvastheid) kon worden gemeten. In beide situaties werden er typische neurologische indicatoren van aandacht oriënterende processen gevonden, waarvan sommige negatief beïnvloed werden door de WG belasting. Dit toont de toepasbaarheid aan van EEG potentialen als neurale indicatoren van visueel-ruimtelijke oriëntatie en afleiding in realistischere taken. Dit toont de toepasbaarheid aan van ERP als neurale indicatoren van visueel-ruimtelijke oriëntatie en afleiding in meer realistische taken. Uit studie 2b blijkt bovendien dat de variëteit in de baanvastheid kleiner werd onder hoge WG belasting. Ook werd gevonden dat WG belasting tot een slechtere prestatie op de geheugentaak leidt. Dit stelden we vast in combinatie met verminderde prestaties op de gesimuleerde aandachtstaak, door een verhoogde neiging om voorrang te geven samen met een kleinere GGP reactie op beweging. Afleiding tijdens het rijden op kruispunten kan de verkeersstroom vertragen wanneer men onnodig tot stilstand komt. Deze hoofdstukken tonen daarbij aan dat een gebrek aan cognitieve middelen de rijprestaties negatief kan beïnvloeden.

In hoofdstuk 3 en 4 onderzochten we hoe de wisselwerking tussen cognitieve en sociaal-emotionele mechanismen het risicovol rijgedrag van jonge beginnende bestuurders beïnvloedt. In hoofdstuk 3 onderzochten we of een verminderde cognitieve controle, hier gedefinieerd als lagere inhibitie en WG capaciteit, risicovol rijgedrag bij jonge beginnende bestuurders gedeeltelijk kan verklaren. Verschillende rijparameters werden geanalyseerd en de relatie tussen cognitieve controle en risicovol rijgedrag werd aangetoond. Deze relatie is echter niet altijd in dezelfde richting. Betere inhibitie en verbale WG capaciteit relateren met een betere baanvastheid. Betere inhibitie, maar niet WG, relateert met een betere reactie t.a.v. gevaren zoals gemeten door: detectie van, reactie op, en botsingen met onverwachte gevaren op de weg. Een betere visuospatiële WG capaciteit is echter gerelateerd aan meer risicogedrag zoals gemeten door doorheen het oranje licht rijden en de volgafstand in de bebouwde kom. In hoofdstuk 4 testten we de duale proces theorie van risicovol rijgedrag door de aanwezigheid van passagiers van dezelfde leeftijdsgroep. Inhibitie diende als maat voor cognitieve controle. De rijparameters werden ingedeeld op basis van een model voor rijfouten. De belangrijkste bevindingen van het onderzoek waren: 1) voor door het rood licht rijden (overtreding)was risicovol rijgedrag verhoogd in de aanwezigheid van peer passagiers; 2) het risico vergrotende effect op snelheid (overtreding) werd gemodereerd (verlaagd) door (betere) inhibitie; 3) afleidende effecten kwamen tot uiting in verminderde variabiliteit in baanvastheid; 4) beschermende effecten traden op voor oranje licht rijden en omgaan met gevaren op de weg (cognitie en besluitvorming). Hoofdstukken drie en vier hebben belangrijke praktische toepassingen aangezien inzichten uit het onderzoek naar cognitieve ontwikkeling toegepast kunnen worden op programma's die gericht zijn op het verminderen van het ongevallenrisico van adolescenten en jonge volwassenen, zoals GDL (Graduated Drivers Licensing, getrapt opleidingssysteem). Bovendien zijn de resultaten relevant voor training van de cognitieve controle, gebaseerd op de aanname dat cognitieve controle tot verhoogde zelfregulatie leidt en zo tot minder risicovol gedrag. De huidige resultaten tonen aan dat meer onderzoek nodig is om de bruikbaarheid van cognitieve training te bepalen aangezien 1) de relatie met risicovol rijgedrag niet altijd negatief was en 2) inhibitie slechts het effect van passagiers op één rijparameter (overdreven snelheid) modereerde.

Deel twee van het proefschrift bevat studies bestaande uit vragenlijsten en VRRS om het rijden van jonge beginnende bestuurders met autisme spectrum stoornissen (ASS) te onderzoeken. Bestuurders met ASS hebben mogelijk bijkomende problemen tijdens het (leren) rijden omwille van cognitieve beperkingen die geassocieerd zijn met ASS.

In hoofdstuk vijf is een bevraging van rijinstructeurs uitgevoerd. Verschillende vragen waren gericht op advies om jongeren met ASS te leren rijden en op het verbeteren van de huidige rijopleiding zodat deze beter aansluit bij de behoeften van jongeren met ASS. Aan de respondenten werd gevraagd aan te geven of specifieke kenmerken die vaak geassocieerd worden met ASS, een impact hebben op de rijvaardigheid. Volgens Vlaamse rijinstructeurs die ervaring hadden met ASS kunnen jonge beginnende bestuurders wel degelijk problemen ondervinden tijdens het leren rijden. Advies was vooral gericht op het bieden van structuur, duidelijkheid, visualisatie, praktijk, herhaling en een geïndividualiseerde aanpak. Uit de resultaten bleek echter ook dat de relatie tussen ASS en rijprestaties niet altijd negatief is, (bijv., gebondenheid aan regels). De resultaten hebben ook een aantal praktische implicaties. Zo kunnen financiële steun en cursussen voor de rijinstructeur de toegankelijkheid van rijlessen voor jongeren met ASS verbeteren. Hoewel niet specifiek bevraagd, werd aangegeven dat VRRS een middel is om jonge beginnende ASS bestuurders vertrouwd te maken met rijden. In hoofdstuk zes geven we hier een logisch vervolg aan. Deze exploratieve studie ging de toepasbaarheid van virtuele rijsimulatie training (VRRST) na om de rijvaardigheid alsook de cognitieve controle van Amerikaanse jonge beginnende bestuurders te verbeteren. VRRST blijkt inderdaad in staat deze vaardigheden te verbeteren. Verschillende VRRST condities (dwz., menselijke feedback, geautomatiseerde feedback, geautomatiseerde feedback + eye tracking) leiden echter tot verschillende resultaten. Interessant om te weten is dat menselijke en geautomatiseerde feedback leiden tot verbetering van rijvaardigheid in termen van snelheid en besturing. Deze resultaten tonen dus aan dat VRRST kan helpen om de rijvaardigheid van jonge beginnende bestuurders met ASS te verbeteren. Bijkomend onderzoek zal echter nodig zijn. Een belangrijk startpunt hierbij, is eerder onderzoek dat aantoonde dat mensen met ASS liever andere vormen van vervoer gebruiken, zelfs nadat ze hun rijbewijs hebben behaald. Verder is het ook zo dat ASS samengaat met een verhoogd risico op angststoornissen. In hoofdstuk zeven onderzoeken we daarom attitudes ten aanzien van rijden wanneer er sprake is van een indicatie van rijangst bij jonge beginnende bestuurders met ASS. Angst wordt gekenmerkt door zorgen, angst voor de toekomst, en verbale uitweidingen over negatieve verwachtingen en angsten. De studie maakt gebruik van een vragenlijst die door ouders werd ingevuld. Hierbij werd ook onderzocht of VRRST deze angst kon verminderen. De resultaten tonen aan dat jonge beginnende bestuurders met ASS meer negatieve en minder positieve attitudes hebben ten aanzien van rijden in vergelijking met een neuro-typische controle groep van jonge beginnende bestuurders. Dit is een indicatie van rijangst, wat veilig rijden kan beperken. Training in een veilige VRRS omgeving resulteert echter in een betere houding ten aanzien van het rijden. Dit ondersteunt opnieuw het idee dat VRRST nuttig kan zijn voor jonge beginnende bestuurders met ASS.

OUTLINE OF THE THESIS

The thesis consists of two separate parts, comprising eight publications, which investigated underlying mechanisms of driving behavior in young novice drivers with and without ASD as well as adult drivers.

Part one includes the original virtual reality driving simulation (VRDS) research that was conducted in order to investigate the influence of dual processes (i.e., cognitive vs. social-emotional) in young novice drivers. Chapter one and two focus on detrimental effects of distraction, with the latter including an adult sample. Chapter two was conducted together with Maastricht University, the Netherlands, and consists of a two-phase study. In the first phase (2a), we wanted to investigate whether well-known EEG markers of spatial orienting identified in isolation, can also be observed in a more complex spatial cueing task simulating a traffic situation, with the inclusion of distraction. In the second phase (2b), this spatial cuing task was translated to a simulated driving environment to enhance ecological validity and to include actual measurement of driving behavior (i.e., lane keeping). These chapters therefore focused on cognitive processes. Chapters three and four, included both cognitive and socio-emotional processes by means of incorporating the influence of peer passengers on driving.

Part two of the thesis includes research that investigated driving in young novice drivers with ASD. Chapter five includes a driver instructor questionnaire that was part of the 'Yes I Drive' project, a collaboration between REVAL (rehabilitation sciences) and IMOB (transportation research institute), both belonging to Hasselt University. This questionnaire served as a preliminary investigation of possible difficulties that may arise when Flemish adolescents and young adults with ASD learn how to drive. Chapters six and seven are based on a collaboration with the University of Virginia, where I did a research internship with Prof. Daniel J. Cox. For those research projects, I assisted in the data analysis and dissemination of the results. Chapter six investigates the usefulness of virtual reality driving simulation training (VRDST) in a sample of young novice ASD drivers. Chapter seven investigates attitudes towards driving of young novice drivers with ASD as an indication of apprehensive driving.

GENERAL METHODOLOGY

The current thesis involved several data collection techniques. First, driving behavior was investigated with the use of different VRDS systems (Fig. 1). Second, EEG was recorded with a BioSemi ActiveTwo System (Fig. 2). Third, computer based cognitive tasks were used to assess cognitive contol (Fig. 3). Finally, it involved questionnaires that query driver instructors and parents of young novice drivers with ASD.

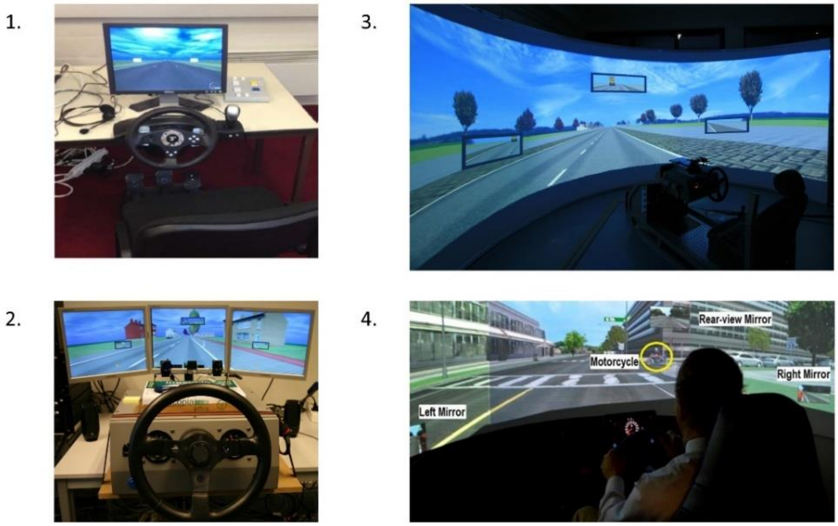

Figure 1: Different VRDS systems. 1. Set-up or the LCT (Mattes, 2003), 2. IMOB's 3-screen set-up, 3. IMOB's 180°-screen set-up, 4. UVA's 210°-screen set-up.

Figure 2: EEG recording with the BioSemi ActiveTwo System.

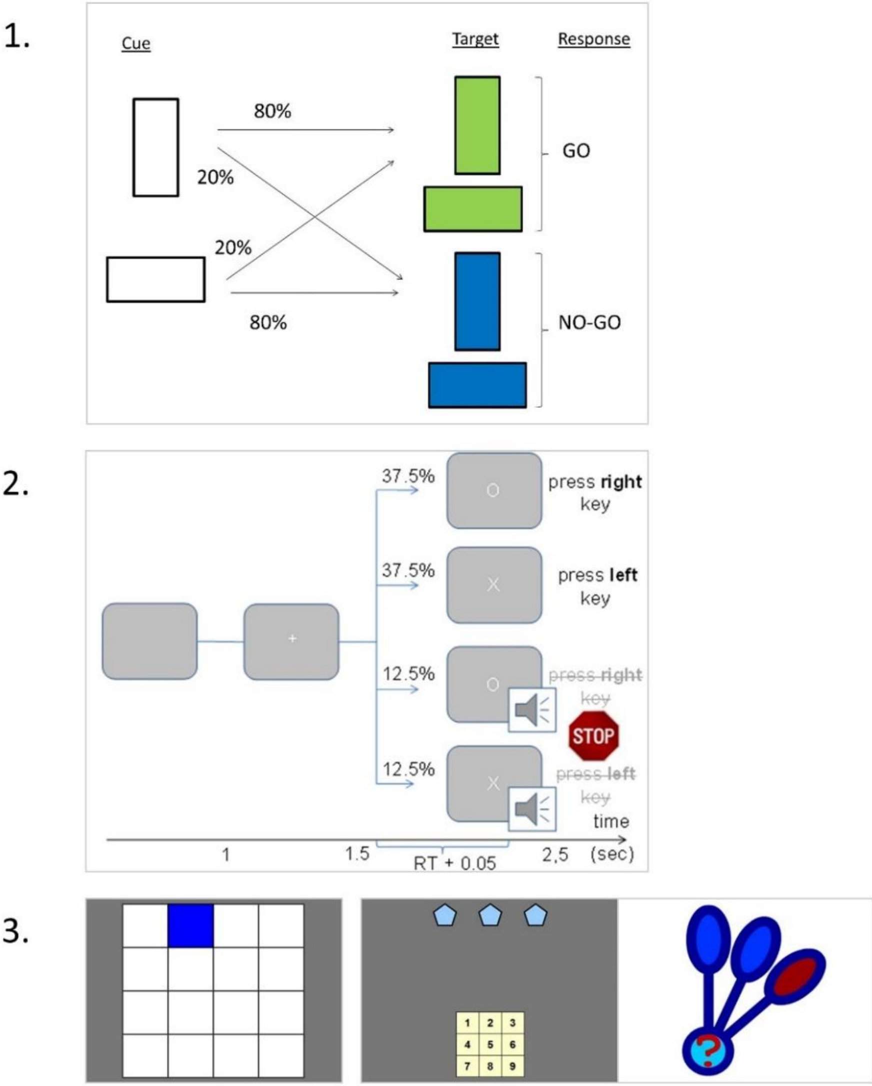

Figure 3: The computer tasks assessing cognitive control functions. 1. the go/no-go task assessing inhibitory control, 2. the stop signal paradigm assessing inhibitory control, 3. three WM tasks, from left to right, visuospatial span, reversed digit span, and letter span.

PART 1

Neuro-typical young novice drivers

"It's like driving a car with a sensitive gas pedal and bad brakes" (Steinberg, 2014).

GENERAL INTRODUCTION

Increased crash risk of young novice drivers

The greatest threats to the well-being of young adults in industrialized societies come from preventable and often self-inflicted causes, including automobile accidents (Casey et al., 2011). Safety programs and policies, such as the GDL system (Vanlaar et al., 2009), have caused ample improvements in the rates of crashes, injuries, and fatalities among young novice drivers. Still the crash and injury risks are unacceptably high (Keating & Halpern-Felsher, 2008) as risks for novice drivers up to 24 years old are two to three times higher when compared to experienced drivers (SafetyNet, 2009). In addition, the risk of a fatal accident increases with the number of peer passengers (Chen et al., 2000; Tefft et al., 2013), with the risk of fatal accidents being higher for male drivers and passengers (Ouimet et al., 2010).

Figures for Belgium reported that in 2009, a young novice driver was involved in 4/10 crashes. With more than three deaths occurring per week for the age-range of 18-24 and almost six for the age-range 18-31 (Casteels et al., 2012). Table 1 displays the increased crash risk for young novice drivers (i.e., age range 18-24) compared to older age groups. Figure 4 shows that although most pronounced in males, also female young novice drivers are susceptible to increased crash risk.

Table 1: Weighted number of injured or killed drivers in Belgium according to age and accident severity in 2009, Source: Casteels et al. (2012), FOD Economie ADSEI / Infografie: BIVV.

	18-24	**25-31**	**18-31**	**32-64**
Death in 30 days	162	128	290	424
Severely injured	1139	840	1979	2615
Light injured	11352	8523	19874	23847
Physical damage	10185	9748	18573	24204

This over-representation of young novice drivers in car crashes is not limited to Belgium. In developed countries world-wide, a quarter of fatalities due to road crashes are in the 15-24 age-group (Bureau of infrastructure, 2013). In European countries, 16-24 year old drivers have a risk-factor that is 2-3 times higher than that of more experienced drivers (SafetyNet, 2009). The magnitude of the problem is represented in Figure 5, where traffic accidents account for 35% of the fatalities among the 15-24 age group.

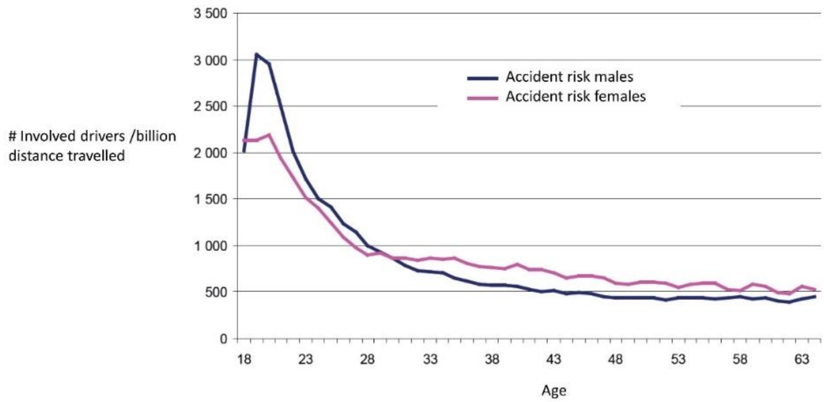

Figure 4: Number of drivers involved in an injury due to a car crash per million traveled kilometers in 2009, by age and sex (weighted), Source: Casteels et al. (2012), GOCA, FOD Economie ADSEI / Infografie: BIVV.

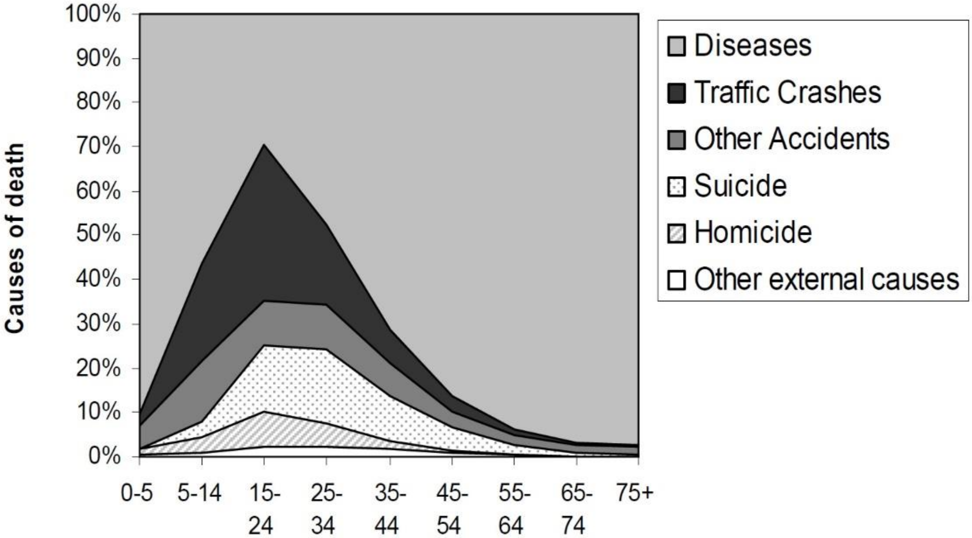

Figure 5: Proportional distribution of causes of death in OECD countries for different age groups. Source: World Health Organization Mortality Database (SafetyNet, 2009).

Driving levels and capabilities

Driving is a complex, goal-directed task that places high demands on perceptual, cognitive, and motor processes (Groeger, 2000). Theoretical models of driving behavior organize driving skills, often in three levels, i.e., operational, tactical and strategic (Dickerson & Bédard, 2014; Durbin et al., 2014; Michon, 1985). The lowest level, the operational level, refers to safe vehicle-control (e.g., steering and braking). Furthermore, it involves skills (i.e., visual-motor and coordination) needed to make decisions at the tactical level. At the intermediate tactical level, are skills needed to negotiate directly prevailing circumstances, including weather conditions, left-turns, over-taking, etc. Finally, the highest strategical level, concerns aspects related to general trip planning, including the determination of goals, route, and modal choice, and a weighing of costs and risks. This level involves personal factors (e.g., attitudes) and decisions made at this level affect all aspects of driving (Dickerson & Bédard, 2014; Michon, 1985). More recent models include even more levels. For instance, the Goals for Driver Education (GDE) framework describes four levels. From high to low: 1) Goals for life and skills for living (general). For instance, lifestyle, sensation seeking, risky habits; 2) Goals and context of driving (trip related). For instance, in-vehicle peer pressure, condition of the driver (e.g., mood), personal planning skills; 3) Mastery of traffic situations. For instance, speed adjustment, risk-increasing driving style (e.g., aggressive), personal safety margins; and 4) Vehicle maneuvering. For instance, control of direction and position, automatism of skills, realistic self-evaluation (Hatakka et al., 2002). In 2010, an additional fifth level was added to this matrix, one that is higher than goals for life and skills for living; namely culture, social, business background (level of cultural requirements). This level reflects the huge variety of different national, social and ethnic circumstances (Weiße & Kaufmann, 2015). Although young novice drivers acquire a driver’s license and possess basic driving skills reflecting lower levels, they do not acquire all necessary driving skills that are reflected in the higher levels during the initial learning phase (Deery, 1999; Durbin et al., 2014; Weiss et al., 2013).

To develop driving skills sufficiently, extensive practice is required under varying circumstances, including nighttime driving (Glendon, 2014). The lack of capabilities from young novice drivers at higher driving task-levels may have detrimental effects in challenging driving situations. Earlier research described that feelings of risk inform decisions of drivers. Drivers often seek to avoid risk and try to escape from situations that are too demanding, for instance by adjusting speed (Fuller, 2000; Fuller, 2005; Michon, 1985). The Task-Capability Interface model (Fuller, 2000; Fuller, 2005) focusses on the relation between task demand and capability. The model implies that driving performance degrades when the available capabilities either approach, or fall below, the task demands.

This reduced driving performance can lead to loss-of-control, and possibly to a crash. The subjective estimation of task demands and capabilities can cause problems in situations where there is underestimation of task demands and/or overestimation of the own capabilities to execute the driving task, which occurs often in young novice drivers (Cestac et al., 2011; Deery, 1999; Sundström, 2008).

Contributors to the increased crash risk

Driving experience

Crash rates among young novice drivers are highest in inexperienced drivers (see Fig. 6). Therefore, a first important factor that helps to explain the high incidence of traffic-related injuries and fatalities in adolescents is a lack of driving experience, including experience with recognizing, assessing, and responding to hazards (McKnight & McKnight, 2003; Sleet et al., 2010; Vlakveld, 2014). Indeed, a review from McCartt et al. (2009) indicated that a steep drop in accident risk exists for all ages, therefore showing benefits for increased driving experience. These rates drop considerably in the first two driving years with the most pronounced declines in the first six months after obtaining the driver's license when drivers gain driving experience (Lee et al., 2011; Mayhew et al., 2003).

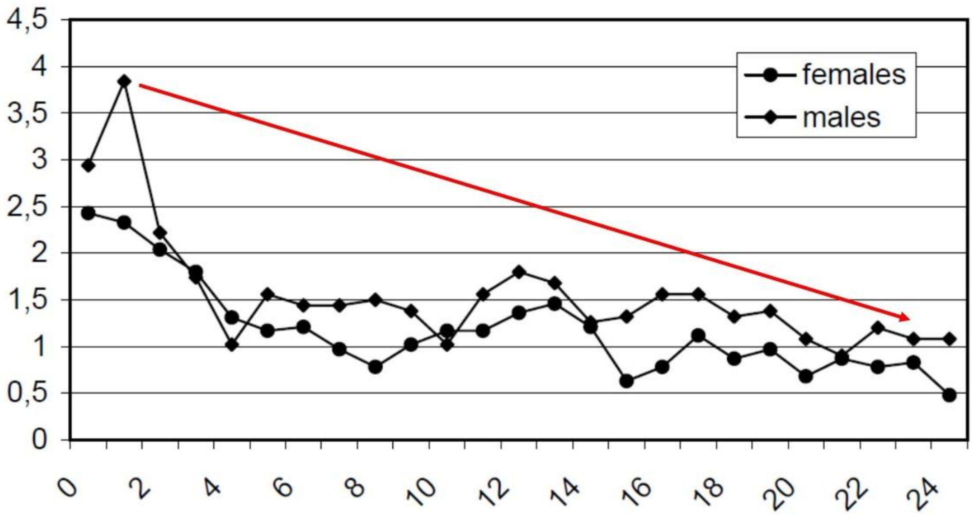

Figure 6: Accidents per 100 drivers during the first two years of driving career. Length of driving career > 24 months, age of drivers < 23 years. Males, n 1665, females n 2058. Source: Laapotti et al. (2003).

The effect of age

Although it has been proven difficult to distinguish effects of age on crash risk from effects of experience, previous research took an attempt to quantify it (Slootmans et al., 2011). For instance, research from the UK (Maycock & Forsyth, 1997) and research from the Netherlands (Vlakveld, 2005) indicated that accident risk for young novice drivers could be ascribed to experience, for about 2/3, and to age, for about 1/3. This can be inferred from the graphical depiction of the drop in accident risk for people that start learning how to drive at a later age (see Fig. 7).

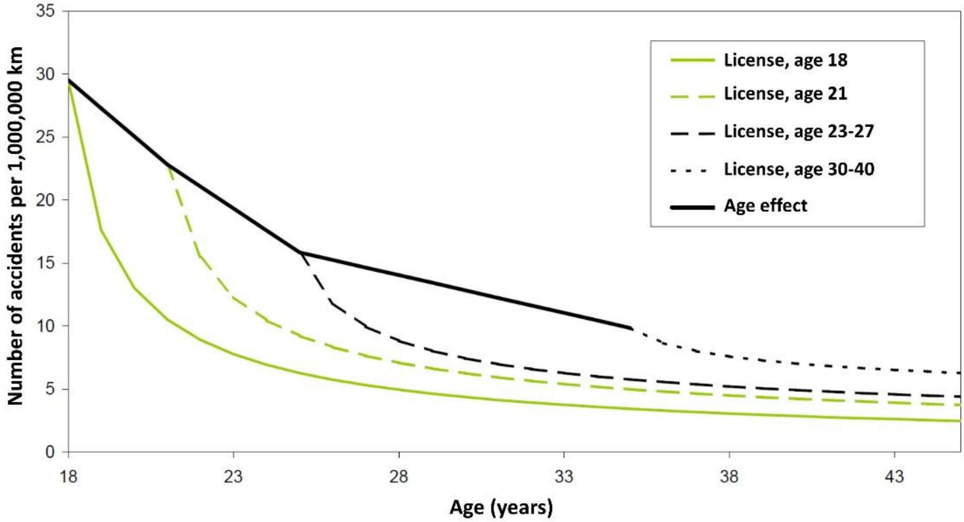

Figure 7: Drop in accident risk for drivers starting to drive at the age of 18 and drivers start at later ages. Adapted from (Vlakveld, 2005).

Driving behaviors

Albeit several risky driving behaviors can be defined that may lead to the increased crash risk in young novice drivers (e.g., driving while under the influence of alcohol, lack of sleep, etc.), the current thesis focusses on two behaviors, namely distracted and risky driving.

Driver distraction has been defined as "the diversion of attention away from activities critical for safe driving toward a competing activity" (Regan et al., 2009). Distracted driving has received increasing attention in the literature due to adverse safety out-comes. At least 20–30% of the car crashes in the United States can be related to some form of driver distraction (Stutts et al., 2001; Talbot et al., 2013; Young & Regan, 2007) and distracted driving is a worldwide problem (Young & Lenné, 2010). Especially the use of cell-phones and in-vehicle technologies has created situations in which driving is combined with other tasks. This is an issue as young novice drivers are more willing to accept and use new technologies (Neyens and Boyle, 2007), and also perceive less risk in using potentially distracting technologies (Fofanova and Vollrath, 2011), in comparison to older drivers.

Adolescence is a developmental period characterized by impulsive and risky choices. Adolescents engage in more risky behavior than adults. Indeed, the greatest threats to the wellbeing of young people in industrialized societies come from preventable and often self-inflicted causes, including automobile accidents (Casey et al., 2011). Furthermore, young novice drivers have a higher risk of crashes when they drive with peer passengers (Lee & Abdel-Aty, 2008; Simons-Morton et al., 2011). Risky driving can be a threat to individuals themselves as well as to other road users. It is therefore necessary to reduce risky driving behavior to improve the overall wellbeing of the population (Steinberg, 2008). Several risky driving behaviors can be described, including for instance; driving at night, driving during the weekend, and exceeding speed limits (Scott-Parker et al., 2013).

Dual-process theory of risky driving

Dual-process-theory of risky driving provides a framework for the increased crash risk in young novice drivers, caused by distraction and risky driving, by considering the imbalance between the development of the cognitive control and the social-affective brain systems (Cascio et al., 2014; Lambert et al., 2014).

Cognitive control is an umbrella term referring to a collection of cognitive functions (e.g., inhibitory control, WM, mental flexibility, and planning). Our WM capacity is limited (Proctor & Van Zandt, 2008) and adverse effects of distraction on driving performance (Castro, 2009; Rosenbloom, 2006) reflect a mismatch between WM resources demanded by the driving task and WM resources devoted to it. Lavie's Load theory (Lavie et al., 2004; Lavie, 2010) states that active maintenance of goal-directed behavior (e.g., driving) in the presence of interference (i.e., distraction) depends on spare WM capacity. Although drivers of all ages are affected by distraction, young novice drivers are thought to be especially susceptible (Spronk & Jonkman, 2012). First, neurocognitive evidence indicated that these cognitive functions advance into young adulthood (Bugg & Crump, 2012; De Luca & Leventer, 2008; Glendon, 2011). Therefore, the WM capacity of young novice drivers is limited in comparison to that of adult drivers. Second, many aspects of driving (e.g., vehicle control: Gugerty, 2011; driving routines and perception processes: Wikman et al., 1998) only become automated over time with increasing driving experience. Since non-automated tasks require a larger investment of WM capacity (Conway et al., 2002; Schneider & Chein, 2003; Shiffrin & Schneider, 1977) young novice drivers need to invest more of their already sparse resources in the driving task (Young & Lenné, 2010; Young & Regan, 2007). Taken together, young novice drivers not only possess less WM capacity resources, they also need to invest more WM capacity in the execution of the driving task. Spare WM capacity resources to perform secondary tasks are therefore limited in young novice drivers. When they perform multiple tasks simultaneously, performance on those tasks likely degrades to a greater extent than that of adult drivers (Neyens & Boyle, 2007; Underwood, 2007; Young & Regan, 2007).

In combination with the late development of the cognitive control system, there is an earlier (i.e., in adolescence) increase in the sensitivity of the social-emotional brain system resulting in a higher sensitivity for reward and punishment (Falk et al., 2014). Adolescents and young adults have been found to be prone to risk-taking when (inappropriate) impulses in response to highly social-affective situations were not appropriately inhibited by cognitive control (Albert et al., 2013; Figner et al., 2009). This even appears to be the case when probabilities of negative outcomes are known (Smith et al., 2014). An important source of reward and punishment during adolescence consists of peers, their opinions and social evaluations. The dual-systems theory states that the imbalance between the early developing socio-emotional system and the prolonged development of the cognitive control system makes adolescents vulnerable to risk (see Fig. 8; Lambert et al., 2014).

Even though a dual process system has been supported by behavioral and neuroanatomical data, research applying the model to simulated or on-road driving is sparse (Lambert et al., 2014). Jongen and colleagues (2011) provided initial support for a dual-process-theory of risky driving by showing that a monetary reward increased risky driving (i.e., speeding and red-light-running) in young novice drivers, while cognitive control interacted with driving performance (i.e., lower inhibitory control related to increased lane keeping variability). However, they did not include a full test of a dual-process-theory of risky driving, including cognitive control and social rewards (i.e., a peer passenger manipulation; Lambert et al., 2014). Cascio and colleagues (2014) did include peer passengers and found that increased inhibitory control allowed to override risky driving (i.e., red-light-running) tendencies when a cautious peer was present. Their study however only included red-light-running, therefore only reflecting a limited part of the complex driving task. A more complete test for a dual-process-theory of risky driving by examining social rewards (i.e., peer passengers) and cognitive control on multiple driving parameters was thus lacking.

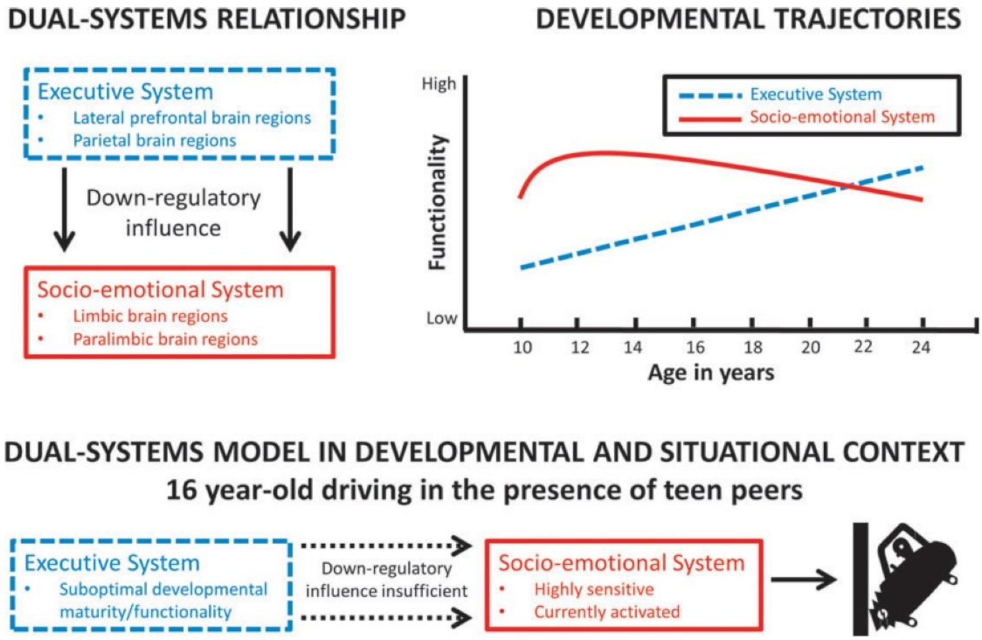

Figure 8: Illustration of the dual process theory applied to risky driving in young drivers. The graph of developmental trajectories is a conceptual approximation. Executive system refers to cognitive control system in this illustration. Source: Lambert et al. (2014).

RESEARCH QUESTIONS

The current thesis aimed to investigate the influence of the above described dual processes on driving by:

1. Investigating effects of distraction on driving behavior and relating this to the cognitive control system:
    a. Is driving performance impaired when young novice drivers combine driving with secondary tasks?
    b. Do increased cognitive capacities moderate distraction?
    c. Can the effects of distraction while driving already be identified in early attention allocation processes?
2. Investigating risky driving in a dual-process framework:
    a. Are cognitive control functions related to measures of risky driving?
    b. Is risky driving increased in the presence of peer passengers?
    c. Do increased cognitive capacities moderate the effect of peer passengers on driving?

CHAPTER 1

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Investigating the influence of working memory capacity when driving behavior is combined with cognitive load: An LCT study of young novice drivers.

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In the following chapter, I was involved in the design and methodological execution, data collection, analyses, and dissemination (presentation at conferences and writing of the paper).

Abstract

Distracted driving has received increasing attention in the literature due to potential adverse safety outcomes. An often posed solution to alleviate distraction while driving is hands-free technology. Interference by distraction can occur however at the sensory input (e.g., visual) level, but also at the cognitive level where hands-free technology induces working memory (WM) load. Active maintenance of goal-directed behavior in the presence of distraction depends on WM capacity (i.e., Lavie's Load theory) which implies that people with higher WM capacity are less susceptible to distractor interference. This study investigated the interaction between verbal WM load and WM capacity on driving performance to deter-mine whether individuals with higher WM capacity were less affected by verbal WM load, leading to a smaller deterioration of driving performance. Driving performance of 46 young novice drivers (17–25years-old) was measured with the lane change task (LCT). Participants drove without and with verbal load of increasing complexity (auditory-verbal response N-back task). Both visuospatial and verbal WM capacity were investigated. Dependent measures were mean deviation in the lane change path (MDEV), lane change initiation (LCI) and percentage of correct lane changes (PCL). Driving experience was included as a covariate. Performance on each dependent measure deteriorated with increasing verbal WM load. Meanwhile, higher WM capacity related to better LCT performance. Finally, for LCI and PCL, participants with higher verbal WM capacity were influenced less by verbal WM load. These findings entail that completely eliminating distraction is necessary to minimize crash risks among young novice drivers.

Keywords: Young novice drivers, lane change task, verbal working memory load, visuospatial working memory capacity, verbal working memory capacity

1. Introduction

Driver distraction has been defined as "the diversion of attention away from activities critical for safe driving toward a competing activity" (Regan et al., 2009). Distracted driving has received increasing attention in the literature due to adverse safety out-comes. At least 20–30% of the car crashes in the United States can be related to some form of driver distraction (Stutts et al.,2001; Talbot et al., in press; Young and Regan, 2007) and distracted driving is a worldwide problem (Young and Lenné, 2010).Especially the use of cell-phones and in-vehicle technologies has created situations in which driving is combined with other tasks. Driving is a complex, goal-directed task that places high demands on perceptual, cognitive, and motor processes and requires working memory (WM) capacity (Groeger, 2000). Our WM capacity is limited (Proctor and Van Zandt, 2008) and adverse effects of dis-traction on driving performance (Rosenbloom, 2006; Castro, 2009) reflect a mismatch between WM resources demanded by the driving task and WM resources devoted to it. Lavie's Load theory (Lavie et al., 2004; Lavie, 2010) states that active maintenance of goal-directed behavior (e.g., driving) in the presence of interference (i.e., distraction) depends on spare WM capacity. This implies that people with higher WM capacity are less susceptible to distractor interference (Engle, 2010; Pratt et al., 2011). Studies on driving performance have investigated effects of distraction induced by WM load (e.g., Engström and Markkula, 2007; Harbluk et al., 2007b) as well as the relation between WM capacity and driving (e.g. Mäntylä et al., 2009; Ross et al., submitted for publication), but the interaction between WM load and WM capacity has not been studied. Yet, this would reflect whether individuals with higher WM capacity are less affected by WM load, leading to a smaller deterioration of driving performance. The present study aimed to investigate this interaction of WM load and WM capacity.

One often posed solution to alleviate distraction while driving is hands-free technology (e.g., hands-free cell phones). This technology should decrease the impact of secondary tasks on driving since it does not require manual adjustments of settings, or shifting visual attention away from the roadway (Harbluk et al., 2007b; Maciej and Vollrath, 2009). Nonetheless, interference by distraction does not only occur at the sensory input level (e.g., visual), but also at the cognitive level where it induces WM load (Recarte and Nunes, 2003; Victor et al., 2009). Two WM capacity subtypes can be distinguished (Baddeley, 1986; Courtney et al., 1996; Wager and Smith, 2003; Johannsdottir and Herdman, 2010; Koppenol-Gonzalez et al., 2012; Van Leijenhorst et al., 2007). Verbal WM capacity is responsible for processing and storing of auditory and verbal information while visuospatial WM capacity is responsible for processing and storing of visual and spatial information. Within visuospatial WM capacity it is possible to separate two subcomponents, spatial (e.g. position in space) and object (e.g., traffic sign or lane change sign) WM capacity. Driving requires processing of verbal as well as visuospatial information and therefore involves both WM capacity subtypes. Even though hands-free technology does not induce visual distraction, it still induces cognitive distraction (e.g., verbal WM load; Recarte and Nunes, 2003). This is supported by studies showing that hands-free technology deteriorates driving performance (Strayeret al., 2003; Treffner and Barrett, 2004; Young and Regan, 2007).For instance, when driving was combined with the use of a hands-free phone, drivers were more likely to miss, or respond slower to, simulated traffic signals (Strayer et al., 2003), and they became less sensitive to prospective information about upcoming events during a braking task (Treffner and Barrett, 2004). These studies indirectly show that WM capacity resources are depleted by hands-free technology. The inclusion of WM capacity in this study allowed a more direct investigation of the relation between WM capacity and the influence of WM load on driving performance.

This study aimed to replicate and extend previous research that either studied the relation of WM load, or WM capacity, with driving performance by additionally investigating the interaction of verbal WM load and WM capacity on driving performance, while discriminating between visuospatial and verbal WM capacity. For this study, we focused on verbal WM load that draws on many of the same cognitive resources as hands-free technology, with-out conflicting with manual control or visual processing (Mehleret al., 2012). More specifically, verbal WM load was induced by an auditory-verbal response N-back task with three different levels of complexity (0-, 1- and 2-back) (Carter et al., 2003; Mehleret al., 2009, 2011; Wild-Wall et al., 2011). The lane change task (LCT) was chosen as an efficient and low-cost driving simulation. Several measures can be derived from the LCT (Engström and Markkula, 2007; ISO, 2010; Young et al., 2011). For instance, the mean lane change path deviation (MDEV) examines whether the driving course deviates from a normative or baseline model. This measure entails processes of lateral control (i.e., lane keeping) and event detection. Event detection can be further broken down in stages of initiation (i.e., lane change initiation: LCI) and execution (percentage of correct lane changes: PCL). These LCT measures are sensitive to WM load, with visual WM load leading to increases of the mean deviation from the normative model (Engström and Markkula, 2007; Fofanova and Vollrath, 2011; Harbluk et al., 2007a; ISO, 2010; Lei and Roetting, 2011), and verbal WM load negatively affecting the mean deviation as well as the initiation and correct execution of lane changes (Engström and Markkula, 2007; Harbluk, 2007a). Furthermore, a negative relation between verbal WM capacity and the driver’s deviation from a normative model has already been shown (Mäntylä et al., 2009). Adding visuospatial WM capacity, as well as measures of initiation and correct execution of the lane change, allowed investigating whether both types of

WM capacity predict superior LCT performance, for measures beyond deviation from a normative model.

Although drivers of all ages are affected by distraction, young novice drivers are thought to be especially susceptible (Spronk and Jonkman, 2012). First, the WM capacity of young drivers is limited in comparison to adult drivers. This because the development of WM capacity depends on the maturation of the prefrontal cortex (PFC) and parietal lobes, which starts at the age of 11 and can last until the age of 25 (De Luca and Leventer, 2008; Glendon, 2011).Second, many aspects of driving (e.g., vehicle control: Gugerty, 2011; driving routines and perception processes: Wikman et al., 1998) only become automated over time with increasing driving experience. Since non-automated tasks require a larger investment of WM capacity (Conway et al., 2002; Schneider and Chein, 2003; Shiffrin and Schneider, 1977) novice drivers need to invest more of their already sparse resources in the driving task (Young and Regan, 2007; Young and Lenné, 2010). Taken together, young novice drivers not only possess less WM capacity resources, they also need to invest more WM capacity in the execution of the driving task. Spare WM capacity resources to perform secondary tasks are therefore limited in young novice drivers. When they perform multiple tasks simultaneously, performance on those tasks likely degrades to a greater extent than that of adult drivers (Young and Regan, 2007; Neyens and Boyle, 2007; Underwood, 2007). Finally, despite their limitations, young novice drivers are more willing to accept and use new technologies (Neyens and Boyle, 2007), and also perceive less risk in using potentially distracting technologies (Fofanova and Vollrath, 2011), in comparison to older drivers. The limited ability to perform multiple tasks, combined with a greater tendency towards the use of potentially distracting technologies, led to the selection of young novice drivers as a target group for this study. Since some novice drivers obtained more driving experience than others, which could influence the results, the total amount of driven kilometers was included in the analyses.

To summarize, it was hypothesized that for young novice drivers: 1) verbal WM load impairs driving performance; 2) increased visuospatial and verbal WM capacity relates to superior driving performance; 3) when verbal WM load increases, driving and secondary task performance of participants with higher WM capacity are less impaired. Due to the secondary task’s auditory-verbal nature, this was expected to occur especially for higher verbal WM capacity.

2. Methods

2.1. Participants

A group of 51 young novice drivers (27 females) participated in the experiment. They either possessed a learners permit and a minimum of 20 h of driving experience (*M* months permit 8.38, *SD* 5.06), or a permanent license and a maximum of two years of license possession (*M* months license 11.16, *SD* 7.68). The removal of outlier cases on the verbal WM load task (see Section 4) led to a reduced sample of 46 participants (23 females) between 17 and 25 years (*M* 19.33; *SD* 1.77) with on average 81533.44 km of total driving experience.

2.2. Working memory load task: auditory-verbal response N-back task

The auditory-verbal response N-back task was adapted from Mehler et al. (2011). A headset with a microphone was used for presentation of the stimuli and recording of the response. Numeric values ranging from zero to nine were presented to the subject. The time interval between stimuli was 2.25 s. The task included three complexity levels: in the 0-back task, the participant was instructed to recall and repeat out loud each number immediately after it was presented; in the 1-back task, the participant was instructed to recall and repeat out loud the number that was presented before the last number they heard (i.e., one stimulus back); in the 2-back task, the participant was instructed to recall and repeat out loud the number that was presented two numbers before the last number they heard. Participants were familiarized with the task by practicing one sequence of the 0-back task, two sequences of the 1-back task, and three sequences of the 2-back task. A limited number of additional practice sequences were allowed when performance was below the minimum proficiency level of seven correct responses on the 0-back task (out of 10 items)and 1-back task (out of nine items), and of four correct responses on the 2-back task (out of eight items; for more information, see Mehler et al., 2011). This allowed an equal minimum proficiency level among participants in order to enhance comparability of results.

2.3. Lane change task (LCT)

The LCT Sim v1.2, developed by Daimler AG, consisted of six 3-km road tracks with 18 lane change signs. Participants used a force-feedback steering wheel to control the simulation. Screen size was 21.6 in. Participants were instructed to perform lane-change maneuvers, in the direction indicated by the sign (Fig. 9), while maintaining a constant speed of 60 km/h. One track can be completed in approximately 180 s (Mattes, 2003). Participants were instructed to initiate lane changing as soon as the information on the sign was visible and to complete the change before reaching the sign. Changes should be deliberate, abrupt and efficient. Mean distance between signs was 150 m, resulting in a mean duration of 9 s between lane changes. Meanwhile, simulated vehicle engine sounds made the driving situation more realistic. Track one and two did not include verbal WM load and served as training tracks to familiarize participants with the driving task; track three served as a baseline driving measurement (i.e., without verbal WM load); tracks four to six were combined with one of the three auditory-verbal response N-back tasks. Whereas every participant first completed tracks one to three, the order of tracks four to six was counterbalanced among participants. Each track consisted of different lane change orders as well as different sign positions.

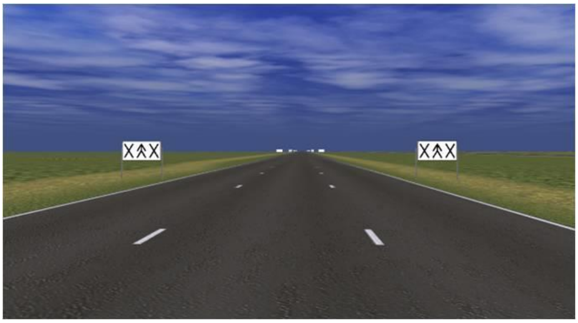

Figure 9: Lane change sign indicating a change to the middle lane.

2.4. Working memory capacity tasks (Fig. 10)

2.4.1. Visuospatial WM capacity: visuospatial span

In this task, a 4-by-4 grid was presented on a 15.6 in. screen where on each trial a number of squares in the grid would sequentially and randomly turn blue. Participants were instructed to reproduce the sequence in the correct order by indicating the squares that had changed color with 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 (Houben et al., 2011).

2.4.2. Verbal WM capacity: letter span

In this task, on each trial a series of letters was presented on a 15.6 in. screen with the letters being connected to a central circle. After presentation of the complete letter set, participants needed to indicate, with a computer mouse, which letter appeared at the location now presented in red (i.e., indicated with an arrow in Fig. 10). The task started with 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 (Houben et al., 2011).

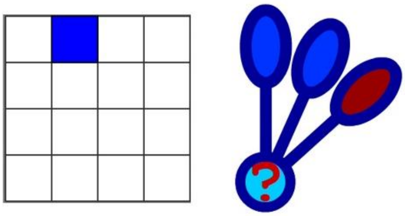

Figure 10: Visuospatial and letter span.

2.5. Procedure

Upon arrival, participant signed an informed consent. They were trained to carry out the auditory-verbal response N-back task before performing the six LCT tracks. To avoid that participants would have been tempted to adopt a compensatory strategy, where they mainly focused on the N-back task during straight segments and the driving task during lane changes, they were asked not to prioritize either task but perform as well as possible on both (Rydström et al., 2009). Lastly, participants completed the visuospatial and verbal WM capacity tasks.

3. Data analysis

3.1. Working memory load task: auditory-verbal response N-back task

For each level of the verbal WM load (0-, 1- and 2-back), the percentage of incorrect responses (i.e., error rate) served as the dependent variable.

3.2. Lane change task (LCT)

Dependent measures, known to be influenced by verbal WM load, were derived from existing literature (Engström and Markkula, 2007; ISO, 2010; Young et al., 2011).

- Mean deviation in lane change path (MDEV): deviation between the position of the baseline model and the actual driven course (Fig. 11). The model was calculated according to ISO annex E standards. This measure covers at least three aspects of LCT performance that can explain 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.

- Event detection measures:
    - 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° when required to move by one lane position, or, 6° when required to move by two lane positions. A steering event was only recorded when the driver steered in the proper direction. The average of the 18 segments that started from the distance traveled in the beginning of the segment, when the road sign appears, to the initiation was computed. This measure assesses merely event detection although it also covers processes of response selection and preparation (i.e. selection of the target lane and preparation of the lane change).
    - Percentage of correct lane changes (PCL): the number of correct lane changes that occurred until 40 m after the sign was assessed (i.e., cases where signs were missed, or incorrectly responded to, were identified) and divided by the total of 18 required changes to calculate the percentage of correct lane changes. This measure reflects stages ranging from detection of the sign, response selection and preparation, to the actual response execution (i.e., the correct lane change).

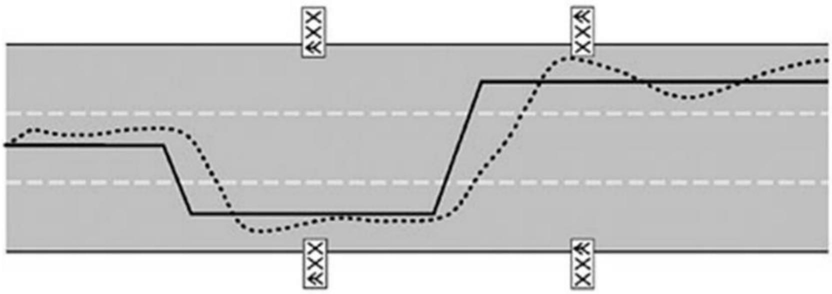

Figure 11: Comparison of a lane change path model and driving data.

3.3. Working memory capacity tasks

For the visuospatial and verbal WM capacity tasks, 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 (Houben et al., 2011).

Table 2: Descriptive statistics of the percentage of incorrect responses (error rate) on the verbal WM load task (n 46), driving measures (MDEV, LCI and PCL; n 46), visuospatial and verbal WM capacity (n 46), verbal WM capacity for the low (n 21) and high (n 25) verbal WM capacity groups, driving experience for the total sample (n 46) and for the low (n 24) and high (n 22) experienced groups.

	Mean	Median	SD	Minimum	Maximum
Dependent measures					
Error rate WM load0	0.12	0	0.39	0	1.41
Error rate WM load1	9.67	8.28	9.09	0	31.43
Error rate WM load2	43.53	41.55	17.26	5.63	87.67
MDEVb	0.44	0.40	0.15	0.21	0.82
MDEV0	0.45	0.44	0.13	0.22	0.78
MDEV1	0.59	0.52	0.23	0.25	1.19
MDEV2	0.74	0.65	0.29	0.25	1.43
LCIb	10.46	10.20	1.31	8.44	13.96
LCI0	11.42	11.25	1.32	9.31	14.73
LCI1	12.86	12.31	2.17	8.79	18.19
LCI2	13.80	12.85	2.35	10.98	19.71
PCLb	99.18	100	2.17	92.29	100
PCL0	99.43	100	1.94	90.39	100
PCL1	96.93	100	3.96	86.44	100
PCL2	94.27	94.44	6.39	76.66	100
Covariates					
Visuospatial WM capacity	6.97	7	1.01	4	9
Verbal WM capacity	8.14	8	2.31	4	14
Low verbal WM capacity group	6.29	7	0.90	4	7
High verbal WM capacity group	9.70	10	1.95	8	14
Driving experience	7767.79	2500	11185.44	100	39078
Low driving experience group	904.38	890	577.39	100	2500
High driving experience group	15255.15	10650	12456.74	3000	39078

b: baseline; 0: 0-back; 1: 1-back; 2: 2-back; SD: standard deviation

4. Statistical analyses

Standard scores (i.e., z-scores < −2.5 or > 2.5) were used to identify outliers. Outlier cases on the verbal WM load task were removed from the analyses as these participants did not follow the instructions to not prioritize either of the tasks. Outliers for MDEV (n 2), LCI (n 2), PCL (n 3), visuospatial WM capacity (n 2), verbal WM capacity (n 2), and driving experience (n 3) were replaced by the mean ± 2.5SD in order to not further reduce the sample while limiting the influence of these outlier cases on the results. To measure the effects of verbal WM load, WM capacity, and their interaction on verbal WM load task performance and on each LCT driving measure (i.e., MDEV, LCI, PCL), an ANCOVA per dependent measure was conducted with load (3: 0-, 1- and 2-back or 4: baseline, 0-, 1- and 2-back) as a within-subjects variable, and WM capacity (visuospatial/verbal) and driving experience as covariates. Covariates that did not contribute significantly to the ANCOVA were removed from the model in order to increase statistical power. Pairwise comparisons of the different load levels were conducted in case of a significant main effect of verbal WM load. Significant interactions between verbal WM load and any of the covariates were further analyzed for participants scoring low and high on that covariate, based on a median split with the median being included in the group that allowed for the most equal distribution, to asses: 1) the main effect of verbal WM load. This was investigated by repeating the initial ANCOVA model for both groups. Pairwise comparisons of the different load levels were conducted in case of a significant main effect of verbal WM load; 2) between-group differences (i.e., main effect of group) for the separate verbal WM load levels. This was investigated with separate univariate analyses of covariance (UNI-ANCOVA) for each load level, including the between-subjects factor group and significant covariates from the initial ANCOVA model.

5. Results

Table 2 provides descriptive statistics for the average percentage of incorrect responses to verbal WM load stimuli and the dependent driving measures as a function of verbal WM load, as well as for each of the covariates included in the different analyses, including verbal WM capacity for the low and high verbal WM capacity groups as well as driving experience for the low and high experienced group.

5.1. Verbal working memory load

Table 3 provides inferential statistics from the ANCOVA model (i.e., excluding non-significant covariates). Table 4 and Fig. 12 provide inferential statistics and a visualization of a significant interaction.

The percentage of incorrect responses increased with increasing complexity, indicated by a significant main effect of verbal WM load. There was no significant main effect (F 2.41, p 0.13), or interaction (F 0.76, p 0.43), of visuospatial WM capacity with verbal WM load, and this covariate was therefore removed from the model. Participants with higher verbal WM capacity, and participants with more driving experience, performed better on the verbal WM load task, as indicated by significant main effects of verbal WM capacity and driving experience, respectively. Finally, although both low and high verbal WM capacity groups were negatively influenced by the increasing verbal WM load participants with higher verbal WM capacity showed a smaller increase of errors as indicated by a significant interaction between verbal WM load and verbal WM capacity.

Table 3: ANCOVA: percentage of incorrect responses (error rate) on the verbal WM load (n 46).

Variable		F	p	ηρ²
Error rate				
	Verbal WM load	265.15	0.00**	0.86
	0-back vs. 1-back	64.73	0.00**	0.60
	1-back vs. 2-back	213.73	0.00**	0.83
	0-back vs. 2-back	376.80	0.00**	0.90
	Verbal WM capacity	19.11	0.00**	0.31
	Driving experience	7.12	0.01*	0.14
	Verbal WM load* verbal WM capacity	8.62	0.00**	0.17
	Verbal WM load* driving experience	2.72	0.09	0.06

**p < .05 (one-tailed); **p < .01 (one-tailed); ηρ²: effect size [SSEffect/(SSEffect+ SSResidual)]*

Table 4: Interaction verbal WM load × verbal WM capacity for the percentage of incorrect responses (error rate) on the verbal WM load.

Variable			F	p	ηρ²
Error rate	**Group**				
	Low verbal WM capacity (n 21)	Verbal WM load	184.15	0.00**	0.91
		0-back vs. 1-back	36.43	0.00**	0.66
		1-back vs. 2-back	153.09	0.00**	0.89
		0-back vs. 2-back	277.89	0.00**	0.94
	High verbal WM capacity (n 25)	Verbal WM load	98.31	0.00**	0.81
		0-back vs. 1-back	22.08	0.00**	0.49
		1-back vs. 2-back	83.84	0.00**	0.79
		0-back vs. 2-back	132.24	0.00**	0.85
	Verbal WM capacity	**Verbal WM load level**	**Mean differences**	**p**	
	Low vs. high	0-back	0.11	0.39	
	Low vs. high	1-back	6.34	0.02*	
	Low vs. high	2-back	16.91	0.00**	

**p < .05 (one-tailed); **p < .01 (one-tailed); ηρ²: effect size [SSEffect/(SSEffect+ SSResidual)]*

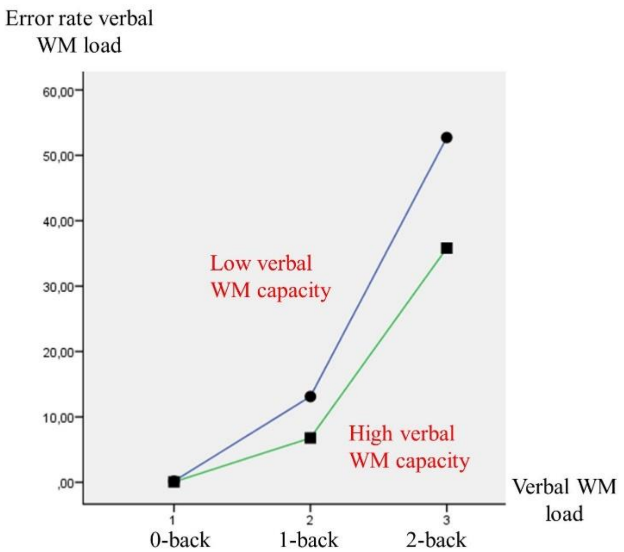

Figure 12: Interaction verbal WM load × verbal WM capacity for the percentage of incorrect responses (error rate) on the verbal WM load.

5.2. LCT driving measures: MDEV, LCI and PCL

Table 5 provides inferential statistics from the ANCOVA models (i.e., excluding non-significant covariates) of each of the dependent driving measures (MDEV, LCI, PCL). Tables 6 and 7 and Fig. 13 provide inferential statistics and visualizations of significant interactions.

5.2.1. MDEV

MDEV degraded with increasing verbal WM load, as indicated by a significant main effect of verbal WM load. Participants with higher visuospatial WM capacity and higher verbal WM capacity showed less deviation from the adaptive path, as indicated by significant main effects of visuospatial and verbal WM capacity, respectively. There was no significant interaction between verbal WM load and either of the WM capacity measures (visuospatial: F 0.52, p 0.61; verbal: F 1.98, p 0.14) as well as no significant main effect (F 0.03, p 0.86), or interaction (F 0.11, p 0.91), of driving experience with verbal WM load. Therefore, driving experience was removed from the model.

Table 5: ANCOVA: MDEV, LCI and PCL (n 46). *p < .05 (one-tailed); **p < .01 (one-tailed); ηρ²: effect size [SSEffect/(SSEffect+ SSResidual)]

Variable		F	p	ηρ²
MDEV				
	Verbal WM load	55.25	0.00**	0.56
	MDEVb vs. MDEV0	1.10	0.30	0.03
	MDEVb vs. MDEV1	39.27	0.00**	0.48
	MDEVb vs. MDEV2	96.70	0.00**	0.69
	MDEV0 vs. MDEV1	31.70	0.00**	0.42
	MDEV0 vs. MDEV2	74.34	0.00**	0.63
	MDEV1 vs. MDEV2	24.71	0.00**	0.37
	Visuospatial WM capacity	4.31	0.04*	0.09
	Verbal WM capacity	7.04	0.01*	0.14
	Verbal WM load* visusospatial WM capacity	0.52	0.61	0.01
	Verbal WM load* verbal WM capacity	1.98	0.14	0.04
LCI				
	Verbal WM load	87.91	0.00**	0.67
	LCIb vs. LCI0	67.71	0.00**	0.61
	LCIb vs. LCI1	144.00	0.00**	0.77
	LCIb vs. LCI2	187.79	0.00**	0.81
	LCI0 vs. LCI1	53.50	0.00**	0.55
	LCI0 vs. LCI2	82.60	0.00**	0.66
	LCI1 vs. LCI2	10.84	0.00**	0.20
	Verbal WM capacity	6.51	0.01*	0.13
	Driving experience	1.24	0.27	0.03
	Verbal WM load* verbal WM capacity	3.06	0.05*	0.07
	Verbal WM load* driving experience	4.19	0.02*	0.09
PCL				
	Verbal WM load	27.65	0.00**	0.39
	PCLb vs. PCL0	0.45	0.51	0.01
	PCLb vs. PCL1	18.81	0.00**	0.30
	PCLb vs. PCL2	36.85	0.00**	0.46
	PCL0 vs. PCL1	22.17	0.00**	0.34
	PCL0 vs. PCL2	37.94	0.00**	0.46
	PCL1 vs. PCL2	15.42	0.00**	0.26
	Verbal WM capacity	10.31	0.00**	0.19
	Verbal WM load* verbal WM capacity	5.76	0.01**	0.12

Table 6: Interaction verbal WM load × verbal WM capacity for LCI; interaction verbal WM load × driving experience for LCI. *p < .05 (one-tailed); **p < .01 (one-tailed); ηρ²: effect size [SSEffect/(SSEffect+ SSResidual)]

Variable			**F**	**p**	**ηρ²**
LCI	**Group**				
	Low verbal WM capacity (n 21)	Verbal WM load	49.73	0.00**	0.72
		LCIb vs. LCI0	55.20	0.00**	0.74
		LCIb vs. LCI1	71.39	0.00**	0.79
		LCIb vs. LCI2	88.53	0.00**	0.82
		LCI0 vs. LCI1	33.21	0.00**	0.64
		LCI0 vs. LCI2	51.38	0.00**	0.73
		LCI1 vs. LCI2	2.30	0.11	0.13
	High verbal WM capacity (n 25)	Verbal WM load	42.41	0.00**	0.65
		LCIb vs. LCI0	25.59	0.00**	0.53
		LCIb vs. LCI1	84.86	0.00**	0.79
		LCIb vs. LCI2	98.98	0.00**	0.81
		LCI0 vs. LCI1	25.40	0.00**	0.53
		LCI0 vs. LCI2	35.03	0.00**	0.60
		LCI1 vs. LCI2	8.67	0.00**	0.27
	Verbal WM capacity	**Verbal WM load level**	**Mean differences**	**p**	
	Low vs. high	LCIb	0.06	0.90	
	Low vs. high	LCI0	0.18	0.68	
	Low vs. high	LCI1	1.49	0.03*	
	Low vs. high	LCI2	0.35	0.65	
LCI	**Group**				
	Low driving experience (n 24)	Verbal WM load	45.63	0.00**	0.68
		LCIb vs. LCI0	32.24	0.00**	0.59
		LCIb vs. LCI1	51.81	0.00**	0.70
		LCIb vs. LCI2	117.71	0.00**	0.84
		LCI0 vs. LCI1	15.22	0.00**	0.41
		LCI0 vs. LCI2	44.96	0.00**	0.67
		LCI1 vs. LCI2	12.35	0.00**	0.36
	High driving experience (n 22)	Verbal WM load	40.70	0.00**	0.67
		LCIb vs. LCI0	37.67	0.00**	0.65
		LCIb vs. LCI1	74.19	0.00**	0.79
		LCIb vs. LCI2	74.84	0.00**	0.79
		LCI0 vs. LCI1	36.01	0.00**	0.64
		LCI0 vs. LCI2	38.11	0.00**	0.66
		LCI1 vs. LCI2	1.11	0.31	0.05
	Driving experience	**Verbal WM load level**	**Mean differences**	**p**	
	Low vs. high	LCIb	0.60	0.27	
	Low vs. high	LCI0	0.91	0.08	
	Low vs. high	LCI1	0.97	0.25	
	Low vs. high	LCI2	1.34	0.15	

Table 7: Interaction verbal WM load*verbal WM capacity for PCL. *p < .05 (one-tailed); **p < .01 (one-tailed); ηρ²: effect size [SSEffect/(SSEffect+ SSResidual)]

Variable			F	p	ηρ²
PCL	**Group**				
	Low verbal	Verbal WM load	16.56	0.00**	0.45
	WM capacity	PCLb vs. PCL0	0.44	0.52	0.02
	(n 21)	PCLb vs. PCL1	10.49	0.00**	0.34
		PCLb vs. PCL2	22.56	0.00**	0.53
		PCL0 vs. PCL1	12.30	0.00**	0.38
		PCL0 vs. PCL2	21.39	0.00**	0.52
		PCL1 vs. PCL2	10.51	0.00**	0.34
		Verbal WM load	11.09	0.00**	0.32
	High verbal	PCLb vs. PCL0	0.05	0.83	0.00
	WM capacity	PCLb vs. PCL1	7.77	0.01*	0.25
	(n 25)	PCLb vs. PCL2	13.97	0.00**	0.37
		PCL0 vs. PCL1	9.33	0.00**	0.28
		PCL0 vs. PCL2	18.53	0.00**	0.44
		PCL1 vs. PCL2	5.20	0.03*	0.18
	Verbal WM capacity	**Verbal WM load level**	**Mean differences**	**p**	
	Low vs. high	PCLb	-1.14	0.15	
	Low vs. high	PCL0	-1.37	0.19	
	Low vs. high	PCL1	-2.98	0.01*	
	Low vs. high	PCL2	-5.66	0.01**	

5.2.2. LCI

Lane changes were initiated slower with increasing verbal WM load, as indicated by a significant main effect of verbal WM load. There was no significant main effect (*F* 0.02, *p* 0.90), or interaction (*F* 0.27, *p* 0.78), of visuospatial WM capacity with verbal WM load, this covariate was therefore removed from the model. Participants with higher verbal WM capacity displayed smaller LCI values indicating that they initiated their lane changes faster than participants with lower verbal WM capacity, as reflected by a significant main effect of verbal WM capacity. Interaction effects between verbal WM capacity and verbal WM load, and between driving experience and verbal WM load, were found indicating that with increasing verbal WM load a stronger increase of LCI was found in the low than in the high verbal WM capacity group, and in the low than in the high driving experience group, respectively. For verbal WM capacity, further analyses for low and high WM capacity groups showed that both low and high WM capacity groups were negatively influenced by the verbal WM load, as indicated by significant verbal WM load effects for each group. However, the lower verbal WM capacity group showed a stronger LCI increase when LCT was combined with the 1-back when compared with the 0-back, resulting in a significant between-group difference for the 1-back level of complexity. For driving experience, further analyses for low and high driving experience groups showed that both low and high driving experience groups were negatively influence by the verbal WM load, as indicated by significant verbal WM load effects for each group. However, only for the low driving experience group a further deterioration of LCI was shown from the 1-back to 2-back level, whereas the deterioration already was maximal at 1-back level for the high driving experience group.

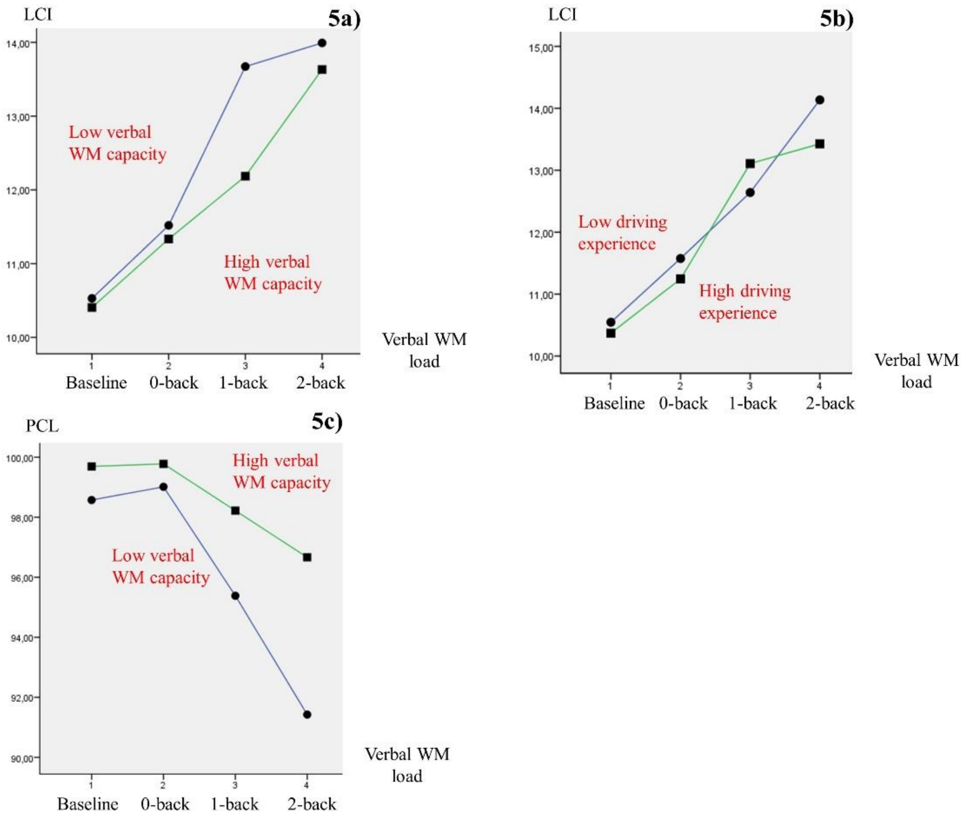

Figure 13: (a) Interaction verbal WM load × verbal WM capacity for LCI; (b) interaction verbal WM load × driving experience for LCI; (c) interaction verbal WM load × verbal WM capacity for PCL.

5.2.3. PCL

The percentage of correct lane changes decreased with increasing verbal WM load, as indicated by a significant main effect of verbal WM load. There was no significant main effect (F 3.36, p 0.07), or interaction (F 0.10, p 0.90), of visuospatial WM capacity with verbal WM load. Driving experience also did not show a significant main effect (F 0.12, p 0.73), or interaction (F 0.26, p 0.76), with verbal WM load. Therefore, both covariates were removed from the model. Participants with higher verbal WM capacity made more correct lane changes, as indicated by a significant main effect of verbal WM capacity. There was a significant interaction of verbal WM load and verbal WM capacity indicating that with increasing verbal WM load there was a stronger decrease of PCL in the low than in the high verbal WM capacity group. Further analyses showed that both low and high WM capacity groups were negatively influenced by the verbal WM load, as indicated by significant verbal WM load effects for each group. The lower verbal WM capacity group showed a stronger PCL decrease when LCT was combined with the 1-back and 2-back, resulting in significant between-group differences for the 1-back and 2-back levels of complexity.

In sum, an increase of verbal WM load led to degraded LCT performance for all the dependent measures (MDEV, LCI and PCL). Participants with higher visuospatial WM capacity showed less deviation from the adaptive model (MDEV). Participants with higher verbal WM capacity showed less deviation from the adaptive model (MDEV), initiated their lane changes faster (LCI) and made more correct lane changes (PCL). With increasing verbal WM load, the increase of lane change initiation and the decrease of correct lane changes were smaller for participants with higher verbal WM capacity.

6. Discussion

The goal of this study was to investigate, for young novice drivers, the influence of verbal and visuospatial WM capacity and verbal WM load on LCT driving performance. It was hypothesized that: 1) verbal WM load impairs driving performance (main effect verbal WM load); 2) increased visuospatial and verbal WM capacity relates to superior driving performance (i.e., main effect visuospatial/verbal WM capacity); 3) when verbal WM load increases, driving and secondary task performance of participants with higher WM capacity are less impaired (interaction effect verbal WM load × visuospatial/verbal WM capacity). Due to the secondary task's auditory-verbal nature, this was expected to occur especially for higher verbal WM capacity. Results will be discussed in the order of the hypotheses. Following this, driving experience results will be discussed. It can be assumed that these resemble WM capacity results, that is, higher driving experience allows for additional resources to deal with the primary driving, as well as the secondary task, because the driving task is automated to a greater extent (see also, discussion of the sample in Section 1).

As for the effects of verbal WM load on LCT performance, even though the current verbal WM load manipulation did not address any visual resources, it induced cognitive distraction and thereby still reduced available and necessary WM resources leading to an impairment of LCT performance. The results replicated previous LCT findings where distraction, induced by verbal WM load, affected the mean deviation from the lane change path model (MDEV: Harbluk et al., 2007a), as well as measures of event detection (PCL: Engström and Markkula, 2007; LCI: Harbluk et al., 2007a). The degradation of LCI and PCL is also in line with on road studies where cognitive distraction, inducing WM load, negatively affected the detection of a decelerating leading car (Lamble et al., 1999) as well as the ability to respond to simulated traffic signals (i.e., more likely to miss, or response slower to, traffic lights; Strayer et al., 2003). LCI and PCL reflect processes of detection, response selection, preparation and execution. A further breakdown of processes, for instance, to a measure solely for sign detection or target lane selection, might have been interesting in order to further under-stand the relation between verbal WM load and LCT performance. This would make it possible to determine the actual moment of detection of the lane change sign. Recarte and Nunes (2003) used eye-tracking in a two-choice reaction time task and found that verbal WM load mainly impaired visual detection due to late detection and poor identification rather than response selection. For the current findings, this might imply that the effect of verbal WM load on LCI and PCL mainly reflects impairment of sign detection rather than response selection. To summarize, verbal WM load degraded MDEV, as well as LCI and PCL. In agreement with previous research (Harbluk et al., 2007b), the results indicate that hands-free technology cannot eliminate detrimental effects of dis-traction. The inclusion of eye tracking in future research will allow more detailed inferences concerning the effect of verbal WM load on event detection measures.

The current study was the first to show that participants with higher WM capacity not only performed better on MDEV (Mäntylä et al., 2009), but also on LCT measures of event detection (LCI, PCL). Furthermore, the current study was the first to investigate the effect of not only verbal, but also visuospatial, WM capacity on these measures. Participants with higher visuospatial WM capacity performed better on MDEV while participants with higher verbal WM capacity performed better on MDEV, LCI and PCL. This is in line with findings that WM capacity predicts performance on a range of cognitive and real-world tasks (Engle, 2002). When considering event detection, the relation of verbal WM capacity with LCI, as well as PCL, could be asserted to the distinction between spatial and object WM capacity. Both LCI and PCL rely on the retention of lane change signs to select the correct target lane and it has been found that a semantic component (i.e., verbal) contributes to object identity retention (Johannsdottir and Herdman, 2010; Postle et al., 2005; Postle and Hamidi, 2007). MDEV is a summary measure that includes detection and response processes, but also path control (ISO, 2010). Only MDEV was related to visuospatial WM capacity, which suggests that this is due to processes of path control. Visuospatial WM capacity has already been related to the execution of movement in the immediate environment (Garden et al., 2002). To change lanes it is necessary to selectively control attention. More specifically, attention needs to be directed to a new location in the visual field (i.e., target lane). Such voluntary shifts of attention have been postulated before to engage WM capacity (Awh et al., 1998; Downing, 2000; Redick and Engle, 2006; Rosen et al., 1999; Ross et al., submitted for publication; Zimmer, 2008). Besides driving, WM memory capacity also related to secondary task performance as participants with higher verbal WM capacity made fewer errors on the verbal WM load task. In sum, visuospatial and verbal WM capacity both related to an increased level of performance, but not in the same manner. Verbal WM capacity related to verbal WM load performance, MDEV, LCI and PCL and visuospatial WM capacity only to MDEV. Meanwhile, verbal WM capacity also related to secondary task performance. Research including distinct measures of spatial and object WM capacity and eye tracking will be necessary to investigate the hypothesized explanation for these results.

Importantly, this study was the first to show that the relation between verbal WM load and driving performance is moderated by WM capacity. Young novice drivers with higher verbal WM capacity were influenced less by increasing verbal WM load. This was reflected by a smaller decrease of lane change initiations, as well as a smaller decrease of correct lane changes, when verbal WM load increased. In addition, people with high (versus low) verbal WM capacity also showed a smaller increase of the percentage of incorrect responses on the verbal WM load task. These findings are in line with Lavie’s Load theory (Lavie et al., 2004; Lavie, 2010). The avail-ability of extra WM capacity allowed prioritization of task-relevant stimuli and minimized distraction (De Fockert et al., 2001; Engle, 2002; Pratt et al., 2011). The interaction was found specifically for event detection measures (LCI, PCL) indicating that with increasing verbal WM load participants with higher verbal WM capacity were faster in initiating lane changes and more successful in selecting the correct lane. Interference of goal-irrelevant information can lead to response conflicts and people with higher WM capacity are known to be better in conflict resolution (Kane and Engle, 2003). When applied to the current driving task, response conflict between the different lanes might occur if participants attend to other lanes than the ones indicated by the lane change sign. Effects of WM capacity on selective attention in situations of conflict have been show before (de Fockert and Bremner, 2011), though not in the applied situation of driving. Since conflict resolution is time consuming (Hommel, 2000), a measure of lane change duration might be of interest to further investigate this effect. An example of a real world driving situation comparable to the LCT driving task used here is when drivers need to take a highway exit. The current results imply that, when verbal WM load is induced (e.g., talking to a passenger, use of hands-free phone/navigation), drivers will be likely to initiate their exit more slowly and miss their exit more often, but this will occur to a smaller extent in drivers with higher verbal WM capacity. As hypothesized, this result was only found for verbal WM capacity (Johannsdottir and Herdman, 2010; Koppenol-Gonzalez et al., 2012). Possibly, a similar interaction will occur for visuospatial WM load and visuospatial WM capacity. In sum, individuals with higher verbal WM capacity were affected less negatively by increasing verbal WM load. This was evident for event detection driving parameters LCI and PCL as well as for the percent-age of incorrect responses on the verbal WM load task. Even though this study does not allow firm conclusions as to why this effect only occurs for measures of event detection it might be related to response conflict and conflict resolution. It would be interesting for future research to include a measure of lane change duration, and to determine the influence of visuospatial WM capacity on LCT performance when combined with visuospatial WM load.

As for driving experience, the relation with the percentage of incorrect responses on the verbal WM load suggests that experienced drivers needed to invest less WM capacity resources in the driving task which left additional capacities to deal with the verbal WM load. Participants with increased driving experience also showed smaller LCI values. This relation, as well as the interaction between driving experience and verbal WM load for LCI, could be explained by a tendency towards longer gaze fixations for inexperienced drivers (Crundall and Underwood, 2011; Konstantopoulos et al., 2010), at least if they initiate their lane changes only after looking at the sign. Eye tracking would be necessary to investigate the gaze pattern in detail. Even though the lack of relations between MDEV, as well as PCL, and driving experience cannot be explained based on the current results, previous research also reported that driving experience did not relate to MDEV (Petzoldt et al., 2009). In sum, increased driving experience left spare resources to devote to the driving and the secondary task. This was reflected in a better performance on the verbal WM load and LCI, as well as in the interaction between driving experience and verbal WM load for LCI. Again, the inclusion of eye tracking in future research could lead to more detailed inferences.

7. Limitations

Questions could be raised concerning the transfer of LCT performance to real-life driving as it only requires lane changes, and the deliberate manner to conduct these lane changes may not resemble daily driving conditions. However, the LCT has been proven a valid way for measuring distraction effects (Engström and Markkula, 2007; Harbluk et al., 2007a). 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 that cannot be investigated with the LCT.

Other limitations are related to the delineation of the sample. Even though the choice to test young novice drivers can be sup-ported by literature (see Section 1), the lack of a comparison group has some disadvantages. First, the results cannot be generalized to the general population. Second, no comparison can be made with on the one hand a control group of adult experienced drivers and on the other hand a group of older drivers. The former would be interesting to further substantiate inferences concerning the risk of accidents caused by distraction for young novice driver. For instance, it would be possible to determine whether a maturational effect of WM capacity is present. The later would be interesting since it is well known that older drivers (i.e., > 70 years) are also at a higher risk of accident involvement (Ball et al., 2006). Further-more, they show a decrement in cognitive functions which relates to decreased driving performance (Anstey and Wood, 2011).

8. Recommendations

There is a limited body of evidence that suggests that distraction does not always have detrimental effects. For instance, during monotonous driving, cognitive distraction (Chan and Atchley, 2011; Gershon et al., 2009) can suppress fatigue. Nonetheless, such exceptional circumstances do not allow general driving recommendations. Recommendations can be made however when considering the current relationship between WM capacity and driving performance as measured by an LCT. Even though increased WM capacity might lead to an overall better driving performance and, at least for some driving parameters, lead to superior coping with distraction, the degrading effect of distraction by verbal WM load in this study for both low and high WM capacity participants clearly indicates the necessity to eliminate distraction as much as possible. This would decrease crash involvement of young novice drivers as they are more susceptible to distraction related crashes and are more willing to accept risks accompanying potentially distracting technology (Neyens and Boyle, 2007). One option is to use technologies to detect and prevent distraction (Lerner et al., 2010). For instance, Shabeer and Wahidabanu (2012) describe a system that detects the use of a mobile phone and notifies the nearest police post who can take legal actions. As another example, the Key2SafeDriving device is a cell phone blocker that transmits a disabling signal to a selected cell phone. Incoming calls are directly send to voicemail. Emergency calls however will never be disabled (NHTSA, 2010). Lastly, most drivers are clueless of the extent to which distractions induced by WM load deteriorate driving performance (Horrey et al., 2008; Council, 2010). Therefore, education, in order to raise awareness, can also be used to target distraction while driving. One example of an educational training program for young novice drivers and passengers targets risks and distractions by teaching communication skills to both parties (Lenné et al., 2011).

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CHAPTER 2A

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Effect of working memory load on electrophysiological markers of visuospatial orienting in a spatial cueing task simulating a traffic situation.

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In the following chapter, I was involved in the design and methodological execution, data collection, analyses, and dissemination (writing of the paper).

Abstract

Visuospatial attentional orienting has typically been studied in abstract tasks with low ecological validity. However, real-life tasks such as driving require allocation of working memory (WM) resources to several subtasks over and above orienting in a complex sensory environment. The aims of this study were twofold: firstly, to establish whether electrophysiological signatures of attentional orienting commonly observed under simplified task conditions generalize to a more naturalistic task situation with realistic-looking stimuli, and, secondly, to assess how these signatures are affected by increased WM load under such conditions. Sixteen healthy participants performed a dual task consisting of a spatial cueing paradigm and a concurrent verbal memory task that simulated aspects of an actual traffic situation. Behaviorally, we observed a load-induced detriment of sensitivity to targets. In the EEG, we replicated orienting-related alpha lateralization, the lateralized ERPs ADAN, EDAN, and LDAP, and the P1-N1 attention effect. When WM load was high (i.e., WM resources were reduced), lateralization of oscillatory activity in the lower alpha band was delayed. In the ERPs, we found that ADAN was also delayed, while EDAN was absent. Later ERP correlates were unaffected by load. Our results show that the findings in highly controlled artificial tasks can be generalized to spatial orienting in ecologically more valid tasks, and further suggest that the initiation of spatial orienting is delayed when WM demands of an unrelated secondary task are high.

Keywords: Attention, working memory, orienting, ERPs, alpha rhythm

1. Introduction

Studies of human vision typically involve simplified task situations and abstract geometric shapes to isolate specific processes that give rise to behavior. With such experiments, specifically, cued attention paradigms, EEG research has identified several electrophysiological signatures that are associated with the orientation and maintenance of visuospatial attention. These include a spectral asymmetry in the alpha band (6–14 Hz) and a sequence of lateralized ERPs (EDAN, ADAN, LDAP) following a symbolic directional cue, as well as modulation of the response to a probe stimulus (P1-N1; discussed below). However, tasks in real life are complex and require the allocation of cognitive resources to multiple subtasks to achieve behavioral goals. This generally involves selective attentional orienting to the most relevant information within a complex sensory environment, in concert with functions such as motor control, memory encoding, and retrieval.

Working memory (WM) provides the mental workspace for the coordination of attentional control (Brady & Alvarez, 2015; Cowan, 2010; Engle, 2010). However, WM capacity is limited, and depleting WM resources by increasing cognitive or perceptual load impairs performance when selective visuospatial attention is required (Ahmed & de Fockert, 2012; Awh, Vogel, & Oh, 2006; Bengson & Mangun, 2011; de Fockert, Rees, Frith, & Lavie, 2001; Engle, 2010; Gazzaley & Nobre, 2012; Just et al., 2001; Kane, Bleckley, Conway, & Engle, 2001; Lavie, 2010; Morey, Cowan, Morey, & Rouder, 2011; Pratt, Willoughby, & Swick, 2011). For instance, increased WM load due to a secondary task slows down response time to task-relevant visual events (Lee, Lee, & Ng Boyle, 2009). Arguably, under such conditions, the timing and magnitude of associated neural responses might be affected. In addition, the processing of abstract versus naturalistic stimuli can be qualitatively different; therefore, a realistic visual scene might give rise to qualitatively different neural responses (Kayser, Körding, & König, 2004; Peelen, Fei-Fei, & Kastner, 2009). The aim of this study was to test whether the well-known EEG markers of spatial orienting identified in isolation can also be observed in complex task settings involving naturalistic scenes with two or more concurrent independent tasks, or how they respond to the reduction of available (nonvisual) WM resources.

An example of a real-life task requiring the coordination of multiple subtasks is driving in traffic. The driver must attend to other vehicles, potential risk situations, and road signs while often simultaneously interacting with passengers or in-vehicle systems. Traffic safety research shows that verbal cognitive load due to driving-unrelated secondary tasks impairs visual spatial processing and event detection (Just, Keller, & Cynkar, 2008; Lee et al., 2009; Recarte & Nunes, 2003; Ross et al., 2014; Wood et al., 2006). Such load effects have been related to weakened or delayed processing of warning cues (e.g., traffic lights, road signs), suggesting interference at early stages of attentional orienting (Bowyer et al., 2009; Fort et al., 2010; Ross et al., 2014). If attentional orienting is affected, this should be reflected in changes in associated neural activity.

EEG activity related to covert attentional orienting following a central symbolic cue falls broadly into two classes: lateralized activity in the period following the cue in anticipation of some target event (i.e., cue-target interval; CTI) and neural activity in response to a probe stimulus (i.e., a target or distracter). Spatial orienting during the CTI is usually accompanied by asymmetry in occipitoparietal oscillatory alpha activity, with relatively greater alpha power in the hemisphere ipsilateral to the cued (attended) hemifield (Kelly, Gomez-Ramirez, & Foxe, 2009; Rihs, Michel, & Thut, 2009; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; Worden, Foxe, Wang, & Simpson, 2000). High alpha power has been linked to reduced sensory detection performance (Ergenoglu et al., 2004; Romei, Gross, & Thut, 2010; Thut et al., 2006) and is thought to act as a filter against irrelevant information (Foxe & Snyder, 2011; Jensen & Mazaheri, 2010). While alpha oscillations appear to play a role in WM maintenance (Bonnefond & Jensen, 2013), it is unknown how orienting-related alpha asymmetry is affected by task-unrelated interference.

During the CTI, attentional orienting is also indicated by ERP modulations, including the early directing attention negativity (EDAN), anterior directing attention negativity (ADAN), and late directing attention positivity (LDAP). These components are thought to represent subsequent stages of attentional orienting and manifest as hemispheric differences contralateral to the cued location. EDAN is observed over posterior scalp electrodes 200–400 ms after cue onset and may reflect the processing of physical cue properties relevant to attentional directing (Jongen, Smulders, & Van der Heiden, 2007; van Velzen & Eimer, 2003; but see Praamstra & Kourtis, 2010). ADAN occurs frontocentrally 300–500 ms after cue onset and has been associated with top-down control in frontal cortex and maintenance of attentional redirection in space (Harter, Miller, Price, LaLonde, & Keyes, 1989; Hopf & Mangun, 2000; Jongen et al., 2007; Nobre, Sebestyen, & Miniussi, 2000). LDAP is a posterior component that follows the ADAN, peaks between 500–700 ms, and presumably reflects anticipatory modulation of excitability in relevant brain regions involved in location coding and target processing (Dale, Simpson, Foxe, Luks, & Worden, 2008; J. J. Green & McDonald, 2010; Harter et al., 1989; Hopf & Mangun, 2000; Jongen, Smulders, & van Breukelen, 2006; Jongen et al., 2007; Nobre et al., 2000; Praamstra & Kourtis, 2010; see Eimer, 2014, for a review). Previous studies indicate that ADAN is enhanced when visual perceptual load is high (Seiss, Driver, & Eimer, 2009) and occurs at longer latencies when cues are harder to interpret (Jongen et al., 2007).

Moreover, ADAN/EDAN magnitude is predictive of visual WM performance (Murray, Nobre, & Stokes, 2011). However, it is unclear whether these observations generalize to task-unrelated nonvisual load.

Visual evoked potentials in response to probe stimuli presented after the CTI include P1 and N1. P1 is an early positive component around 100 ms poststimulus over the lateral occipital cortex, which is followed by N1, a negative deflection about 50 ms later (Hillyard & Anllo-Vento, 1998; Luck & Kappenman, 2012; Mangun, Hillyard, & Luck, 1993). Both P1 and N1 amplitudes are typically enhanced for stimuli presented at attended compared to unattended locations, and thus provide an indication of sustained spatial attention (P1-N1 attention effect; Jongen et al., 2007; Mangun et al., 1993). While P1 is thought to represent filtering of information at unattended locations, N1 may reflect a limited-capacity discrimination mechanism (Luck & Kappenman, 2012). Behaviorally, these neural markers are generally accompanied by faster and more accurate responses to visual events at attended compared to unattended locations. Load effects may depend on type of load (Handy & Mangun, 2000; Pratt et al., 2011) but are not always observed (Seiss et al., 2009).

Beyond orienting, the selection negativity (SN) reflects attentional selection, whereas the P3 complex provides an index of target updating and (memory-dependent) stimulus evaluation (Johnson, 1993; Kok, 2001; Polich, 2007). The nonsensory SN can be observed for task-relevant objects roughly 300–400 ms following stimulus onset in tasks requiring hierarchical selection of target location and features (Harter et al., 1989; Karayanidis & Michie, 1997). The P3 complex has a latency of 250–500 ms and is sensitive to cognitive task demands (Harter et al., 1989; Kok, 2001; Pratt et al., 2011; Wester, Böcker, Volkerts, Verster, & Kenemans, 2008).

To test the prediction that delayed warning cue processing under increased verbal WM load leads to changes in cue-related EEG activity, this study aimed, firstly, to replicate these attentional signatures using a dual task in a naturalistic scenario and, secondly, to test if, and at what processing stage, these signatures respond to heightened unrelated verbal task demands. In order to create a more ecologically valid scenario, we designed a spatial cueing paradigm that resembled a common traffic situation. The task simulated a right-of-way situation, where a car with right of way must be carefully attended, while another car that must yield can be (potentially) ignored. A first-person view of an intersection served as visual background, a traffic sign served as directional cue, and the probes were images of cars (Fig. 14). The spatial cueing task was combined with a simultaneous auditory memory task (cf. de Fockert et al., 2001) whose demands overlap with memory functions needed in passenger or phone conversations, or while listening to an in-vehicle navigation system (Just et al., 2008).

We expected that, unless the above-mentioned EEG signatures are artifacts of simplistic task conditions, attentional orienting should be reflected in lateralized alpha activity and the typical sequence of EDAN-ADAN-LDAP in the CTI, and amplitude modulation of the P1-N1 complex. Subject to this, we hypothesized that, if verbal WM load interferes with visuospatial orienting, increasing verbal WM load in the secondary memory task will be accompanied by both a decline in performance on the spatial cueing task, as well as by changes in EDAN/ADAN/LDAP and/or alpha lateralization. If load interferes with attentional maintenance or target selectivity, we additionally expect changes in activity downstream of spatial orienting, that is, a reduction in the P1-N1 attention effect or SN, or a relative change in P3 response to targets versus distracters.

2. Methods

2.1. Participants

Of the 25 participants who took part in the study and who all had a driver's license, three were excluded due to insufficient performance on behavioral measures (for details, please refer to the last paragraph in Dual Task), four because of excessive horizontal eye movements and two due to the poor quality of their EEG recordings. Sixteen data sets (9 female, *M* age 24.1, age range: 17–33 years) were subjected to further statistical analysis. All participants gave written informed consent and were compensated for their time. The study was approved by the Ethical Review Board of Psychology and Neuroscience at Maastricht University.

2.2. EEG recording

Reference-free EEG was recorded with a BioSemi ActiveTwo System (BioSemi, Amsterdam, Netherlands) at a sampling rate of 256 Hz using the system's default online filter between DC and 52 Hz. Scalp activity was measured at 64 locations based on the International 10-20 system using sintered Ag/AgCl electrodes. Horizontal and vertical activity related to eye movements was recorded with pairs of unipolar electrodes placed on the left and right outer canthi and above and below the left eye, respectively. Signals were also obtained from the left and right mastoid bone for offline re-referencing of EEG/EOG (electrooculogram) electrodes to their average. Electrode offsets were kept below 40 mV.

2.3. Tasks

Stimulus delivery was controlled by Presentation software (version 15.0, Neurobehavioral Systems, Albany, CA) running on a Windows 7 32-bit operating system. The tasks were presented on an LCD monitor (14.8 X 11.9 inches with 1,280 X 1,024 pixel resolution) at 60 Hz refresh rate.

2.3.1. Dual task

The dual task consisted of an auditory version of the memory task employed by de Fockert et al. (2001) and a task that involved centrally cued covert spatial attention and the discrimination between peripheral moving targets versus stationary non-targets on the cued side. Crucially, WM load during spatial orienting was manipulated by asking participants to retain memory sets of variable complexity during the (unrelated) orienting task. Participants were instructed to respond as quickly and accurately as possible to both tasks. A typical trial is outlined in Figure 14A.

In the memory task, participants were acoustically presented with a prerecorded sequence of the digits 0, 1, 2, 3, and 4 (stimulus onset asynchrony between digits: *M* 1.4 s, *SD* 0.1, sequence duration *M* 6.0 s, *SD* 0.1), always starting with zero. After a variable retention interval, during which participants performed a sequence of orienting trials (see below), an acoustic probe consisting of a single digit between 0 and 4 was presented. Participants had to respond by saying the number that followed this probe in the original set. Following a response interval of 1 s, the next memory set was presented. In the low load condition, digits were presented in ascending order (i.e., 01234). Therefore, participants only needed to remember that the current task goal was to "add one" to each probe. In the high load condition, digit order was randomized (e.g., 03421), so each sequence had to be memorized and retained until the next probe. Each memory sequence in the high load was drawn randomly without replacement to avoid repetition effects.
Probes were chosen randomly on the condition that the single digit did not match the last digit of the memory set. Verbal responses were manually recorded by the experimenter.

In the orienting task, the computer screen showed the image of an intersection from a driver's perspective (see Figure 14B, C). Participants were asked to maintain fixation to a central cross. A central cue in the shape of a dim red arrow in a white square and an approximate size of 18 visual angle (1.2 X 1.3 cm) based on an actual road sign was presented for 400 ms (Figure 14B). The cue duration was based on Jongen et al. (2006), but shortened from 600 ms to 400 ms to save experimental time. This cue informed the participant to direct attention, but not gaze, to the left or right, thus mimicking a traffic situation in which a road sign informs the driver to pay attention to an intersection with right of way for cars coming from a particular direction. After a CTI of 1,217 ms (long enough to allow time frequency analysis in the alpha band; see Jongen et al., 2006), the image of a car (5.6 X 2.3 cm) appeared on either of the two side roads at a visual angle of approximately 78 from fixation (Figure 14C), corresponding to 7.2-cm distance on screen between the center of fixation and the front bumper of the car (see Jongen et al., 2006). The car had similar luminance as the background to diminish its saliency.

There were two conditions: moving and stationary. In both conditions, the car was presented stationary for 260 ms. This permitted analysis of early visual ERPs P1/N1 without contamination by motion- and response-related activity. After this interval, the car in the moving condition started moving toward the intersection.
Motion was simulated by two successive stationary image frames (17 ms each), each with the position of the car by 0.38 more shifted toward the center. In the stationary condition, the position of the car did not change during these two frames. Thus, stationary and moving cars were presented equally long (294 ms) and then disappeared. The task was to respond only when a moving car appeared at the attended location (target); stationary cars at both attended and unattended locations, as well as moving cars at the unattended location, were nontargets and should be ignored. Hence, the role of the cue was to indicate the next task-relevant location, despite being noninformative as to whether an actual target would appear there on any given trial. These instructions were meant to simulate traffic behavior toward cars with (attended) or without (unattended) right of way.

There were 72 memory trials and 256 orienting trials per WM load condition (low vs. high), with 32 orienting trials in each of the eight stimulus conditions: Cue Direction (left vs. right) X Car Location (left vs. right) X Motion (stationary vs. moving). Orienting trial order was randomized within each WM load condition.
Each dual task trial comprised a memory set, a sequence of 2–8 orienting trials (within each load condition: 25 sequences of 2 orienting trials, 17 of 3, 12 of 4, 8 of 5, 5 of 6, 3 of 7, and 2 of 8 trials, to make memory probe onset less predictable), and a memory probe. The order of low and high load dual task trials was also randomized. Data of participants who performed below a cut-off score in one or more of the subtasks (memory [high load]: < 75%, orienting: < 90% hits, or > 5% false alarms) were not included in further analyses.

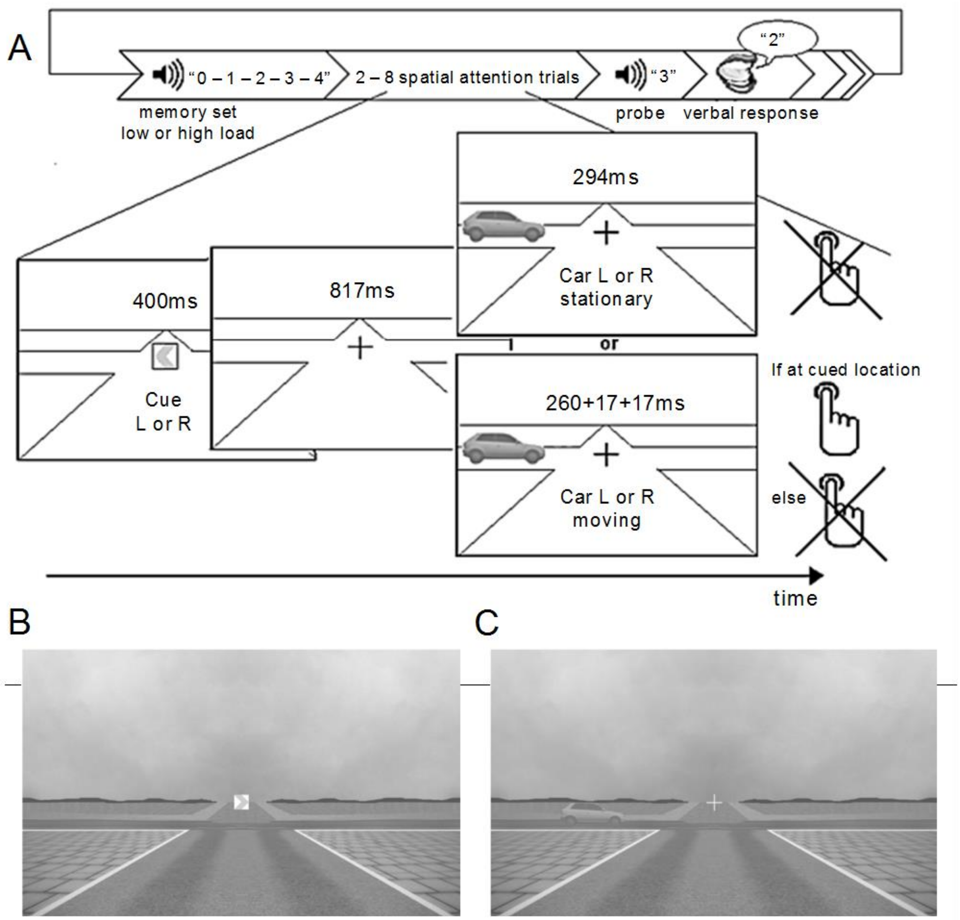

Figure 14: Task. A: Schematic outline of a dual task trial. B, C: Orienting task scenario with naturalistic stimuli from a participant's point of view. B:
Example of a (right-pointing) cue. C: Example of a car.

2.3.2. Horizontal EOG (HEOG) calibration task

This task was performed before the experiment to be able to relate HEOG amplitude to the magnitude of any lateral eye movements during the orienting task. A white dot on a gray background moved from the screen center to a location equivalent to the car's position to the left and right of center, as well as 38 up and down, returning to the starting point after 1.5 s (10 trials per condition). Participants were instructed to follow the dot with their eyes.

2.4. Procedure

Participants were seated approximately 57 cm from the computer screen. First, they performed the HEOG task. Subjects were then trained in the orienting task (40 trials) and memory task (20 trials) separately as well as in both tasks combined (16 memory orienting trials). If a minimum score of 75/80% (memory/orienting task) was not achieved, the particular training session was repeated. The duration of the actual experiment was about 50 min. After each block of 16 dual task trials, participants were given a self-timed break.

2.5. EEG preprocessing

EEG data were processed using the EEGLAB (Delorme & Makeig, 2004) and FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011) toolboxes in MATLAB (MathWorks, Natick, MA).

2.5.1. Dual task

Raw EEG data were filtered between 0.1–35 Hz. Epochs of 2.4 s were extracted that encompassed orienting trials from 200 ms before cue onset to 996 ms after car onset. The whole epoch served as baseline. Noisy epochs were rejected visually before running independent component analyses for identification and subsequent removal of blinks and other artifacts (components removed: *M* 13, *SD* 4 of 72 components per participant). We dealt with eye movements by first removing only the blink component for each participant and then selecting all trials in which the amplitude of the bipolar HEOG derivation (right minus left HEOG) exceeded the previously established eye movement criterion for rejection (the blink component was removed prior to running the thresholding procedure as otherwise the latter would reject not only epochs with horizontal motion but often also valid epochs with blinks). After this HEOG rejection step, other artifactual components were removed from the data set.

For the remaining data, the voltage difference between bipolar HEOGs following the presentation of a left versus right cue generally did not exceed 4 MV except in some instances in four participants; however, these differences did not contribute to the observed effect (see Results section, final paragraph). On average, 83 (range 14–162) of 512 trials were discarded per participant. The number of rejected trials was not different between low and high WM load (low: *M* 33.88; high: *M* 36.50; *t*(15) -.95, *p* 5.36, *d* -.24), confirming that higher task demands did not affect the rate or magnitude of eye movements. Nor did the number of ERP trials per person significantly differ between low and high load (low: *M* 216.88; high: *M* 212.62; *t*(15) 1.56, *p* .14, *d* .39), ensuring similar statistical power for ERP analyses. On average, 107 trials (of 128 possible, *SD* 11) and 27 trials (of 32 possible, *SD* 3) were included in the individual event-related averages per condition for cue-locked and car-locked activity, respectively.

2.5.2. Statistical analysis

All statistical tests were run in IBM SPSS Statistics 19. When univariate test results involve more than one degree of freedom (i.e., factors with more than two levels), Greenhouse-Geisser-corrected p values. Effects sizes are indicated by Cohen's d for paired t tests and partial eta squared (ηp^2) for repeated measures analysis of variance (rmANOVA). Only correct trials were entered into EEG analyses.

3. Results

3.1. Task performance is reduced by increased working memory load

Memory task performance (% correct) was worse in the high than in the low load condition (high: *M* 94.44, *SD* 3.96; *low*: *M* 98.87, *SD* 2.16; *t*(15) 3.92, *p* .001, *d* .98, confirming that the manipulation of WM load was successful (Figure 15A). Reaction times (in ms, from motion onset) in the orienting task were unaffected by memory load (low: *M* 355.58, *SD* 59.26; high: *M* 356.68, *SD* 71.46; *t*(15) .18, p .86, *d* .05 (Figure 15B). To analyze accuracy in the orienting task, the signal detection parameters (Green & Swets, 1966; Sorkin, 1999) *d'* (for sensitivity) and *c* (response criterion) were computed from hit (low: *M* 97.95, *SD* 2.33; high: *M* 96.78, *SD* 3.04) and false alarm (low: *M* 0.62, *SD* 1.06; high: *M* 1.01, *SD* 1.27) rates (both in percent). Whereas *d'* was significantly lower under high than under low load (*M* 3.96, *SD* 0.69; *M* 4.24, *SD* 0.58; *t*(15) 2.05, *p* .03, *d* .63; Figure 15C), *c* was not affected (low: *M* .034, *SD* 0.21; high: *M* .036, *SD* 0.24; *t*(15) -.03, *p* .98, *d* 2.01; Figure 15D). Thus, although participants performed almost perfectly, they showed a small but significant decline in detection performance when memory load was increased, and this decline was not due to a change in response bias.

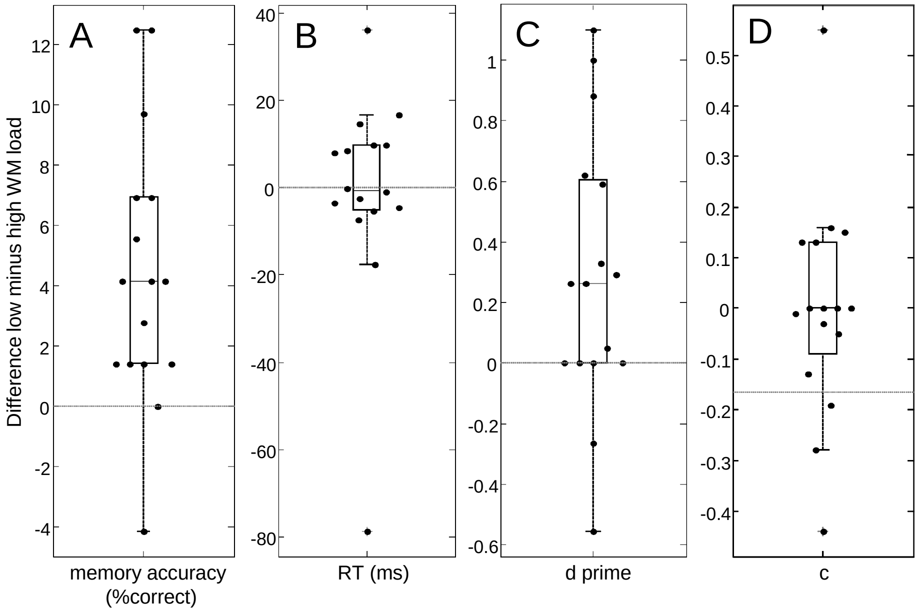

Figure 15: Behavioral results. All results are reported as mean performance difference (N516) under different memory load conditions (low minus high load). A: Memory task accuracy (% correct). B: Reaction time to targets in the orienting task with respect to motion onset (ms). C: Sensitivity index d'. D: Response criterion c. Dots are individual data points, gray dotted horizontal lines represent no difference. Whiskers indicate lowest/highest data point still within 1.5 interquartile range of the lower/upper quartile, respectively.

3.2. CTI power lateralization in the power alpha band as delayed by increased WM load

First, epochs time-locked to cue onset were sorted by cue direction and WM load and averaged per person for each of the four conditions. The event-related average was then subtracted from the EEG of each trial within the respective condition to obtain induced activity (Cohen, 2014; Jongen et al., 2006). The mean amplitude across time was subtracted per epoch. For a time-frequency representation of power in the alpha band (6–14 Hz at 1 Hz frequency resolution), fast Fourier transforms were calculated for each trial over the interval between 2200 ms and 1,200 ms relative to cue onset (Hanning-tapered sliding window: width 400 ms, step size 50 ms; zero padding 2 s) and the resulting spectra averaged. Following Thut and colleagues (2006), a normalized alpha lateralization index (LI) was calculated for each participant, cue condition, frequency, time point, and homologous electrode pair as:

$$\mathrm{LI} = \frac{(\alpha \text{ right hemisphere} - \alpha \text{ left hemisphere})}{((\alpha \text{ right hemisphere} - \alpha \text{ left hemisphere})/2)}$$

where α is alpha power and the index indicates the location of the electrode. A negative LI means greater alpha power in the channel over the left hemisphere and a positive LI greater alpha power in the homologous channel over the right hemisphere. The LI was baseline-corrected by subtracting the values at the first valid time point (representing the first 400-ms window centered around 18 ms postcue onset) from all subsequent time points (while time-frequency analysis inherently includes activity from neighboring time points, it is unlikely that attention-related lateralization occurs earlier than 200 ms and has been observed after ~400 ms; Kelly et al., 2009; Worden et al., 2000). For statistical analysis, we defined an area of interest based on the topographies of the grand average difference in LI between right- and left-directing cues (see Figure 16B), including channel pairs O1/2, PO3/4, and PO7/8, and calculated the average within this area across three successive (nonoverlapping) time points. Previous work from our lab and elsewhere suggests that attentional modulation in the alpha band may behave differently in different frequency subbands and may be more pronounced for lower alpha frequencies (Babiloni et al., 2004; Jongen et al., 2006; Klimesch, 1999). Therefore, we defined and averaged LI across a lower (6–9 Hz) and upper alpha band (10–13 Hz). Separate rmANOVAs were calculated for each alpha band (lower, upper) and four time windows (~170– 270 ms, 320–420 ms, 470–570 ms, and 620–720 ms, corresponding approximately to the time course in the ERP analysis) separately with factors cue (left vs. right) and WM load (low vs. high).

The respective time courses of the difference in lateralization indices (cue right minus cue left) during the CTI in the lower and upper alpha bands during low and high load are depicted in Figure 16A. For the lower alpha band, there was a main effect of cue in the third and fourth time windows (470–570 ms: $F(1,15)$ 4.69, p .047, $\eta\rho^2$ .24; 620–720 ms: $F(1,15)$ 5.34, p .035, $\eta\rho^2$ .26; other windows: $F < 1$). Post hoc pairwise comparisons confirmed that LI for left-directing cues was significantly more negative than for right-directing cues. Importantly, there was also a significant interaction of Cue X WM Load in the second time window (320–420 ms: $F(1,15)$ 8.50, p .011, $\eta\rho^2$ .36; other windows: 170–270 ms: $F(1,15)$ 2.44, p .14, $\eta\rho^2$ .14; 470–570 ms: $F(1,15)$ 3.03, p .10, $\eta\rho^2$ .17; other windows: $F < 1$).

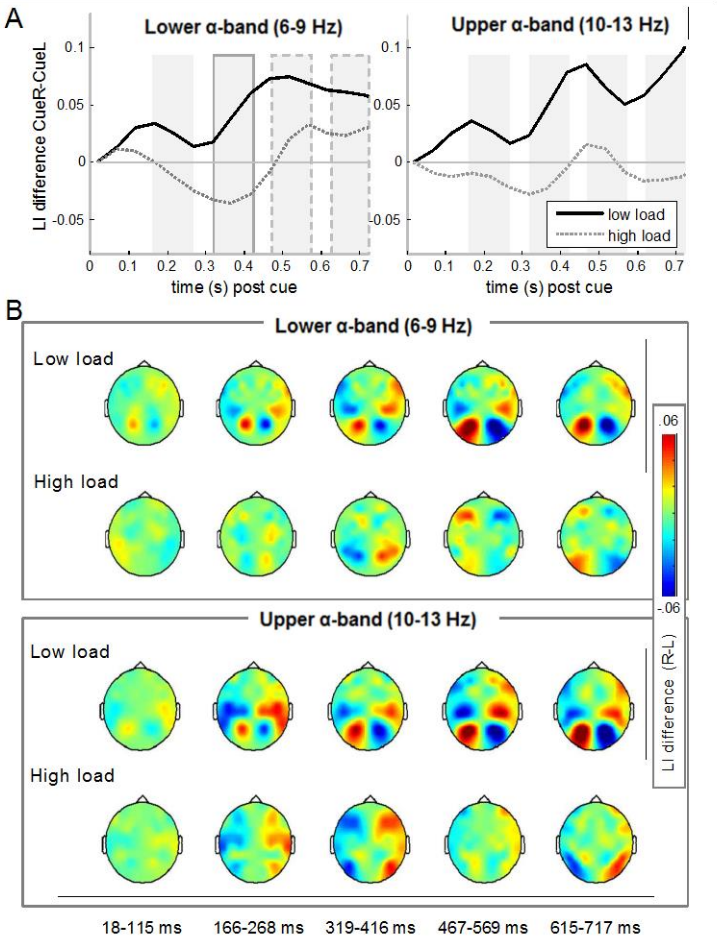

Figure 16: Alpha lateralization in the cue target interval. A: Grand-averaged time course (N516) of the difference in lateralization index (LI) between cues directing attention to the right versus left visual field under both low (solid line) and high load (dotted line) for the lower (left) and upper (right) alpha bands in the lateral occipital areas of interest. As LI was generally positive for right-directing cues (i.e., greater alpha power over the right hemisphere) and generally negative for left-directing cues (i.e., greater alpha power over the left hemisphere), the difference cue right minus cue left is positive. Gray shaded areas mark the time windows in the analysis. The dark gray solid box indicates a significant effect of WM load on hemispheric lateralization (interaction Attention X Hemisphere). Light gray dashed boxes show significant lateralization independent of load (main effect attention).

B: Topographies of alpha lateralization, conceptualized (as above) as the difference in LI for right-directing minus left-directing cues for the lower and upper alpha band (top and bottom panel, respectively). Panels show (from left to right) topography at baseline and for each time window in the analysis. As LI is an integrative measure across hemispheres, the right hemisphere mirrors data over the left hemisphere.

Pairwise comparisons for low and high load separately confirmed that, only under low load, the LI for left-pointing arrow cues was significantly more negative than for right-pointing arrow cues in this time window, indicating that load delayed the time course of lateralization. Despite the similar time course of lateralized activity in the upper alpha band, there were no significant effects at the group level within the analyzed time windows (all *Fs* < 1 except Cue X WM Load in Windows 2 and 4; 320–420 ms: $F(1,15)$ 1.97, p .18, $\eta\rho^2$ .12; 620–720 ms: $F(1,15)$ 3.02, p .09, $\eta\rho^2$ .18).

3.3. CTI ERPs: ADAN is delayed and EDAN absent when WM load is high

First, ERPs were calculated as described above. Averages were then pooled across cue directions (with electrode sites over left and right hemisphere assigned to the hemisphere ipsi- or contralateral to the cue as appropriate). For statistical analysis, electrode pairs in two regions of interest (ROI) were selected (anterior: F3/4, F7/8, FC5/6; posterior: P3/4, P7/8, PO7/8; cf. Dale et al., 2008; Jongen et al., 2007; van Velzen & Eimer, 2003, see Figures 17 and 18A). Amplitudes of individual ERPs at these channels were averaged across time points in five 100-ms windows between 200 and 700 ms after cue onset. rmANOVAs were conducted for each ROI and time window with factors hemisphere (ipsi- vs. contralateral), WM load (low vs. high), and electrode (respective sets of anterior vs. posterior electrode pairs).

For the anterior ROI, we found a significant main effect for hemisphere in the three earliest 100-ms time windows (200–300 ms: $F(1,15)$ 5.09, p .039, $\eta\rho^2$ .25; 300–400 ms: $F(1,15)$ 22.69, $p < .001$, $\eta\rho^2$ .60; 400–500 ms: $F(1,15)$ 9.89, p .007, $\eta\rho^2$ .40). Pairwise comparisons confirmed lower amplitudes in channels contra- versus ipsilateral to the cued location, indicating the presence of ADAN within the predicted latency window (Figure 17). Importantly, the hemispheric effect in the earliest time window (200–300 ms) was dependent on WM load (WM Load X Hemisphere: $F(1,15)$ 6.84, p .019, $\eta\rho^2$ .31, Figure 18). Only under low load was the hemispheric asymmetry significant (hemisphere, low load: $F(1,15)$ 513.19, p .002, $\eta\rho^2$ .47; high load: $F(1,15)$ .25, p .62, $\eta\rho^2$ .02). In convergence with the apparent delay of alpha lateralization, these results support the interpretation that, under high WM load, attentional orienting was delayed.

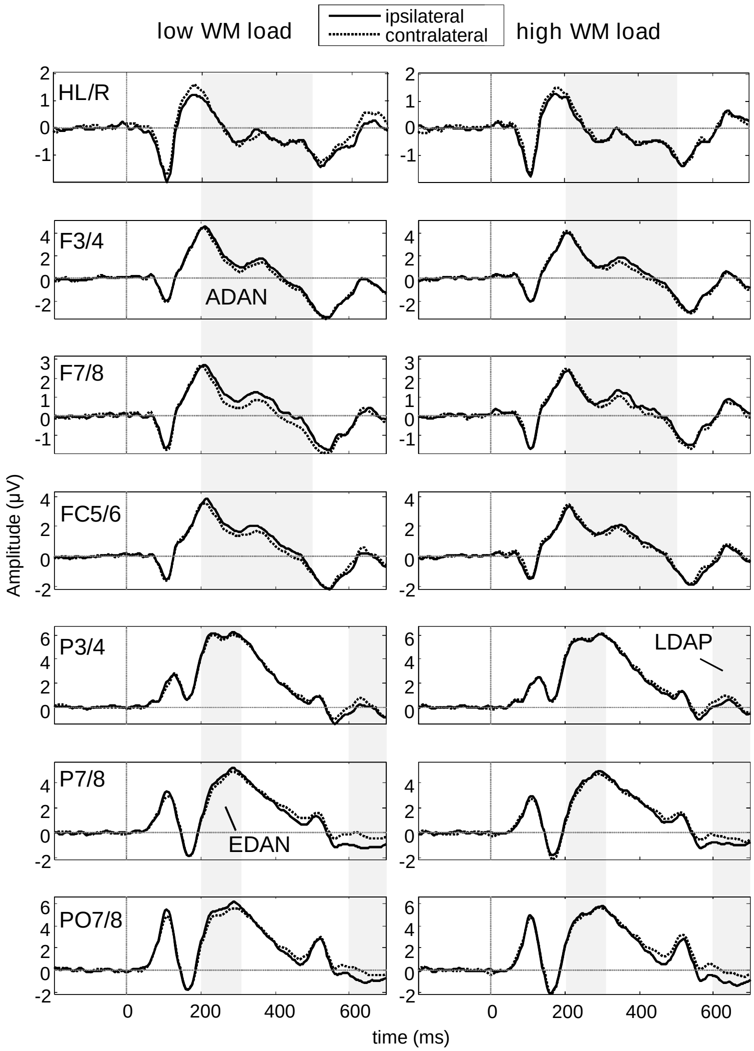

Figure 17: Event-related responses in the cue target interval. Grand-averaged cue ERPs (N516), time-locked to cue onset, recorded at channels either ipsilateral (solid line) or contralateral (dotted line) to the cued direction under low (left column) and high WM load (right column). Gray shaded areas indicate time windows for ADAN, EDAN, and LDAP, respectively. HL/R5horizontal electrooculogram channel pair.

For the posterior region, we found an interaction between hemisphere and WM load in the window 200–300 ms, $F(1,15)$ 4.68, p .047, $\eta\rho^2$ .24. Follow-up analyses showed a significant contralateral negativity in the low load (hemisphere: $F(1,15)$ 8.51, p .011, $\eta\rho^2$ .36) but not in the high load condition (hemisphere: $F(1,15)$ .42, p .52, $\eta\rho^2$ .03). This confirms (as suggested by Figure 18A) that an EDAN was absent, or at least reduced, when WM load was increased. In addition, there was a main effect of hemisphere in the two latest time windows (hemisphere, 500–600 ms: $F(1,15)$ 8.07, p .012, $\eta\rho^2$ .35; 600–700 ms: $F(1,15)$ 12.69, p .003, $\eta\rho^2$ .46), with higher amplitudes in electrodes contralateral compared to ipsilateral to the cued location, supporting the presence of an LDAP at the appropriate latency. However, this effect was not dependent on memory load (WM Load X Hemisphere, 500–600 ms: $F(1,15)$ .21, p .65, $\eta\rho^2$ .01; 600–700 ms: $F(1,15)$ .19, p .67, $\eta\rho^2$ .01).

To confirm that the anterior and posterior negativities indeed represent two separate components, we performed a control analysis with the same rmANOVA for central electrodes (C3/4, C5/6) between the former areas of interest. In support, this analysis revealed no significant effect of hemisphere, nor any two- or three way interaction with WM load and/or electrode (hemisphere: $F(1,15)$ 2.87, p .11, $\eta\rho^2$ .16; Electrode X Hemisphere X WM Load: $F(1,15)$ 2.16, p .16, $\eta\rho^2$ .13; all other *Fs* < 1; for topography, see Figure 18B).

An additional control analysis on the HEOG channels revealed no significant effects (all *Fs* < 1), except for a significant interaction in the time window 600–700 ms in the data (which was not observed in the ERP analysis; $F(1,15)$ 4.79, p .045, $\eta\rho^2$ .24) and which was not substantiated in post hoc t tests for each load condition separately (p > .33). This indicates that the effects observed in EEG channels were not driven by systematic small eye movements toward the cued location.

3.4. Car ERPs: Load has no effect on attentional modulation related to target processing

Epochs time-locked to car onset were sorted by cue direction, car location, motion condition, and WM load, and then averaged. Based on cue direction, averages were then resorted based on whether cars were presented at attended or unattended locations and pooled. Due to LDAP, the ERP contralateral to the attended side was more positive before stimulus onset. Although baseline correction could in principle account for this difference, artefactual differences between hemispheres still arise in the ERPs if the LDAP subsides after stimulus onset (Jongen et al., 2007). To avoid this confound, electrode sites over the ipsi- and contralateral hemisphere were averaged. Visual inspection of the data in Figure 19 suggested P1-N1 enhancement for cars presented at attended locations at lateral posterior electrodes roughly between 100–200 ms after car onset. In

addition, at midline electrodes (Figure 20), the waveforms for attended and unattended locations diverged at around 220 ms, resulting in a prominent SN predominantly at frontal and central electrodes. Finally, a large P3 emerged after about 500 ms with mostly posterior topography. For statistical analysis of the effect of WM load on these components, we averaged the amplitude values across time points for selected electrodes: for P1, P7/8, and PO7/8 between 120–150 ms; for N1, P7/8, and PO7/8 between 170–200 ms (cf. Jongen et al., 2007; Luck & Kappenman, 2012); for SN, Fz, and Cz between 300–400 ms (Harter et al., 1989; Karayanidis & Michie, 1997); and for P3, Fz, Cz, Pz, and Oz between 520–650 ms (Johnson, 1993; Polich, 2007). Separate rmANOVAs were run for each time window. For P1-N1 (before motion onset) and SN (40–140 ms after motion onset), we looked at the factors attention (attended vs. unattended, depending on cued location), WM load (low vs. high), and electrode (as specified above).
For P3 (after motion onset), motion (stationary vs. moving) was included as additional factor.

A main effect of attention was present for the P1, $F(1,15)$ 18.56, p .001, $\eta\rho^2$ .55, and N1, $F(1,15)$ 20.38, $p < .001$, $\eta\rho^2$ .58, windows at both P7/8 and PO7/8, although for P1 the difference was greater at the latter location (interaction of Electrode X Attention: $F(1,15)$ 15.27, p .001, $\eta\rho^2$ .51). Pairwise comparisons confirmed that attended cars induced a more positive amplitude in the P1 window and a more negative amplitude in the N1 window, consistent with the classic P1-N1 attention effect. However, neither P1 nor N1 was significantly affected by WM load (Attention X WM Load (P1: $F(1,15)$ .12, p .73, $\eta\rho^2$ .01; N1: $F(1,15)$ 1.22, p .29, $\eta\rho^2$ .08; Figure 19). The ERP in the SN window was significantly more negative for attended than unattended cars (attention: $F(1,15)$ 24.02, $p < .001$, $\eta\rho^2$ .61). This provides an additional electrophysiological marker for selectivity toward potential targets. However, there was no effect of WM load on SN amplitude (Attention X WM load: $F(1,15) < .1$; Figure 20). In the P3 window, a three-way interaction of motion, attention, and electrode, $F(3,45)$ 19.13, $p <$ .001, $\eta\rho^2$ .56, superseded main effects of these factors and two-way interactions.

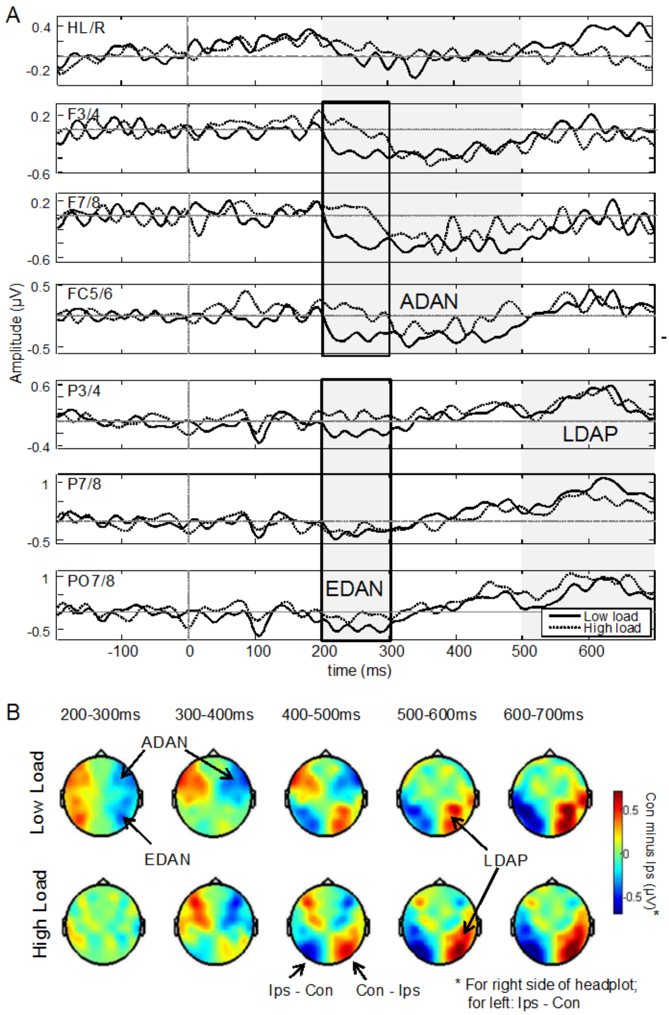

Figure 18: Lateralized activity in the cue target interval. A: Grand-averaged hemispheric differences in cue ERPs (N 16, contra- minus ipsilateral channels), time-locked to cue onset. Gray shaded areas indicate time windows for ADAN, EDAN, and LDAP, respectively. The black box indicates a significant effect of WM load on hemispheric lateralization (interaction Attention X Hemisphere). HL/R = horizontal electrooculogram channel pair. B: Topographies of the hemispheric differences in the cue target interval for each time window of analysis for low (top panel) and high load (bottom panel). Left hemisphere shows ipsi- minus contralateral channels, mirrored by the right hemisphere. Arrows indicate ADAN, EDAN, and LDAP.

Tested per electrode, Attention X Motion interaction effects were significant at Pz: $F(1,15)$ 70.53, p < .001, $\eta\rho^2$ .83, and Oz: $F(1,15)$ 60.21, p < .001, $\eta\rho^2$ .80, but not at Fz: $F(1,15)$ .22, p .64, $\eta\rho^2$ .02, and Cz: $F(1,15)$ .78, p .39, $\eta\rho^2$ .05. At the occipitoparietal sites, moving cars resulted in greater P3 amplitudes compared to stationary cars when presented at attended locations (motion, Pz: $F(1,15)$ 77.36, p < .001, $\eta\rho^2$ .84; Oz: $F(1,15)$ 83.78, p < .001, $\eta\rho^2$ .85). For cars presented at unattended locations, this motion-induced increase was less pronounced (motion, Pz: $F(1,15)$ 4.71, p .046, $\eta\rho^2$ .24) or absent (Oz: $F(1,15)$ 2.01, p .18, $\eta\rho^2$ .12), thus reflecting target-specific processing. Again, WM load had no effect (Attention X Motion X WM Load: $F(1,15)$ 1.23, p .29, $\eta\rho^2$ .29; Electrode X Attention X WM Load: $F(3,45)$ 1.25, p .30, $\eta\rho^2$ .08; Electrode X Attention X Motion X WM Load: $F(3,45)$ 2.02, p .16, $\eta\rho^2$ .12; all other Fs < 1).

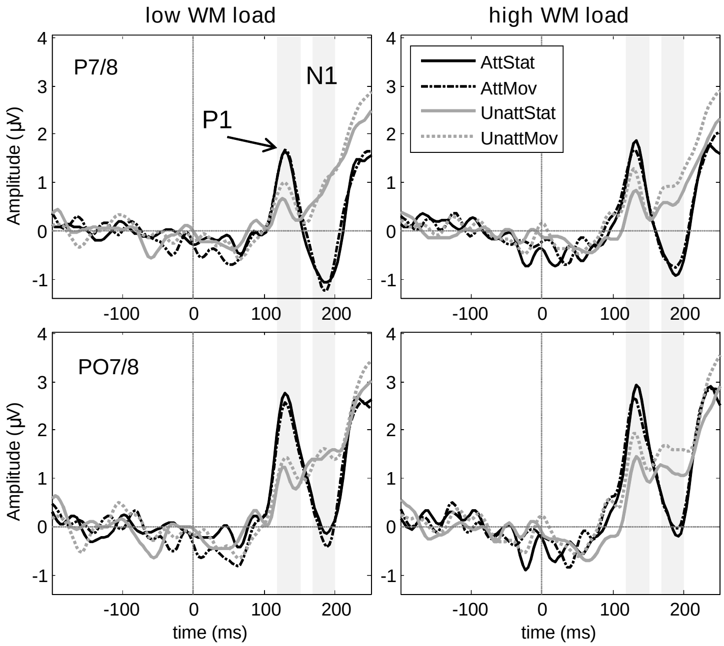

Figure 19: P1-N1 attention effect. Grand-averaged (N 16) ERPs time-locked to car onset and averaged across ipsi- and contralateral channel pairs under low (left column) and high WM load (right column). Gray shaded areas indicate P1 and N1 windows. Note that P1 is more positive and N1 more negative for attended (black lines) compared to unattended cars (gray lines). Although the time courses seem to diverge between motion conditions, this nonsignificant difference is due to noise in the measurement (as it occurs before motion onset). AttStat = attended stationary cars; AttMov = attended moving cars; UnattStat = unattended stationary cars; UnattMov = unattended moving cars.

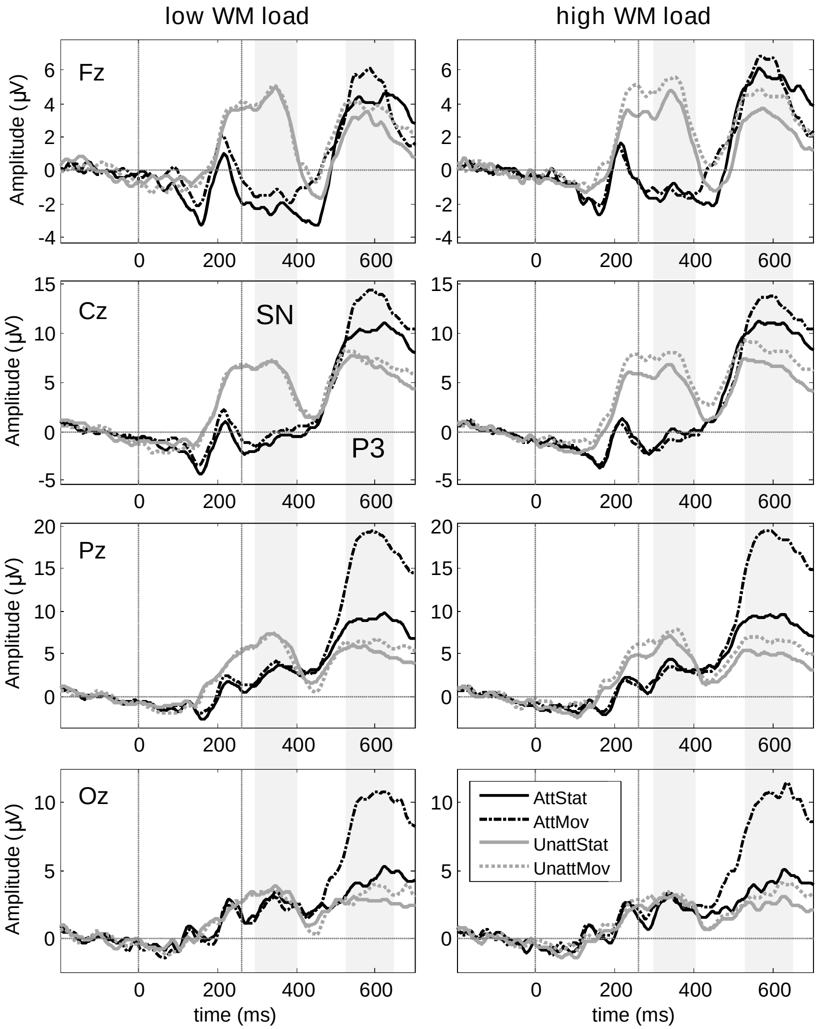

Figure 20: Event-related responses to cars (car ERPs). Grand-averaged (N 16) ERPs, time-locked to car onset and averaged across ipsi- and contralateral channel pairs under low (left column) and high WM load (right column). Gray shaded areas indicate selection negativity (SN) and P3 windows. AttMov = attended moving cars; UnattStat = unattended stationary cars; UnattMov = unattended moving cars.

3.5. Changes in ADAN/EDAN/Alpha lateralization do not predict changes in task performance

Pearson product-moment correlation analyses were conducted to assess whether the individual differences in load-induced changes of *d*‛ in the orienting task could be predicted by the load-induced changes in ADAN, EDAN, and/or alpha lateralization in the respective time window containing the interaction with WM load. However, change in *d*‛ was not associated with the change in either ADAN, *r*(14) 2.06, *p* .84; EDAN, *r*(14) .07, *p* .79; or LI difference between left and right cues, *r*(14) .04, *p* .89.

Discussion

The current study investigated electrophysiological changes associated with visuospatial attention in a naturalistic scene, and how they reflect the impact of increased working memory load on the orienting of visuospatial attention. To this end, we used a dual task that combined spatial attentional demands with concurrent verbal memory rehearsal, thereby mimicking some aspects of an actual traffic situation. Behaviorally, we found that, when WM load was high, participants not only performed worse in the memory task but also showed a decrease in sensitivity to targets in the concurrent orienting task. This demonstrates that our manipulation of WM load was successful in that it interfered with spatial attention. One critical question, and prerequisite for further analyses, was whether our complex task (i.e., with a secondary memory task and natural scenelike visual input) would still elicit the specific EEG signatures related to attentional orienting (i.e., alpha lateralization, ADAN/EDAN/LDAP sequence, P1-N1 enhancement for attended locations) that are normally observed in highly controlled artificial laboratory tasks. These EEG markers were successfully replicated, demonstrating their robustness and generalizability to spatial orienting in simulated real-life tasks. This encourages the study of attentional orienting in even more ecologically valid tasks (for an example, see Ross et al., submitted for publication). Their presence also confirms that volunteers followed the instructions to allocate their spatial attention to the cued location.

Higher WM load had a small but significant negative impact on task performance requiring spatial attention, as reflected by reduced sensitivity to targets (d’), with no change in response bias (c). This provides evidence that an unrelated, nonvisual working memory task draws on the same resources as those required for visuospatial attention.

In addition, higher WM load delayed early neural markers of spatial orienting during the cue-target interval, while those related to spatial attentional focus (showing that participants indeed retained cue direction) and target selection were unaffected. This suggests interference during early stages of attentional orienting. Specifically, we found evidence for delayed alpha lateralization indicated by a difference in the cue-dependent hemispheric lateralization index under low but not high load in an early time window (from 320 ms), whereas in a later window this hemispheric asymmetry was present in both load conditions. In accordance with previous observations, this effect was specific to the lower alpha band (Babiloni et al., 2004; Jongen et al., 2006; Klimesch, 1999), suggesting a delay in the active filtering of irrelevant information (Jensen & Mazaheri, 2010).

Interestingly, the delay in alpha lateralization was accompanied by a delay in ADAN, which was present in the earliest time bin (200–300 ms after the cue) and only in the low but not the high memory load condition, while in later time bins (300–500 ms), the magnitude of ADAN was equivalent in both load conditions. This provides further evidence that the latency of ADAN is responsive to task difficulty (Jongen et al., 2007). Despite the delays of alpha lateralization and ADAN, all subsequent processes and behavioral responses (given that EEG analysis only included correct trials) were implemented normally. Assuming their hierarchical dependency, this suggests that the process(es) reflected by ADAN/alpha were not degenerated by WM load and, once initiated, followed their normal course.

Due to the inherently lower time selectivity of time-frequency analysis, the respective time courses of alpha and ADAN are difficult to contrast directly, and we cannot conclude from the temporal windows that ADAN precedes alpha lateralization. However, the source of ADAN has been localized to the frontal eye fields (FEF)/lateral premotor cortex (Praamstra, Boutsen, & Humphreys, 2005; van der Lubbe, Neggers, Verleger, & Kenemans, 2006). Interference with preparatory activity in the FEF disrupts attentional alpha modulation in parietal-occipital cortex (Capotosto, Babiloni, Romani, & Corbetta, 2009). This, and the mutual delay, suggest that alpha lateralization may be a process downstream of the ADAN generator.

We found an EDAN in the 200–300 ms time window only under low load. We can think of two explanations for the absence of EDAN under high load. Whatever process is reflected by EDAN could genuinely be absent, as might be consistent with an auxiliary function, rather than a crucial one. One interpretation of EDAN consistent with this explanation is that it reflects processing of lateralized cue stimulus attributes, rather than spatial orienting proper (van Velzen & Eimer, 2003). Alternatively, the EDAN, like the ADAN, may have been delayed and thereby obscured by the onset of the positive and much larger LDAP. Either way, this observation suggests that LDAP, which presumably reflects anticipatory biasing of sensory cortex (Dale et al., 2008; J. J. Green & McDonald, 2010; Kelly et al., 2009; Praamstra et al., 2005) and which was unaffected by load, is not hierarchically contingent on earlier neural activity reflected in EDAN.

Despite the delay of ADAN and the absence of EDAN, high WM load had no effect on later components including LDAP, P1- N1, and SN, or on the interaction of attention and motion during later target selection (P3). Hence, higher cognitive load did not appear to have a significant negative impact on the filtering of information once attentional orienting has been established. Unfortunately, we cannot dissociate the cognitive processes relating to the processing of motion from attention in this design (as attended moving cars required a response while unattended cars did not). However, the comparison of stationary and moving nontargets tells us that motion onset is not processed to a greater degree when WM load is high. It has been observed that high WM load can lead to enhanced processing of distracting visual information (Lavie, 2010) and potentially lead to (at least an initiation of) erroneous prepotent responses (de Fockert et al., 2001; Kane & Engle, 2003). In our experiment, motion at unattended locations was processed to the same (low) extent, relative to stationary cars, under both low and high WM load (i.e., was suppressed compared to targets). The lack of greater processing of unattended moving cars in the high load condition indicates that intrusion by distracters is not enhanced, which is consistent with an effective filtering mechanism.

The absence of a predictive relationship between electrophysiological markers and decline in behavioral sensitivity has been reported before (Kelly et al., 2009) but can be explained in the present case by the fact that these markers were calculated from correct trials only. In other words, in those trials included in each average the behavioral outcome was always a success (i.e., either a hit or correct rejection). In addition, the presence of later attentional markers indicates that the task was performed normally after the delay. This suggests that changes in EEG activity might provide a more sensitive measure of memory load effects than ultimate overt behavior.

In this experiment, we found statistical evidence for ADAN in a window starting at 200 ms postcue. While ADAN onset is often estimated at around 300 ms or later (Harter et al., 1989; Hopf & Mangun, 2000; Jongen et al., 2006; Kelly et al., 2009; Praamstra & Kourtis, 2010), temporal estimates have been variable, and at least two other studies have found ADAN at a similar latency (Dale et al., 2008; Nobre et al., 2000). A possible explanation for this early onset is based on the observation that ADAN onset tends to occur later with greater task difficulty

(Jongen et al., 2007). Our visual scene provided strong visual cues (intersection) as placeholders for potential targets (which always appeared at the same position on the side roads), which possibly also made particularly easy targets for attentional reorientation. In addition, the car stimuli covered a comparably large area of peripheral space, allowing for a wider attentional "spotlight." It is arguably easier to focus attention on a wider compared to a smaller target area. More generally, it has been shown that natural scenes are processed more automatically than abstract scenes (Li, VanRullen, Koch, & Perona, 2002; Peelen et al., 2009), which may have conveyed an advantage under low load that was lost with high load.

A shared resources account that assumes that both tasks draw on available resources simultaneously would predict that, with increasing secondary task difficulty, the deficit in the primary task would rise proportionally, and neural activity would be scaled or altered accordingly. Thus, the fact that neither the (delayed) ADAN nor any of the subsequent ERPs were significantly reduced in amplitude under high load is more consistent with a taskswitching account, that is, with the alternating allocation of full cognitive resources between the two tasks, rather than partial allocation of diminished resources to both tasks simultaneously. In other words, the dual task demands were handled in a serial, rather than a parallel fashion. In this interpretation, participants used the early portion of the orienting task trials to rehearse the current memory set, and then shifted their attentional focus back to the cue. The delay of ADAN should thus approximately scale with the longer rehearsal time for the harder memory sets. Accordingly, load may not interfere with spatial orienting as an ongoing process, but rather with its initiation. Such interference is suggestive of a common neural substrate, as cognitive subtasks that require the same resources will be adversely affected (Salvucci & Taatgen, 2011). Translated to actual driving, a distracting conversation or listening to a GPS device draws working memory resources from the visual attention-demanding driving task; while the driver is engaged, this can delay voluntary orienting toward potentially risky situations such as a car with right of way. The observed decrease in sensitivity might translate into a slight increase in uncertainty about specific traffic interactions and their correct resolution, thereby increasing the probability of an accident.

In line with our interpretation of delayed, rather than degraded, spatial orienting, participants still performed very well on the orienting task (M accuracy > 96%). This makes it unlikely that WM load could interrupt crucial early processes entirely. However, one can argue that on its own the orienting task was quite simple, as it did not involve the reaction to unpredictable events, and followed a fully predictable time course. It is possible that as time pressure, perceptual load, and/or the need for multitasking increase as they would in an actual traffic situation, the delay in orienting could exceed a critical point after which it would not be possible for the performer to retrieve information about the to-be-attended location. This could then lead to changes in the later orienting-related ERPs as well as to more dramatic consequences for performance. Thus, delayed orienting in a real-world driving scenario could very well translate into an increase in response time with potentially harmful consequences.

Limitations

The task design was aimed at maximizing performance in order to maximize the number of trials going into any particular ERP analysis. Participants indeed performed the spatial task with high accuracy and few false alarms. Accordingly, there were too few incorrect response trials for a meaningful separate analysis. Ideally, the differences between correct versus incorrect trials would be examined to confirm a critical delay, the absence of early attentional orienting, or a reduction of later components of attentional selection, in incorrect trials.

The experiment did not include a control condition without a concurrent memory task. Arguably, the additional demand of holding an active representation of the current task setting (i.e., remember the set vs. add one to the next probe) may have already increased task difficulty to a level that interfered with selective attention. Therefore, the impact of load on markers of attentional orienting might have been more pronounced when contrasted with ERPs obtained without a secondary task. As we were specifically interested in the effect of an increase in cognitive load in a secondary task, however, this manipulation was a better control for the high load condition than a single task control.

While we show that EEG activity observed with abstract stimuli in simplified task conditions generalizes to more naturalistic scenes, we cannot automatically assume that in reverse the load effect in this experiment would be observed in a more typical abstract laboratory task. Since the task was similarly static, and delays in ADAN have been observed previously (cf. Jongen et al., 2007), it is plausible but should be subjected to additional testing.

Conclusion

This study successfully replicated EEG markers of visuospatial orienting in a dual, naturalistic-looking spatial cueing task simulating a traffic scenario. This demonstrates their applicability as neural indicators in the study of visuospatial orienting also in more realistic task conditions. In addition, the changes in early cue-related activity suggest that the initiation of spatial orienting is delayed when WM demands due to an unrelated concurrent secondary task are high. This finding is more consistent with alternate allocation of common neural resources to independent tasks (i.e., task switching), rather than depletion of simultaneously shared resources. Despite the load-induced delay, once the orienting response was initiated, performance requiring visuospatial attention was hardly affected. It remains to be tested whether an additional increase in cognitive load—alongside a greater decline in task performance—would also lead to a decrement in later electrophysiological correlates of attentional orienting.

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CHAPTER 2B

Ergonomics, First review

Measuring working memory load effects on attention orienting during a simulated attention task.

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In the following chapter, I was involved in the design and methodological execution, data collection, analyses, and dissemination (presentation at conferences and writing of the paper).

Abstract

Intersection accidents encompass a significant proportion of fatalities and attention allocation likely plays a key role. Attention allocation depends on an orienting mechanism pending on limited working memory (WM) capacity, whereas driving is often combined with tasks increasing WM load. This study (n 22) investigated WM load (memory task) effects on orienting processes by analyzing event-related potentials (ERPs) and behavioral outcomes on a simulated attention task, consisting of 512 intersections. A driving simulator allowed continuous lane-keeping measurement. Participants needed to covertly orient attention towards the side indicated by an arrow, and respond only to moving cars appearing on the attended side. Typical ERPs were found (cue: contralateral negativity, LDAP; target: N1, P1, SN, and P3). With increased WM load, lane-keeping performance improved while dual task performance degraded (memory task: increased error-rate; attention task: increased false alarms, smaller P3). Implications for the usefulness of ERPs in driver-support systems are discussed.

Key words: attention orienting, working memory load, event-related potentials, driving simulation

Practitioner Summary

Intersection driver-support systems are used to improve traffic-safety and - flow. However, in-vehicle systems induce working memory (WM) load, increasing the tendency to yield. Traffic flow will be reduced if drivers stop at inappropriate times, reducing the effectiveness of such systems. Consequently, intersection driver-support systems should include WM load measurement.

1. Introduction

Driving is a highly complicated task requiring the integration of various attentional, cognitive, sensory, and psychomotor functions (Ross et al., 2015; Young & Regan, 2007) in road environments of different complexities (Horberry, Anderson, Regan, Triggs, & Brown, 2006). Even though most countries successfully decreased the number of road fatalities, this number still remains too high with the WHO reporting fatality rates of 1.24 million per year (Fort, et al. 2010; World Health Organization, 2013). Intersection accidents constitute a major problem and encompass a significant proportion of fatalities each year. Often, these accidents result from situations where drivers fail to yield (Bao & Boyle, 2009; Sandin, 2009; Werneke & Vollrath, 2012). Insufficient visuospatial attention allocation has been proposed as an underlying cause for the failure to yield to other road users (Werneke & Vollrath, 2012). Attention allocation is accomplished through an orienting mechanism (Müller & Rabbitt, 1989; Posner, 1980) and depends on working memory (WM), which keeps information available online for processing purposes (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003; Mongillo, Barak, & Tsodyks, 2008). Available WM capacity however is limited (Lavie, Hirst, de Fockert, & Viding, 2004). Meanwhile, driving is often combined with secondary tasks that increase WM load, leaving less spare WM capacity to devote to the driving task (Lavie, 2010; Recarte & Nunes, 2003; Ross, et al., 2014). Accordingly, WM load degrades driving performance at intersections as shown by increased crash risks and yielding violations (Fu, Pei, Wu, & Qi, 2013; McEvoy, Stevenson, & Woodward, 2007; Neyens & Boyle, 2007). Although it is assumed that increased WM load degrades attention processes, measures distinguishing various information processing stages are necessary to identify the underlying mechanisms of performance degradation (Fort, Collette, Bueno, Deleurence, & Bonnard, 2013). Electroencephalography (EEG), for instance, provides additional on-line information of attentional processes as it is not dependent on a convergence of effects in a single outcome measure, in contrast to reaction time measures (Kessels, Ruiter, & Jansma, 2010). This study therefore aimed to investigate underlying mechanisms of attention orienting at intersections by measuring behavioral responses as well as brain responses (event-related potentials, ERPs).

Spatial cueing tasks are often used to assess attention orienting (Posner, 1980). The rationale behind these tasks is that reaction times are faster and responses are more accurate to stimuli that appear at the cued location (valid trials) than to stimuli that appear at an uncued location (invalid trials) (e.g., Posner, 1978). In addition, previous EEG research indicated event-related potential (ERP) signatures related to spatial and nonspatial processes of attention orienting. A sequence of lateralized components with a positive or negative voltage over the hemisphere contralateral to the direction of the cue has been related to different stages in the control of attention. These include: the early directing attention negativity (EDAN) occurring at posterior sites (200-400 ms after cue onset), the anterior directing attention negativity (ADAN) at frontocentral sites (300-500 ms after cue onset) and the late directing attention positivity (LDAP) at posterior sites (500-700 ms after cue onset) (Jongen, Smulders, & Van Breukelen, 2006; Jongen, Smulders, & van der Heiden, 2007; Murray, Nobre, & Stokes, 2011). The EDAN may represent processing of physical properties from the cue that are relevant for attention orienting. Meanwhile, the ADAN and LDAP are related to attention orienting, but do not rely on physical cue properties (Jongen et al., 2007; Van Velzen & Eimer, 2003). The former relates to frontal cortex top-down control as well as maintenance of spatial redirection of attention, the latter relates to the anticipatory biasing of brain regions involved in location coding and target processing (McDonald & Green, 2008; Vossen, Ross, Jongen, Ruiter, & Smulders, 2016). Subsequently, a sequence of ERP components is evoked in response to the target stimulus over lateral occipital sites consisting of an early P1 component (onset at about 100ms), followed by an N1 component (onset at about 150 ms). Modulatory effects of attention on processing of the target stimulus are reflected by P1 and N1 amplitude enhancements for attended stimuli in comparison to unattended stimuli (Herrmann & Knight, 2001; Luck, Heinze, Mangun, & Hillyard, 1990; Ruiter, Kessels, Jansma, & Brug, 2006). Finally, ERP components related to non-spatial attention indicate attentional selection and cognitive processing of stimulus features (e.g., movement). Selection negativity (SN) is a broad negativity (150–300 ms after stimulus onset) of which the location varies with the nature of the to-be-attended feature. P3 is a late positivity (300 ms after stimulus onset) generated by multiple distributed generators, indicating a cognitive distribution of resources and an update of stimulus processing with WM information. Furthermore, P3 reflects post-perceptual processes necessary for carrying-out the task, albeit not necessary for conscious awareness (Herrmann & Knight, 2001; McGinnis & Keil, 2011; Nobre, Sebestyen, & Miniussi, 2000; Pitts, Padwal, Fennelly, Martínez, & Hillyard, 2014; Ruiter et al., 2006; Shedden & Nordgaard, 2001).

In addition to WM load effects on behavioral measures of attention orienting, the inclusion of ERPs allows the investigation of WM load on underlying attention orienting processes. WM load has been shown to degrade behavioral task performance and/or reduce ERP amplitude, for the primary and/or secondary task (Prinzel, Freeman, Scerbo, Mikulka, & Pope, 2003; Strayer, Drews, & Johnston, 2003; Ullsperger, Freude, & Erdmann, 2000; Wester, Bocker, Volkerts, Verster, & Kenemans, 2008). For instance, Lee, Lee, and Boyle (2009) adapted a cueing task to a complex driving situation where pedestrian crossing-signs predicted pedestrians' spatial location. WM load was introduced by a verbal-auditory task resembling in-vehicle technology (i.e., listen and respond to auditory messages). It was found that WM load delayed attention orienting as was indicated by delayed responses to pedestrians. To investigate underlying mechanisms affected by WM load, Fort and colleagues (2013) used ERP measures while investigating the impact of different warning systems on visual target processing. WM load degraded visual information processing, indicated by an amplitude reduction of N1 and N2/P3. Finally, WM load not only affects responses to changing environments or sudden events, but also continuous driving measures such as steering and speed management (Allen, Marcotte, Rosenthal, & Aponso, 2005; Engström, Johansson, & Östlund, 2005; Ross et al., 2014). For instance, Engström and colleagues (2005) found that WM load resulted in increased lane-keeping performance.

Vossen and colleagues (2016) used a computerized cued attention task resembling an intersection environment to investigate WM load effects on spatial and nonspatial processes of attention orienting. Participants had to covertly (i.e., without moving the eyes) allocate attention to cars appearing on the left-or-right side of an intersection. The instruction was to press a button as quickly as possible whenever a vehicle appearing at the attended location started to move towards the intersection, while stationary cars and moving cars at the unattended location could be ignored. The behavioral response therefore is comparable to yielding. An auditory-verbal version of the memory task employed by de Fockert, Rees, Frith, and Lavie (2001) was used to introduce WM load, requiring participants to remember and respond to a set of digits in an ascending (i.e., low WM load, 01234) or a randomized order (i.e., high WM load, e.g., 03421). ERP results indicated that drivers used the arrow signs to direct their attention. When WM load was high, performance in the memory task and the concurrent attention task decreased. Furthermore, ERP components indicated a delay of attention orienting for high versus low WM load. Despite the driving context, continuous measures of driving performance cannot be included in a static lab environment. These results therefore needed to be replicated in more ecologically valid conditions.

The current study (n 22) was the first to translate a cued attention task to a simulated driving environment to investigate the effect of WM load on spatial and nonspatial processes of attention orienting by analyzing ERPs and behavioral outcomes. This allowed to not only measure WM load effects on behavioral and brain responses (i.e., spatial and non-spatial), but also on a continuous driving measure (i.e., lane-keeping), increasing ecological validity.

2. Methods

2.1. Participants

Twenty-two participants with a preliminary or permanent driver's license (i.e., at least 20 hours of driving experience) were included in this study (12 women; age range: 17-33; *M* age 22.91, *SD* 4.23; *M* experience in kilometers 56,891, *SD* 92,237; experience range: [210 360,365]. For two participants, part of the EEG data was compromised due to technical difficulties, the behavioral response data however were complete and were therefore still included in task performance analyses. All participants gave informed consent and received a gift voucher as well as two cinema tickets, with a total value of €34 ($46 USD), upon completion of the experiment.

2.2. Driving simulator

The experiment was conducted with a fixed-based STISIM M400 (Systems Technology Incorporated) driving simulator including a force feedback steering wheel, brake pedal, accelerator, clutch, and automatic transmission. The virtual environment was displayed on a 180° field screen by a three-part projection system (Fig. 21). Three projectors offered a resolution of 1,024 pixels X 768 pixels, each, and a 60-Hz frame rate. Typical sounds from an engine were added to the simulation. Data were collected at frame rate.

2.3. EEG recording

A BioSemi ActiveTwo System (BioSemi, Amsterdam/NL), with sintered Ag/AgCl electrodes, and an ActiveTwo head cap were used to record reference-free EEG with a sampling rate of 256 Hz. Scalp activity was measured at 64 electrode locations following the international 10-20 system (Fig. 21). Electrode offsets were kept below 40 mV. The EEG signal was re-referenced to the average mastoid signal. Activity related to horizontal and vertical eye movements was recorded from four electrodes (i.e., two at the outer canthi, one above and one below the left eye).

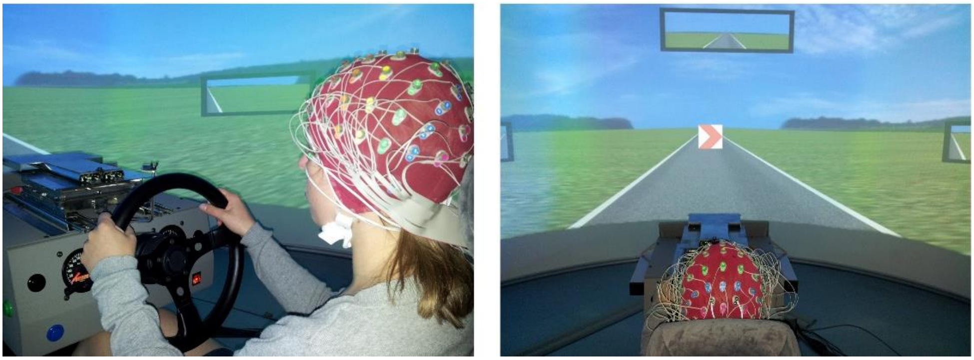

Figure 21: Experimental environment.

2.4. Tasks

2.4.1. Memory task

The memory task was identical to the one from Vossen and colleagues (2016; see also: de Fockert et al., 2001). Participants were presented with verbally recorded digit sets from one to four, recorded at a rate of 43 bpm. In the low WM load condition the order of the digits was fixed (i.e. 01234). In the high WM load condition, the order of the digits was random (e.g. 03421). Each set lasted about 5-6 s. When an auditory probe consisting of a single digit (e.g., 3) was presented, participants had to respond by saying out loud the number that followed this probe in the set they had previously heard (e.g., 4). To be able to use all four digits, sets always started with zero. Therefore, zero could act as a probe but was never the correct response. The next set of digits was presented after a 2 s interval. There were 72 WM load trials per condition (i.e. low and high WM load). Verbal responses were manually recorded by the experimenter.

2.4.2. Simulated attention task

The cued attention task was designed to match Vossen and colleagues (2016) as closely as possible while keeping simulator software limitations into account (e.g., feedback during the experimental trial or reduced luminance of the target were not possible). The simulated driving environment consisted of a one-lane road on which participants responded to yielding situations at 512 unsignalized priority intersection, the most used roadway junction in highway transportation systems (Wu, 2001). The timing (Fig. 22) was adapted from a study investigating similar ERP components of attention orienting (Jongen et al., 2006). At each intersection, a cue in the shape of a red arrow in a white square (i.e., resembling an actual road sign, Fig. 21), was presented for 400 ms. After a CTI of 1,217 ms, the target (car) appeared on the left-or-right side of the road, centered at a visual angle of about 7° from the center of the screen. After a stationary interval of 260 ms, the car either started to move for 34 ms towards the intersection, or remained stationary for 34 ms. After that, stationary and moving cars disappeared (Vossen et al., 2016). Participants were instructed to covertly orient attention towards the side indicated by the arrow, and only respond to moving car stimuli appearing at the location previously indicated by the cue. Although the cues indicated the following task-relevant location, they were non-predictive as to whether an actual target would appear. Cruise control was used to drive at a constant speed (i.e., 70 km/h) to control task timing and minimize EEG artifacts due to movement. A button-press was used to simulate a braking response without reducing speed, and although the horn-button was used, no actual horn was sounded.

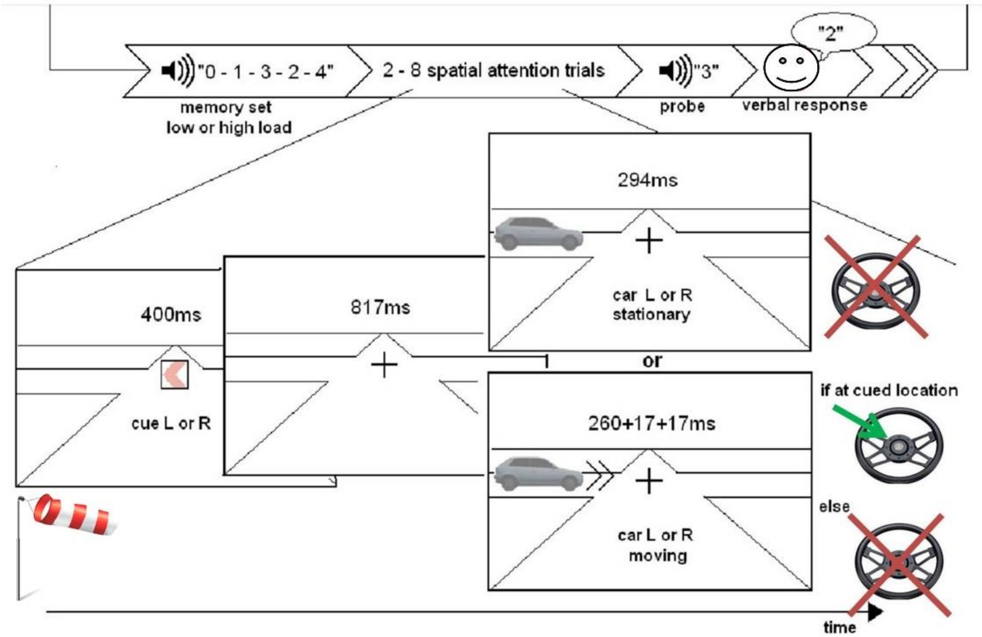

Figure 22: Schematic Representation of the Dual Task (Adapted from Vossen et al., 2016).

2.4.3. Dual task

See figure 22 for a schematic representation of the dual task. The dual task served to manipulate WM load in the simulated attention task. There were eight conditions: cue (2: left, right) X target (2: left, right) X 2 movement (2: stationary, moving). Each condition occurred 32 times under low and high WM load, respectively. The instructions were to respond as quickly and accurately as possible to both tasks. After every memory set, participants performed a variable amount of cueing trials (i.e., 2-8), after which they needed to respond to the probe. Cueing trials were presented in sequences of lengths ranging from two to eight trials in order to keep the probe unexpected so that constant memorization was encouraged. Dual task trials (i.e., a memory set, followed by a number of attention trials, and then the probe) were presented in randomized order. The order of low and high load dual task trials was also randomized.

2.4.4. Horizontal electro-oculogram (HEOG) calibration task

The HEOG calibration task was adapted from (Jongen et al., 2007). Participants had to follow a white dot on a grey background that moved from a central location to the left-or-right side of the screen (i.e., equivalent to the target location in the simulated attention task), as well as 3° up and down (10 trials per condition). The dot returned to the starting position after 1.5 s (Vossen et al., 2016). This task provided a calibration for horizontal eye movements, linking the voltage measurements to lateral movement. Trials with horizontal eye movements could thus be discarded to assure that only trials with covert attention allocation were included.

2.4.5. Continuous driving task

Continuous driving control can be measured by providing a controlled stimulus to the driver or the vehicle and measuring the driver response to those manipulations. Examples of controlled stimuli are, wind gusts, roadway curvature, etc. (Allen et al., 2005). Therefore, to measure lane-keeping performance, wind gusts were added to the driving simulation (van Kessel, Geurts, Brouwer, & Fasotti, 2013) in the form of a variable lateral force (i.e., wave pattern computed by the sum of three sine waves). The wind force was modulated using the sum of three sinusoids at 3, 9, and 18 periods per minute. Participants were instructed to try to remain in the middle of the driving lane, requiring active lane-keeping.

2.5. Procedure

Participants were given a cover story that this study investigated cruise control effects on reaction time. The attention and memory task were practiced separately (40 trials and 60 trials, respectively) and combined (76 dual task trials). Verbal feedback was provided by the experimenter during training and sessions were repeated if the performance level dropped below 80%. No feedback was provided during the experimental trials. The actual experiment consisted of three experimental blocks separated by self-timed breaks and two short (i.e., 5.5 km) regular drives (i.e., rural and urban driving environment) to reduce fatigue effects.

2.6. Preprocessing

EEG data were processed using EEGlab and MATLAB (MathWorks, Natick/US).

2.6.1. Dual task

EEG data were filtered with an FIR filter (0.1-38 Hz). Epochs of 4 s (i.e., a cueing trial) were extracted from 200 ms before cue onset until 1s after car offset. Epochs were baseline corrected by subtracting the average amplitude across the whole epoch. Noisy epochs were removed by visual inspection (*M* % rejected epochs 0.40, *SD* 0.47). Blink and artifact identification/removal was executed with independent component analyses (ICA) (*M* number of rejected components 9.18, *SD* 2.13). Remaining noisy epochs (*M* % rejected epochs 1.30, *SD* 2.36) were removed after a second visual inspection.

2.6.2. HEOG Calibration Task

EEG data were filtered with an FIR filter (0.1-10 Hz). Epochs of 1 s were time-locked to dot movement and baseline corrected (200 ms before). The median amplitude was first calculated per epoch, and then across trials, for left-and-right eye movements separately. Thirty-five percent of the average of left and right medians served as the criterion for detecting horizontal eye movements. Trials were rejected if the bipolar HEOG derivation exceeded this criterion (*M* % rejected epoch 20.18, *SD* 23.07). Two participants were excluded after HEOG correction (i.e., 74% and 75% of the trials were rejected).

2.7. Measurements

Statistical analyses were performed with IBM SPSS statistics 20 software with a significance level of alpha 0.05.

2.7.1 Memory task

The error rate of the verbal responses was calculated on the total sample (n 22) as the percentage of errors in low and high WM load conditions.

2.7.2. Simulated attention task.

Hits and false alarms rates determined sensitivity *d'* (i.e., the distance between signal and noise) and response bias *c* (i.e., favoring a response regardless of the stimulus). Reaction times towards targets, *'d* and *c*, and hit and false alarm rates, for the total sample (n 22) were entered in three repeated measures analyses of variance (RMANOVA) with factor WM load (low/high).

2.7.3. Event-related potentials

Cue ERPs. Epochs related to cue onset were sorted by cue direction and WM load, and were averaged (n 17, *M* number of trials 96.68, *SD* trials 19.50 trials). Averages were pooled across cue locations and assigned as ipsi- or contralateral. Anterior electrode pairs consisted of F7/8, FC5/6 and posterior electrode pairs consisted of P7/8, PO7/8 (Fig. 23 and 24). Electrode pairs were entered in a RMANOVA with factors hemisphere (ipsi-/contralateral), WM load (low/high), and electrode (electrode pairs).

Car ERPs. Trials related to car onset were sorted by cue direction, car location, motion condition, and WM load, and were averaged (n 14, M number of trials 28.70, SD 2.16 trials per condition and participant). Trials were assigned as attended or unattended. Electrode sites over the left-and-right hemisphere were averaged to avoid confounding of target processing by cue-related lateralization's (Jongen et al., 2007). The following electrodes and electrode pairs were investigated: Fz, Cz, Pz, Oz, P7/8, PO7/8 (Fig. 25) and entered in a RMANOVA with factors attention (attended/unattended), WM load (low/high), motion (stationary/moving), and electrode (electrode pairs).

2.7.4. Continuous driving task

Lane-keeping was assessed by calculating the standard deviation of the lateral lane position (SDLP). SDLP is a measure of road tracking precision (i.e., lane-keeping variability) that represents a reliable characteristic of individual driving performance, and is sensitive to driver impairment, for instance due to workload or various drugs (De Waard, 1996; Ramaekers, 2003; Ross et al., 2015). SDLP was collected throughout the entire scenario for the total sample (n 22). The first 500 m (i.e., cruise control initiation) and segments with lane excursions were excluded from the analyses. SDLP was entered in a RMANOVA with factor WM load (low/high).

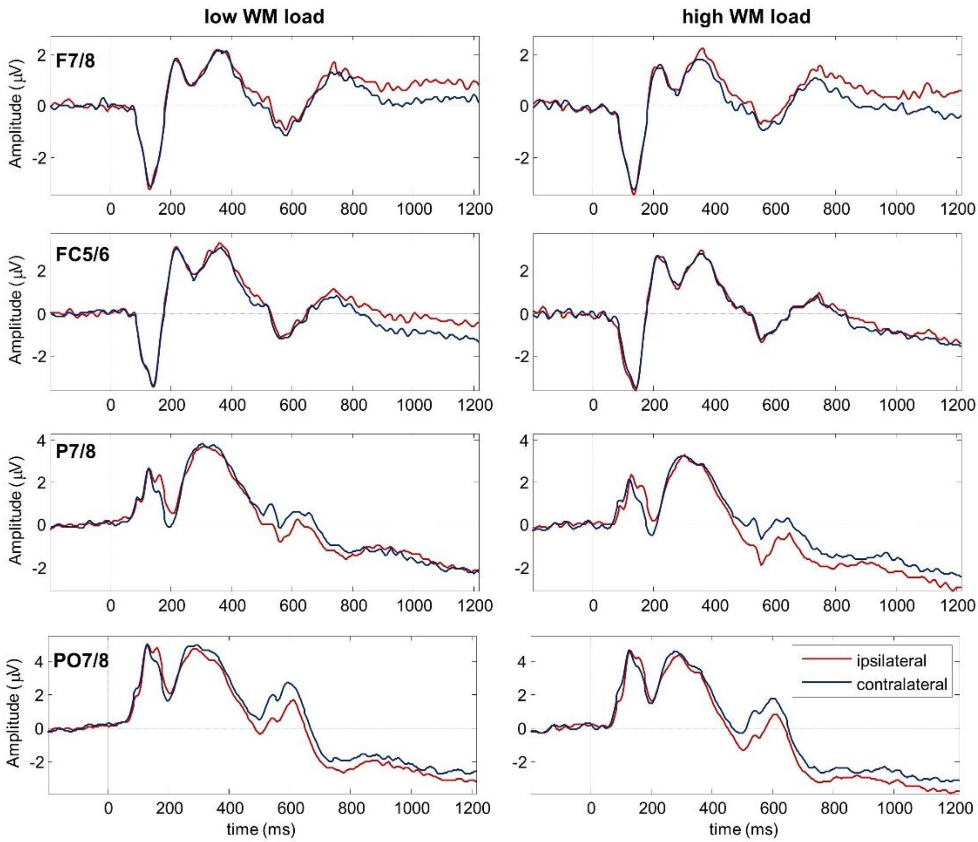

Figure 23: Grand average cue ERPs to the cued direction, under low (left column) and high WM load (right column), recorded ipsilateral (solid line) or contralateral (dotted line) channels.

3. Results

3.1. Dual task

3.1.1. Memory task

Accuracy (% error) in the memory task differed significantly between the low and high WM load condition (low: *M* 2.40, *SD* 2.65; high: *M* 9.41, *SD* 7.07; $F(1,21)$ 23.58, $p < .0005$, $\eta\rho^2$ .529).

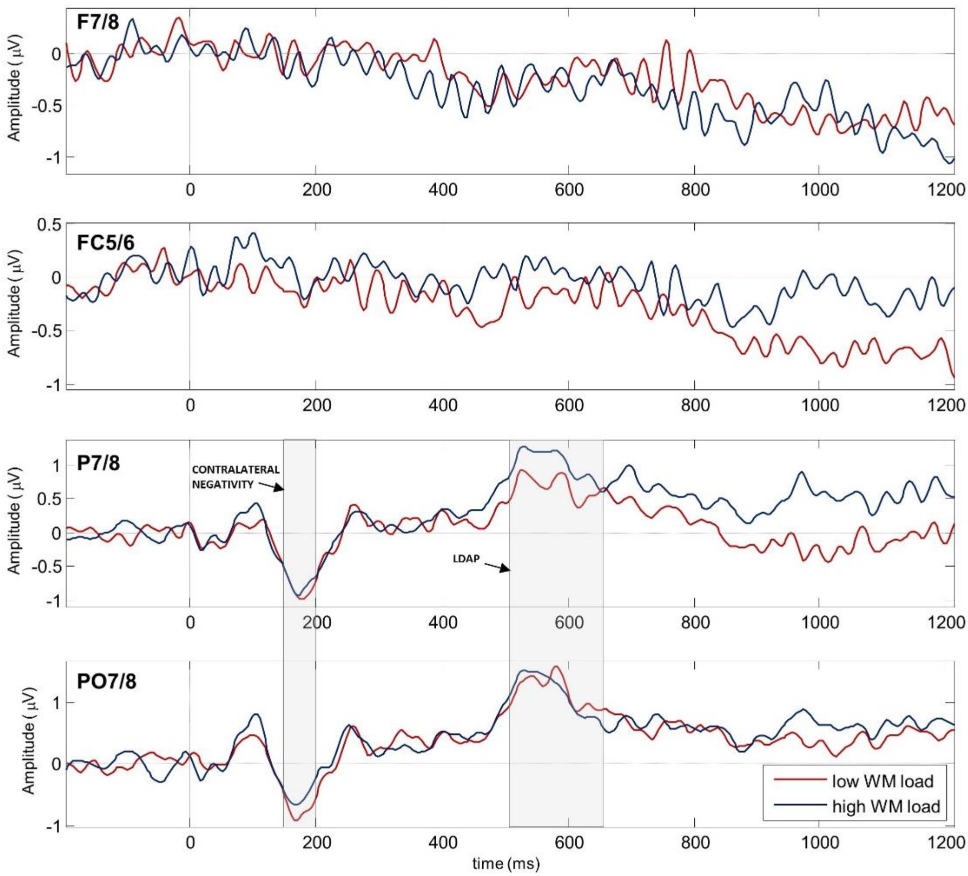

Figure 24: Hemispheric differences in Cue ERPs (contra- minus ipsilateral channels). Grey shaded areas indicate the found components.

3.1.2. Simulated attention task

Reaction times (*Md*, in ms) were unaffected by WM load (low: *M* 454.09, *SD* 55.99; high: *M* 453.18, *SD* 59.05; *F*(1,21) 0.04, *p* .850, $\eta\rho^2$ .002). A trend towards significance was present for *d′* (low: *M* 3.72, *SD* .68; high: *M* 3.50, *SD* .71; *F* 4.09, *p* .056), while *c* did not reach significance (low: *M* .28, *SD* .25; high: *M* .21, *SD* .35; *F* 1.47, *p* .24). With increased WM load, participant thus showed a trend towards decline in detection performance that was not due to a change in response bias. Separate RMANOVA's were conducted to determine whether WM load increased hits and/or false alarms, allowing interpretation in terms of traffic safety implications. Hits were not significantly affected by WM load (low: *M* 92.12%, *SD* 7.00; high: *M* 91.05%, *SD* 8.79; $F(1,21)$ 0.67, *p* .421, $\eta\rho^2$ .031). False alarms however were significantly affected by WM load (low: M 0.57%, SD 0.71; high: *M* 1.16%, *SD* 1.39; $F(1,21)$ 5.70, *p* .026, $\eta\rho^2$ .214), indicating an increase of false alarms under high WM load.

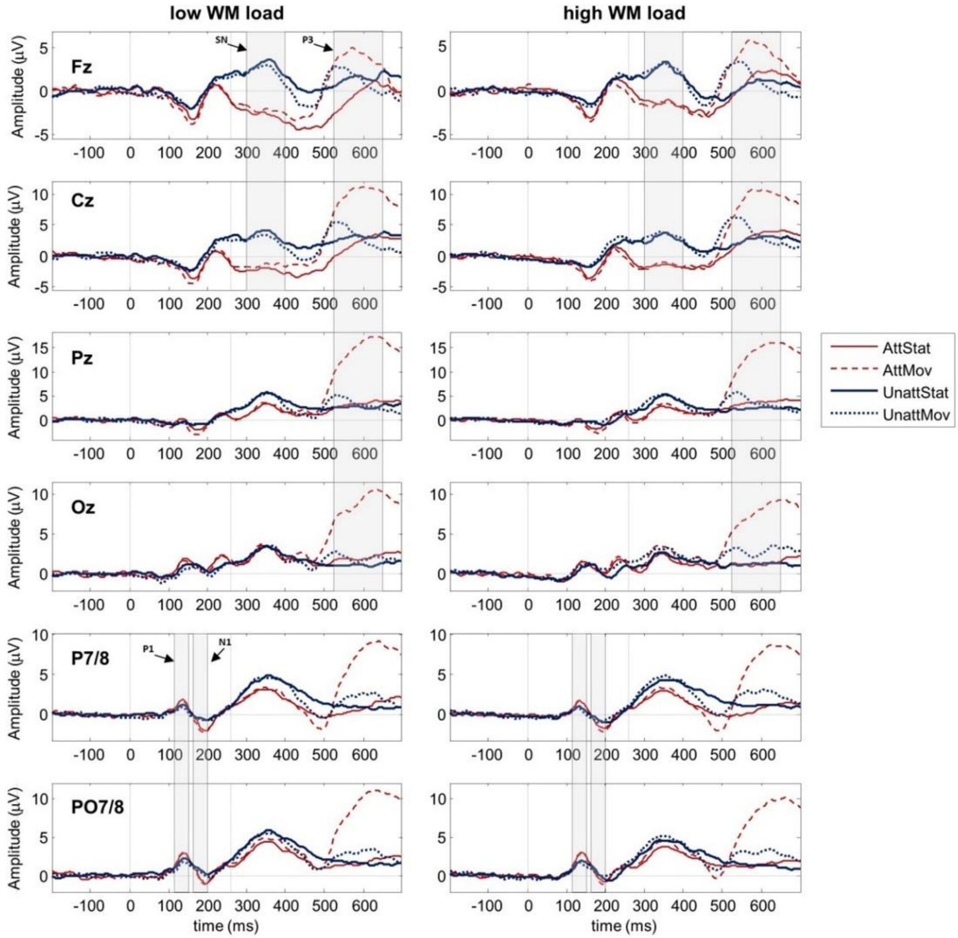

Figure 25: Car ERPs, averaged across ipsi- and contralateral channels, under low (left column) and high WM load (right column). Grey shaded areas indicate the found ERP components.

3.2. Event-related potentials

3.2.1. Cue ERPs

For P7/8 and PO7/8, three time windows were entered into the RMANOVA. An early positive component indicating sensory processing of the arrow cues was not significant (50-100 ms, $F(1,16)$ 0.71, p .413, $\eta\rho^2$ .042). A significant main effect of hemisphere (ipsi vs. contralateral) was the result of a contralateral negativity (150-200 ms, $F(1,16)$ 7.49, p .015, $\eta\rho^2$ .319) and a contralateral positivity (LDAP: 500-650 ms, $F(1,16)$ 40.25, $p < .0005$, $\eta\rho^2$ .716), indicating interpretation of cue direction and directing of attention. No effect of WM load was found. See figure 24 for a visualization of the significant ERP components in response to the cue.

3.2.2. Car ERPs

Four time windows were entered in the RMANOVA. Two main effects of attention contained P1 (120-150 ms, $F(1,13)$ 9.09, p .010, $\eta\rho^2$ .412) and N1 (170-200 ms, $F(1,13)$ 5.97, p .030, $\eta\rho^2$ .315) enhancements for validly versus invalidly cued car stimuli at P7/8 and PO7/8, indicating that target processing was modulated by attention. No WM load effects were found. A main effect of attention was found for SN (300-400 ms, $F(1,13)$ 48.54, $p < .0005$, $\eta\rho^2$ .789) at Fz and Cz, indicating non-spatial processing of target features. Again, no WM load effects were found. Finally, for the last P3 window (520-650 ms) two significant three-way interactions were found (attention by movement by channel, $F(1,13)$ 17.21, $p < .0005$, $\eta\rho^2$ .570; attention by WM load by channel, $F(1,13)$ 5.89, p .011, $\eta\rho^2$ .321). Therefore, RMANOVA's were conducted per channel (Fz, Cz, Pz and Oz), with factors attention (attended/unattended), WM load (low/high) and movement (stationary/moving). Significant interactions between attention and movement (Table 8) were found for all four channels indicating that an increase in P3 amplitude for moving as opposed to stationary cars was greater at attended than at unattended locations. A significant interaction between attention and WM load (Table 8) was found at Oz, indicating that an increase in P3 amplitude for attended as opposed to unattended cars was smaller under high than under low WM load conditions. The same interaction at Fz just missed significance (an additional ANOVA showed no significant effect of attention per load condition). See figure 25 for a visualization of the significant ERP components in response to the car, under low and high WM load.

Table 8: P3 means and standard errors describing Attention by Movement (Att X Mov) and Attention by Load (Att X Load) contrasts; El = electrode, Con = Condition, AS = Attended Stationary, AM = Attended Moving, US = Unattended Stationary, UM = Unattended Moving, AL = Attended Low load, AH = Attended High load, UL = Unattended Low load, UH = Unattended High load; $^{*}p < .05$.

		Att X Mov						Att X Load			
El	**Con**	**M**	**SE**	**F**	**p**	**El**	**Con**	**M**	**SE**	**F**	**p**
Fz	**AS**	.478	1.38	10.10	.01*	**Fz**	**AL**	1.74	1.32	4.50	.05*
	AM	4.32	1.31				**AH**	3.05	1.24		
	US	1.07	.64				**UL**	1.39	.71		
	UM	1.52	.79				**UH**	1.21	.78		
Cz	**AS**	2.55	1.43	22.13	.00*	**Cz**	**AL**	6.04	1.50	.02	.90
	AM	9.81	1.81				**AH**	6.29	1.51		
	US	2.87	.88				**UL**	3.16	1.36		
	UM	3.60	1.03				**UH**	3.30	1.26		
Pz	**AS**	3.40	1.28	77.79	.00*	**Pz**	**AL**	9.05	1.62	.20	.67
	AM	14.28	2.13				**AH**	8.63	1.70		
	US	2.48	.78				**UL**	3.08	.74		
	UM	3.71	.81				**UH**	3.11	.90		
Oz	**AS**	1.60	.85	63.76	.00*	**Oz**	**AL**	5.42	.97	6.16	.03*
	AM	8.24	1.26				**AH**	4.41	1.00		
	US	1.17	.39				**UL**	1.55	.48		
	UM	2.45	.43				**UH**	2.06	.40		

3.3. Continuous Driving

Compared to the low WM load condition, SDLP decreased significantly in the high WM load condition indicating increased lane-keeping performance with increased WM load (low: *M* 0.040, *SD* 0.01; high: *M* 0.037, *SD* 0.01; *F* 9.09, *p* .01).

4. Discussion

This study (n 22) was the first to investigate the effect of WM load on spatial and nonspatial processes of attention orienting in a simulated driving environment by analyzing ERPs and behavioral outcomes, while including a continuous measure of driving performance (i.e., lane-keeping). Results showed that typical ERP markers of attention orienting that are usually observed in laboratory tasks were also present in a simulated driving environment. In accordance with Vossen and colleagues (2016), we found markers in response to the cue (contralateral negativity and LDAP), attentional modulation of the target (P1, N1 and SN), and target-evaluation in response to movement (P3). Similar to Vossen and colleagues (2016), the effect of movement onset was larger at attended than at unattended locations, indicating an effective filtering mechanism. The early negativity appeared too early (i.e., 150-200 ms) to be considered an EDAN (Jongen et al., 2007; Murray et al., 2011). Therefore, similar to Jongen and colleagues (Jongen et al., 2006; Jongen et al., 2007), we interpret it as an early posterior component related to sensory aspects of the cue but not to attention orienting. Contrary to Vossen and colleagues (2016), an ADAN in response to the cue, reflecting the programming and initiation of attention shifts (Eimer, 2014), was lacking. The ADAN is usually considered a modality-unspecific attentional control mechanism that is mainly related to attention orienting. Recent studies however questioned this assumption, or ascribed more functionality to the occurrence of an ADAN (Talsma, Sikkens, & Theeuwes, 2011). The absence of an ADAN in the current study is consistent with the notion that ADAN reflects another process than attention orienting (Green, Conder, & Mc Donald, 2008; Praamstra, Boutsen, & Humphreys, 2005; van der Lubbe, Neggers, Verleger, & Kenemans, 2006). Research from van der Lubbe and colleagues (2006) indicated that the presence of ADAN reflects saccadic inhibition as participants need to inhibit eye movements towards target appearance. Or, as van der Lubbe and colleagues (2006) state: "Ah, the right side is relevant" (EDAN); "… I shouldn't look at the right…" (ADAN); "but focus my attention over there" (LDAP)." Although speculative, it is possible that the instruction to stay in the middle of the lane increased the ease to concentrate on the middle of the road, thereby automatically inhibiting the tendency to look at relevant target locations.

The error rate on the memory task, and the false alarm rate on the simulated attention task, increased under high WM load. This resembles previous research indicating that WM load degrades attention (Lee et al., 2009; Vossen et al., 2016). With respect to the simulated attention task, participants tended to respond more liberally. Possibly, participants were unsure whether the car was a target or not, and decided to respond 'just in case' it would be. Translated to real driving, in case of high WM load and ensuing doubt, drivers have an increased tendency to yield, thereby increasing their safety margins (as found previously under conditions of increased WM load; Engström et al., 2005; Son, Lee, & Kim, 2011) and reducing chances for crossing-path crashes. Therefore, the increased tendency to yield might be a compensatory strategy to deal with reduced resources to devote to the task. In this way, traffic safety would not be directly compromised by the increased WM load. Nevertheless, traffic flow will be reduced when drivers stop at inappropriate times. Indeed, albeit most pronounced for distraction induced by texting, distraction introduced by WM load (i.e., talking on the phone) negatively influenced traffic flow in a study from Stavrinos and colleagues (2013). Importantly, as reduced traffic flow might lead to congestion, traffic safety could be indirectly affected in case the increased proximity of following-vehicles leads to 'secondary crashes' (e.g., multiple-vehicle crashes) (Stavrinos et al., 2013), which is supported by an increased likelihood of rear-end-crashes in teen drivers under conditions of increased WM load (Neyens & Boyle, 2007).

The results showed no effects of WM load on ERP responses to the cue, which is in contrast to Vossen and colleagues (2016) who found WM load effects on markers of orienting that indicated decreased processing of the cue. However, these effects concerned modulations of ADAN and EDAN, components that did not appear to begin with in the current study. Similar to Vossen and colleagues (2016), WM load did not affect markers of nonspatial orienting in response to the target. Finally, in contrast to Vossen and colleagues (2016), WM load decreased attentional resources available for processing a salient task-relevant event, as indicated by a reduced P3 in the high WM load condition. The current P3 reduction was only found for Oz, which resembles results of Pinal, Zurrón, and Díaz (2014) where, as deducted from Figure 25, WM load effects during retrieval in a cognitive task (i.e. delayed matching to sample task) mainly reduced P3 amplitude in occipital regions. As no WM load effects were found when the cue indicated the to-be-attended side (i.e., resembling a road sign indicating right-of-way) or when the car appeared (i.e., simulating an approaching car), WM load only affected later stages of decision-making (i.e., does the approaching car have right-of-way). This phase probably required more baseline attentional resources as a decision to act or not needs to be taken, in contrast to the earlier phases only including the processing of stimulus properties and attention orienting. According to task-description, as well as latency and scalp topography, the current results could contain a decrease in P3b. The P3b is a late central-parietal component (~400-700ms) indicating categorization, the update of working memory, or monitoring of decision-making (Bruder, Kayser, & Tenke, 2009; Verleger, Jaskowski, & Wascher, 2005). Furthermore, P3b is elicited when being presented with stimuli of unequal probability, and attention needs to be paid to the infrequent ones (Fjell & Walhovd, 2003). This coincides with research where WM load decreased P3b in response to a sign indicating the direction of a required lane change (550 ms post-stimulus) (Lei, Welke, & Roetting, 2009).

In line with previous research (Cuenen et al., 2015; Engström et al., 2005; He, McCarley, & Kramer, 2014), the SDLP measurement indicated improved lane-keeping performance with increasing WM load. There are two prevailing theories to explain this effect (Lemercier et al., 2014). First, increased lane-keeping is accompanied by reduced visual scanning, indicating attention decrement (Reimer, 2009). Second, it signals the prioritization of driving over the memory task, indicating improved performance (Becic et al., 2010; Engström et al., 2005). Recent research favors the latter. First, WM load was found to relate to increased lane-keeping performance independently of eye movements during a simulated drive (Cooper, Medeiros-Ward, & Strayer, 2013). Second, He and colleagues

(2014) let participants perform a simulated lane-keeping task under conditions of lateral wind, finding a similar increase in lane-keeping. An increased coupling of steering-to-lateral-winds under high WM load suggested that the increased lane-keeping indicated true improvement in lateral control. Therefore, participants in our study likely compensated for increasing WM load by prioritizing lane-keeping. As in He and colleagues (2014), it is still not clear why drivers would selectively protect lateral control as participants were not instructed to prioritize lane-keeping. However, there also is a chance that drivers did not voluntarily and consciously prioritized lane-keeping but rather performed automatically due to the lack of available WM capacity to be devoted to the task. Cooper and colleagues (2013) suggested that under conditions of high WM load, lane-keeping becomes an encapsulated inner-loop process requiring minimal attention, a process they describe as being similar to the swing of professional golf players which has been found to degrade when attention is paid to it (Cooper et al., 2013).

5. Limitations

First, questions can be raised concerning the ecological validity of these results as the driving context was rather simplistic, while driving through intersections in real-life can be extremely complicated. The simplified nature of the driving task allowed us to investigate ERPs related to spatial and nonspatial processes of attention orienting, which would otherwise be compromised by movement. The choice of a simplistic scenario can be further supported by a driving simulator study (Werneke & Vollrath, 2012) that found the highest level of crashes at the least complicated intersections and attributed this result to inadequate attention allocation. Second, to reduce fatigue effects (i.e., the current procedure already took three to four hours) the study lacked a condition without WM load. As the low WM load condition was already quite demanding due to the combination with the attention task, and active lane-keeping, an alternative, truly non-demanding, baseline condition might have revealed additional effects of WM load. Nevertheless, this situation more closely resembles true driving which is executed in a dynamic and complex environment requiring vehicle control in changing circumstances. Third, as a crash would discontinue cruise control, vehicles owning right-of-way did not complete their maneuver to drive onto the road. A study from China indicated that drivers decide to yield 1.3-1.5 s before reaching the merging point at unsignalized intersections (i.e., no priority control) (Liu, Lu, Wang, Wang, & Zhang, 2013), leaving a time-window between the decision and the event. From the current results, it is not possible to determine how drivers might have reacted during this limited time-gap from brake-onset to the merging point. It is possible however that drivers initially brake but continue driving when they realize the error (i.e., false alarm). Transferred to driving, if the driver owning right-of-way assumes that the other driver will stop, the risk of a crossing-path crash increases.

6. Recommendations

Intersection driver-support systems have been used to improve traffic safety, and recently also traffic flow (e.g., Chen, Cao, & Logan, 2011; Dotzauer, de Waard, Caljouw, Pöhler, & Brouwer, 2015). Still, in-vehicle systems induce WM load, even without using visual stimuli (Becic, Manser, Creaser, & Donath, 2012; Becic, Manser, Drucker, & Donath, 2013; Solovey, Zec, Perez, Reimer, & Mehler, 2014). As this could increase the tendency to yield, affecting traffic flow, the effectiveness of such systems might be reduced. Including EEG measurement to intersection driver-support systems would allow to assess the WM load of drivers (Lei et al., 2009). Previous research already investigated the use of ERPs to measure WM load with the use of a secondary task (Coleman, Turrill, Hopman, Cooper, & Strayer, 2015; Lei et al., 2009). For instance, Coleman and colleagues (2015) found an increased P3 latency, together with a reduced P3 amplitude, in a signal detection task when drivers interact with in-vehicle voice-command systems resembling varying levels of WM load. Nevertheless, including secondary tasks to measure WM load is not advisable as it would divert attention away from the primary task of driving. With respect to yielding situations however, the current results show that it is possible to identify WM load based on the driving task itself, indicated by a reduced P3 in response to a vehicle owning right-of-way. The use of ERPs in response to the driving task to measure WM load is further supported by previous research indicating a reduction of P3 amplitude, elicited by brake lights of a leading vehicle in a car-following-task, while drivers were talking on the phone (Strayer & Drews, 2007). A major concern however concerns the practical applicability. Although wireless EEG systems are available, further advances in measurement and analysis are necessary to implement them in driver-support systems (Haufe, et al., 2011). Furthermore, in the study from Coleman and colleagues (2015), there was a degradation of signal quality due to increased environmental noise (e.g., computers), making the transfer to on-road driving, where even more noise will be present, challenging.

7. Conclusion

The current results confirm that attention orienting depends on available WM capacity (Lavie, 2010; Ross et al., 2014). Although lane-keeping increased under high WM load, task performance decreased as indicated by an increased error rate in the memory task, increased tendency to inappropriately yield in the simulated attention task, and a smaller P3 in response to movement. Furthermore, this study confirmed that typical markers of attention orienting can be found in more ecologically valid settings. Although further applications in even more realistic driving environments are called for, the current results support the usefulness of ERPs in WM load measurement during driving.

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CHAPTER 3

Applied Neuropsychology-Adult, 22 (1), p. 61-72

The relation between cognitive control and risky driving in young novice drivers.

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In the following chapter, I was involved in the design and methodological execution, data collection, analyses, and dissemination (presentation at conferences and writing of the paper).

Abstract

This study investigated if decreased cognitive control, reflected in response inhibition and working memory performance, is an underlying mechanism of risky driving in young, novice drivers. Thirty-eight participants aged 17 to 25 years, with less than one year of driving experience, completed a simulated drive that included several risky driving measures. Measures of response inhibition and verbal working memory were negatively associated with the standard deviation of the lateral lane position. Response inhibition, but not working memory, was also negatively related with the detection of, reaction to, and crashes with road hazards. Unexpectedly, increased cognitive control did not always relate to decreased risky driving. Visuospatial working memory performance related positively with yellow light running and negatively with the minimal following distance inside the city center. The findings evidence the role of cognitive control in explaining risky driving in young, novice drivers. This relationship, however, differed per cognitive function and per driving parameter. Implications for future research and traffic safety interventions are discussed.

Keywords: Cognitive control, response inhibition, working memory, young novice drivers, risky driving

1. Introduction

Background

Adolescence is a developmental period characterized by impulsive and risky choices. Adolescents engage in more risky behavior than adults. Indeed, the greatest threats to the wellbeing of young people in industrialized societies come from preventable and often self-inflicted causes, including automobile accidents (Casey, Jones & Somerville, 2011). Risky driving can be a threat to individuals themselves as well as to other road users. It is therefore necessary to reduce risky driving behavior to improve the overall wellbeing of the population (Steinberg, 2008). Safety programs and policies, such as GDL (Vanlaar, Mayhew, Marcoux, Wets, Brijs & Shope, 2009), have caused ample improvements in the rates of crashes, injuries and fatalities among adolescent drivers. Still the crash and injury risks are unacceptably high (Keating & Halpern-Felsher, 2008) as risks for novice drivers up to 24 years old are two to three times higher when compared to experienced drivers (SafetyNet, 2009). In order to develop interventions that target mechanisms of risky driving behavior rather than restricting risk-facilitating circumstances (i.e., the core of GDL programs), knowledge about the underlying mechanisms of risky driving among young novice drivers is crucial.

An important factor that helps to explain the high incidence of traffic related injuries and fatalities in adolescents is a lack of driving experience, including experience to recognize, assess, and respond to hazards (McKnight & McKnight, 2003; Sleet, Ballesteros & Borse, 2010). Crash rates among young novice drivers are highest in the first months after licensure. These rates drop considerably in the first two driving years with the most pronounced declines in the first six months (Mayhew, Simpson & Pak, 2003). Another possible reason for the high incidence of adolescent traffic related injury and fatality, and the focus of our study, is cognitive control.

Cognitive control refers to the ability to coordinate thoughts and actions in accordance with short- and long-term goals, and in response to changing environmental demands (Brass, Derrfuss, Forstmann & von Cramon, 2005; Crone & Dahl, 2012; Koechlin, Ody & Kouneiher, 2003). Response inhibition and working memory are both important control functions. Response inhibition refers to the ability to withhold inappropriate response tendencies which allows to be guided by task goals. These inappropriate responses can be dominant, reflexive to external stimuli, or learned and automatic (Bunge & Crone, 2009; Hofmann, Schmeichel & Baddeley, 2012; Luna, Padmanabhan & O'Hearn, 2010). Working memory refers to the ability to temporarily keep information activated to carry out an immediate goal and is important for various cognitive capacities, such as problem solving (Anderson, 2008; Klingberg, Forssberg & Westerberg, 2002; Mongillo, Barak & Tsodyks, 2008). Different working memory storage types can be discriminated, visuospatial and verbal working memory (Wager & Smith, 2003). Visuospatial working memory is responsible for processing and storing of visual and spatial information. Verbal working memory is responsible for processing and storing of verbal and auditory information (Koppenol-Gonzalez, Bouwmeester, Vermunt, 2012).

Driving is a complex, goal directed task that places high demands on perceptual, cognitive and motor processes (Groeger, 2000). This complexity suggests that driving requires the use of cognitive control to promote safe driving in normal and risky circumstances. Former studies already found relations between measures of cognitive control and driving performance (Adrian, Postal, Moessinger, Rascle & Charles, 2011; Freund, Gravenstein, Ferris, Burke & Shaheen, 2005; Isler, Starkey & Sheppard, 2011; Jongen, Brijs, Komlos, Brijs & Wets, 2011; Mäntylä, Karlsson & Marklund, 2009). For instance, in a previous study from Jongen et al. (2011), a group of adolescents (i.e., 17-18 years) and a group of young adults (i.e., 22-24 years) participated in a small-fidelity driving simulator study. Across groups, drivers with lower response inhibition displayed a higher standard deviation of the lane position (SDLP). SDLP is an index of road tracking precision (Ramaekers, 2003), which is considered a highly reliable characteristic of individual driving performance (O'Hanlon & Ramaekers, 1995; Vuurman, Theunissen, van Oers, van Leeuwen & Jolles, 2007; Wester, Bocker, Volkerts, Verster & Kenemans, 2008) and provides a sensitive measure of driver impairment (e.g., due to drugs or mental workload; De Waard, 1996; Ramaekers, 2003). Mäntylä et al. (2009) found a negative relation between working memory performance and lateral deviations in a PC-setting based study of 15-19 years old participants. This study only included verbal working memory performance. Meanwhile, driving relies heavily on visuospatial abilities (Anstey, Horswill, Wood & Hatherly, 2012; Marmeleira, Ferreira, Godinho & Fernandes, 2007; Uc et al., 2009; Underwood, 2007). The above findings suggest that increases in response inhibition and working memory performance might relate to decreased risky driving.

Aim of the study

This study aimed to further investigate the relation between cognitive control and driving performance of young novice drivers. It extends on previous research of Mäntylä et al. (2009) and Jongen et al. (2011) as risky driving was measured in a medium-fidelity driving simulator, both response inhibition and working memory were measured and visuospatial working memory was added to a measure of verbal working memory. Furthermore, in addition to SDLP, a broader set of risky driving measures were investigated: speeding, responses to red and yellow traffic lights, responses to road hazards, and the following distance to slow vehicles. Finally, age, driving experience and gender were assessed and included in the analyses. Due to the complexity of the driving task, it was hypothesized that individual differences in the level of cognitive control are related to differences in risky driving. More specifically, we predicted that young novice drivers with lower cognitive control levels (i.e., decreased response inhibition and working memory performance) show an increased SDLP and exceed the speed limit more often. In addition, it was predicted that they show increased risky driving in response to traffic lights (i.e., increased red and yellow light running), to hazards (i.e., more collisions and slower reaction times), and to slow vehicles (i.e., decreased following distance) during a driving simulation.

2. Methods

2.1. Participants

Three inclusion criteria were used to recruit participants: (1) age between 17 and 25 years (2) permanent driving license, and (3) no more than 12 months driving experience. All participants were Belgian with driving experience in the Flemish part of Belgium. The sample consisted of 38 participants (18 women; *M* age 19.3, *SD* 2.32; *M* experience in kilometers 2580.76, *SD* 2615.75; *M* months license 4.31, *SD* 2.84). All participants gave informed consent and received two cinema tickets for their participation with a total value of €14.

2.2. Cognitive tasks

Four cognitive tasks were administered. Response inhibition was measured with two tasks. First, the stop signal paradigm was used to replicate the results of Jongen et al. (2011). Second, the cued go/no-go task was used as an extension to determine if the relation between response inhibition and risky driving could be repeated, or if it this relation was task dependent. Two tasks, derived from Klingberg et al. (2002) and Houben, Wiers & Jansen (2011b) who used them for assessment and training purposes, measured visuospatial and verbal working memory respectively.

2.2.1. Stop signal task

The stop signal paradigm was adapted from Jongen et al. (2011) (see also: Logan & Cowan, 1984; for a review, see Verbruggen & Logan, 2008). This task included two practice sessions (40 trials each) and one experimental session (96 trials). In each session, a two-choice reaction time task was used requiring participants to press a button (left or right) in response to a stimulus ('X' or 'O') presented centrally on screen. In each trial, after 1000ms, a fixation cross was presented for 500ms. After this, stimuli that required a response 150-1000ms after onset were presented for 1000ms. This first practice session served to determine the individual speed level, which was used as a reference for the second practice and the experimental session. These sessions consisted of the same two-choice reaction time task, but on a randomly selected 25% of the trials, an auditory stimulus (1000Hz, 70dB, 100ms) was presented in addition to the visual primary task stimulus. Presentation of this tone designated that the subject was to refrain from responding to the stimulus on that trial. Importantly, the time interval between the stimulus and the stop signal was initially set 50ms below the individual speed level. Subsequently the interval varied dynamically, according to a staircase algorithm, to converge on a stop signal delay at which the probability of stopping is 50%. Stop signal delay was increased by 50ms if the response was withheld and decreased by 50ms when it was not.

2.2.2. Cued go/no-go task

The cued go/no-go task (Fillmore, Rush & Hays, 2006) is based on the assumption that response inhibition can depend strongly on cues. Inhibiting a response to a no-go cue is much more difficult when preceded by go cues in comparison to when preceded by no-go cues, indicating that it is more challenging to inhibit predominant responses (Fillmore et al., 2006).

A trial involved the following sequence: (a) presentation of a fixation point (+) for 200ms; (b) a blank white screen for 500ms; (c) a cue, displayed for a variable duration (100, 200, 300, 400 or 500ms); (d) a go or no-go target, which remained visible until a response occurred or 500ms had elapsed; and (e) an intertrial interval (ITI) of 50ms. The cue was a rectangle, the orientation of the cue signaled the probability of a go or no-go target. Vertical cues preceded the go target on 80% (valid go cue) of the trials and the no-go target on 20% (invalid go cue) of the trials. Horizontal cues preceded the no-go target on 80% (valid no-go cue) of the trials and preceded the go target on 20% (invalid no-go cue) of the trials. Vertical cues thus served as go cues while horizontal cues served as no-go cues. The targets were displayed as a solid hue that filled the rectangle (i.e., the cue): go targets were presented in green while no-go targets were presented in blue. Participants were instructed to press the space bar with the index finger of their preferred hand when a go target appeared, and to refrain from responding when a no-go target appeared. Variable and random stimulus onset asynchronies (SOAs) between the cues and targets served to encourage participants to pay attention to the cues and prevent them from anticipating the exact onset of the targets. The test session consisted of 250 trials and was preceded by a practice session of 50 trials.

This cued go/no-go task differed from the version used by Fillmore et al. (2006) in two parameters[1]: 1) ITI was lowered from 700ms to 50ms; 2) stimulus duration was lowered from 1000ms to 500ms.

2.2.3. Visuospatial working memory: visuospatial span task

In the visuospatial span task (Houben et al., 2011b), 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 the sequences on two consecutive trials, the task stopped.

2.2.4. Verbal working memory: backward digit span task

In the backward digit span task (Houben et al., 2011b), a consecutive sequence of numbers was presented on screen. Participants were instructed to remember these numbers and reproduce them in reversed order by clicking the respective number in a grid that displayed the numbers one to nine. 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 the sequences on two consecutive trials, the task stopped.

2.3. Driving task

Before starting the 25 km long experimental driving task, participants completed an 8 km long practice session to familiarize them with accelerating, braking and shifting in the driving simulator. Both practice and experimental sessions consisted of daylight driving scenarios on a two-lane road. Both inner and outer city sections were included with speed limits of respectively 50, 70 and 90 km/h. The road design was based on Flemish standards.

Several measures of risky driving, which based on literature all relate to traffic safety, were included. SDLP was collected throughout the entire scenario. As mentioned in the introduction, this index of road tracking precision (Ramaekers,

2003) is a reliable characteristic of driving behavior. Driving speed was collected since adolescent drivers are more likely to engage in excessive speeding (Allen & Brown, 2008). Young drivers are also more likely to run lights (Adu-Frema, Perrino & Saka, 1997; Jonah, 1986; Masten, 2004). Therefore, 24 traffic lights were calibrated to change based on the approaching vehicle's speed. The drive entailed 10 yellow, 3 red and 11 green lights. The latter made participants less suspicious to the research intentions, red and yellow light running. The simulator calculates Time to Stop Line (TSL) values (i.e., time for a vehicle to reach the intersection stop line without braking or accelerating). Based on Caird, Chisholm, Edwards and Creaser (2007), pilot testing started with TSL being 2610ms. At this value, however, the majority of drivers in the pilot test crossed all or most yellow lights. Therefore, lights were programmed to change from green to yellow with TSL values between 2700 and 3600ms. There are differences in the capabilities of novice drivers and experienced drivers to identify and respond to hazards (Deery, 1999; Isler, Starkey & Williamson, 2009; McKenna & Crick, 1991; Scialfa et al., 2011). For this reason, the scenario entailed 10 hazards that consisted of unexpected vehicles and pedestrians. These were calibrated so that participants could avoid crashes if they braked (i.e., while driving at speed limit) or if they steered around the obstacle. Finally, following too closely behind a leading vehicle can be considered an important contributor to rear end collisions (Lee, 2006). In a study from Bina, Graziano and Bonino (2006), 49% of young drivers did not adopt safe braking distances. The current scenario entailed four slow vehicles to measure following distance. Inside the city center, where the speed limit was 50 km/h, the speed of slow vehicles was fixed at 35 km/h. Outside the city center, where the speed limit was 70 km/h, speed was fixed at 55 km/h.

2.4. Driving simulator

The experiment was conducted on a fixed based STISIM M400 (Systems Technology Incorporated) driving simulator with a force feedback steering wheel, brake pedal, accelerator, clutch, and manual transmission. The virtual environment was displayed on a 180° wide screen by a 3-part projection system and typical sounds from an engine were added to the simulation. Three projectors offer a resolution of 1024X768 pixels and a 60Hz frame rate. Data were collected at frame rate.

2.5. Procedure

Half of the participants started with the go/no-go task while the other half started with the working memory tasks. The warm up drive and the experimental drive were conducted afterwards. The stop signal task was always presented last to avoid impact on the other measures[2].

2.6. Data collection

2.6.1. Stop signal task

The stop signal reaction time (SSRT) is the time participants need to inhibit their predominant response after hearing the stop signal. This measure can be derived by subtracting the average stop signal delay from the average reaction time (Verbruggen & Logan, 2008). A longer SSRT therefore indicates decreased response inhibition.

2.6.2. Cued go/no-go task

Response inhibition failure was measured as the percentage of no-go targets preceded by an invalid cue to which participants could not inhibit their response (key press). This measure was dichotomized (0 = no errors, 1 = at least one error) given the low rate of errors, the maximum amount of invalid no-go errors was four (i.e., 60.5% of the participants made no errors). The making of invalid no-go errors indicated decreased response inhibition.

2.6.3. Working memory tasks

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 for both tasks. A lower performance level indicated decreased working memory performance.

2.6.4. Driving task

To calculate SDLP, the standard deviation of the lateral position was averaged across the entire ride, excluding segments with traffic lights, hazards, slow vehicles, curves and lane crossings. Speeding was measured as the percentage of distance that participants exceeded the speed limit in segments with a speed limit of 50, 70 and 90 km/h. For traffic lights, the number of times the drivers ran a yellow or red light was measured. Since only one participant ran one red light, red light running was not further analyzed3. The number of collisions with, and the response to, hazards were measured. Responses were characterized by three values (Shinar, 2007): perception reaction time (i.e., onset throttle release relative to onset of the hazard), movement time (i.e., onset of braking relative to the onset of throttle release) and the total braking reaction time (i.e., onset of braking relative to the onset of the hazard). To characterize car following, the minimum following distance behind each of the slow vehicles inside and outside the city center was measured.

2.7. Design

A within subjects design was used. Independent variables were SSRT, invalidly cued no-go errors and two working memory span levels (i.e., visuospatial and verbal). As dependent variables, the following risky driving measures were included: SDLP, percentage of distance over the speed limit in segments with a speed limit of 50, 70 and 90 km/h, yellow light crossings, collisions with, and perception reaction time, movement time and total braking reaction time to hazards and minimal following distance to slow vehicles inside and outside the city center.

2.8. Data analyses

Pearson's coefficient r, was used as a correlation measure with a significance value of .05. One-tailed tests were used given the hypotheses on the direction of the relations between study variables. Multiple regression analyses were performed separately for each risky driving measure to determine the unique contribution of significant univariate correlates. By only including measures of response inhibition and working memory performance that were significantly univariately correlated with the outcome measure, an optimal tradeoff between statistical power (i.e., including all variables would reduce power) and completeness (i.e., not excluding important variables) was ensured. If age, gender and driving experience correlated significantly with driving performance measures, they were also entered in the model to determine the unique contribution of cognitive control functions while controlling for their effects. Both age and experience were dichotomized to correct for non-normality of the data with '0' indicating below the median and '1' indicating above the median.

3. Results

Table 9 gives an overview of the descriptive statistics. The table provides the mean, median, standard deviation (*SD*), minimum and maximum values for each of the independent and dependent variables. In this table, invalid no-go errors are depicted as a percentage, in the remaining part of the article refers to the dichotomized no-go errors.

Table 9: Descriptive Statistics. SSRT: stop signal reaction time; No-go errors: only the errors with an invalid cue were included; VSWM: visuospatial working memory; VWM: verbal working memory; SDLP: standard deviation of lateral lane position; Speeding: percentage of distance driven over the speed limit in zones 50, 70 and 90 km/h; Yellow lights: number of yellow light running's; Collisions: amount of crashes; PRT: perception reaction time; MT: movement time; TBRT: total braking reaction time; Following: minimal following distance to lead vehicle inside and outside the city centre.

Measure	Mean	Median	SD	Minimum	Maximum
SSRT (ms)	214.53	209.41	38.62	142.53	334.78
No-go errors (%)	3.05	0	4.69	0	16
VSWM (level)	6.84	7	1.03	4	9
VWM (level)	6.47	6	1.35	3	10
SDLP (m)	0.2	0.19	0.04	0.13	0.35
Speeding (%> 50km/h)	26.77	28.95	12.6	4.58	48.48
Speeding (%> 70km/h)	18.77	16.62	10.11	3.9	37.28
Speeding (%> 90km/h)	12.82	9.05	12.96	.41	46.56
Yellow lights (number)	4.74	4	3	0	10
Collisions (number)	1.82	2	.96	0	4
Hazard PRT (s)	0.88	0.86	0.18	0.52	1.32
Hazard MT (s)	0.36	0.36	0.08	0.21	0.6
Hazard TBRT (s)	1.2	1.18	0.18	0.83	1.59
Following inside (m)	33.04	26.13	16.22	9.16	69.11
Following outside (m)	29.02	24.97	17.27	8.47	95

3.1. Correlation analyses

Correlations are shown in Table 10. There were several significant univariate associations between measures of response inhibition or working memory and risky driving measures, although not always in the expected direction.

In line with our expectations about the negative relation between cognitive control and risky driving, lane keeping variability (larger SDLP), collisions and hazard perception reaction time were negatively associated with SSRT. Collisions, hazard perception reaction time, and hazard total braking reaction time were also negatively associated with the second indicator of inhibition, invalid no-go errors. Finally, lane keeping variability was negatively associated with verbal working memory performance.

Not in line with our expectations, yellow light running related positively to visuospatial working memory performance. Furthermore, the minimum following distance inside the city centre related negatively to verbal and visuospatial working memory performance.

Finally, demographic variables related to some risky driving measures: older (vs. younger) participants and women (vs. men) maintained a larger following distance inside the city centre. Women (vs. men) also showed decreased speeding behavior in 50 km/h zones and a faster total braking reaction time to hazards. Lastly, participants with more driving experience displayed increased yellow light running.

Table 10: Correlations. $^{*}p < .05$ (one-tailed); $^{**}p < .01$ (one-tailed); SSRT: stop signal reaction time; No-go errors: 0 = no invalid no-go errors, 1 = invalid no-go errors; VSWM: visuospatial working memory; VWM: verbal working memory; age: 0 = 18 years, 1 = > 18 years; gender: 0 = men, 1 = women; driving experience: 0 = < 1287 km; 1 = > 1287 km; SDLP: standard deviation of lateral lane position; Speeding: percentage of distance driven over the speed limit in zones 50, 70 and 90 km/h; Yellow lights: number of yellow light running's; Collisions: amount of crashes; PRT: perception reaction time; MT: movement time; TBRT: total braking reaction time; Following: minimal following distance to lead vehicle inside and outside the city centre.

	SSRT	**No-go errors**	**VSWM**	**VWM**	**Age**	**Gender**	**Driving experience**
SDLP	,352*	-.168	-.069	-,375*	.003	-.191	.013
Speeding (50)	.011	.169	.255	.222	-.140	-.290*	.055
Speeding (70)	.194	.083	.255	.072	-.212	-.269	-.028
Speeding (90)	.135	.173	.266	-.228	-.097	-.113	.021
Yellow lights	-.231	.254	,284*	.032	-.031	.084	.284*
Collisions	,395**	,329*	-.030	-.077	-.130	-.038	-.028
Hazard PRT	,351*	,389**	-.106	.156	-.265	-.260	-.032
Hazard MT	-.053	-.135	.172	.030	.250	-.034	-.206
Hazard TBRT	.262	,304*	.028	.206	-.158	-.344*	-.039
Following inside	-.137	-.076	-,352*	-,332*	.388**	.326*	.067
Following outside	-.162	-.268	-.103	-.226	.266	.155	.277*

Table 11: Regression analyses. $^{*}p < .05$ (one-tailed); $^{**}p < .01$ (one-tailed); B: unstandardized beta-coefficient; β: standardized beta-coefficient; SDLP: standard deviation of lateral lane position; Yellow lights: number of yellow light running's; Collisions: amount of crashes; PRT: perception reaction time; TBRT: total braking reaction time; Following: minimal following distance to lead vehicle inside and outside the city centre; SSRT: stop signal reaction time; No-go errors: 0 = no invalid no-go errors, 1 = invalid no-go errors; VSWM: visuospatial working memory; VWM: verbal working memory; Age: 0 = 18 years, 1 = > 18 years; Gender: 0 = men, 1 = women; Driving experience: 0 = < 1287 km; 1 = > 1287 km.

Model	R^2	Predictor	B	β	95.0% Confidence Interval for B
SDLP	.268	SSRT**	.000	.357	[.000, .001]
		VWM**	-.011	-.380	[-.020, -.002]
Yellow lights	.218	VSWM**	1.121	.384	[.203, 2.039]
		Driving experience**	2.274	.384	[.413, 4.136]
Collisions 1	.156	SSRT**	.010	.395	[.002, .017]
Collisions 2	.109	No-go errors*	.635	.329	[.020, 1.250]
Hazard PRT 1	.123	SSRT*	.002	.351	[.000, .003]
Hazard PRT 2	.152	No-go errors**	.140	.389	[.028, .253]
Hazard TBRT	.209	No-go errors*	.107	.300	[-.002, .215]
		Gender*	-.119	-.341	[-.225, -.012]
Following inside 1	.427	VSWM**	-5.799	-.363	[-10.156, -1.442]
		Age**	10.537	.498	[1.703, 19.371]
		Gender*	16.143	.325	[7.399, 24.887]
Following inside 2	.350	VWM	-2.715	-.223	[-6.228, .798]
		Age**	12.139	.398	[2.874, 21.405]
		Gender**	12.890	.374	[3.417, 22.364]

3.2. Regression analyses

Table 11 presents the model summaries, R^2 of the multivariate regression models, B and β-coefficients and the 95% confidence intervals for B. (1) Decreased response inhibition and verbal working memory performance significantly predicted increased variability in lane keeping (lower SDLP). The model with SSRT and verbal working memory performance accounted for 26.8% explained variance in SDLP (*F* 6.407, *p* .002). (2) Decreased response inhibition significantly predicted more collisions: (a) the collisions model with SSRT as a significant predictor explained 15.6% of the variance (*F* 6.653, *p* .007); (b) the model with invalid no-go errors as a significant predictor explained 10.9% of the variance (*F* 4.382, *p* .022). (3) Decreased response inhibition significantly predicted increased reaction times in response to hazards: (a) the perception reaction time model with SSRT as a significant predictor explained 12.3% of the variance (*F* 5.054, *p* .016); (b) the perception reaction time model with invalid no-go errors as a significant predictor explained 15.2% of the variance (*F* 6.429, *p* .008); (c) for total braking reaction time, beside response inhibition, gender also appeared a significant predictor. The model with invalid no-go errors and gender as significant predictors explained 20.9% of the variance (*F* 4.615, *p* .009). (4) Increased visuospatial working memory performance significantly predicted increased risky driving: (a) for increased yellow light running the model that included visuospatial working memory performance and experience explained 21.8% of the variance (*F* 4.885, *p* .007); (b) the following distance model inside the city centre, including visuospatial working memory performance together with age and gender, predicted 42.7% of the variance (*F* 8.432, *p* .000).

4. Discussion

The goal of this study was to investigate the relation between cognitive control and driving performance in young novice drivers. It was hypothesized that lower levels of cognitive control (i.e., decreased response inhibition and working memory performance) would relate to increased risky driving. Driving performance was measured with a driving simulator. Performance measures were SDLP, speeding, yellow light running, collisions with and the reaction to hazards, and following distance. Regression analyses indicated several predictors of risky driving. Importantly, increased cognitive control in this study did not necessarily imply a reduction in risky driving. In line with the hypothesis, decreased response inhibition and verbal working memory performance predicted more variability in lane keeping. Furthermore, decreased response inhibition predicted more collisions and increased reaction times in response to hazards. However, in contrast with the hypothesis, increased visuospatial working memory performance predicted increased yellow light running and a decreased following distance inside the city centre.

Our study replicates and extends prior research on the relation between cognitive control and driving. Previous findings of a negative relation between response inhibition and SDLP (Jongen et al., 2011), and between verbal working memory performance and lateral position (Mäntylä et al., 2009), were replicated and extended in a larger and more realistic driving simulator. This implies that the inhibition of inappropriate response tendencies is important for reducing lane keeping variability. Possibly these tendencies are represented by steering maneuvers as response inhibition of such maneuvers might be necessary to avert swaying over the road thus preventing, for instance, driving into the gaze direction while scanning the road environment. Since lane keeping is based on visuospatial information processing, it could be expected that visuospatial rather than verbal working memory performance would relate to SDLP. Nonetheless, verbal working memory performance related to SDLP while visuospatial working memory performance did not. An important difference between the verbal and visuospatial working memory task other than the storage type might explain this effect. Different processes of working memory can be distinguished: working memory maintenance and working memory updating. Maintenance refers to keeping information available online, while updating refers to the constant addition or removal of items, or manipulation, of the information kept online (Schmiedek, Hildebrandt, Lövdén, Lindenberger & Wilhelm, 2009). In contrast to conducting the visuospatial working memory task (i.e., visuospatial span), participants needed not only to maintain, and add to, numbers in memory, but also needed to manipulate them by reversing their order when executing the verbal working memory task employed in this study (i.e., reversed digit span). The verbal working memory task used by Mäntylä et al. (2009) similarly required manipulating information in working memory. Possibly, to reduce lane keeping variability, it is necessary to constantly manipulate in memory the information of the vehicle position on the road. To bolster this conclusion future research should specifically investigate the relation of different working memory processes with driving parameters in a full factorial design.

Response inhibition also related negatively to measures of hazard perception, which is more directly associated with traffic safety since the detection of, and fast and accurate responses to, hazards in the driving environment are critical components of safe driving (Anstey, Wood, Lord & Walker, 2005). Hazard perception is a visually and cognitively demanding skill (McKenna & Farrand, 1999) that improves with experience. Young novice drivers identify fewer hazards and respond slower to those hazards than more experienced drivers (Isler et al., 2009; McKenna & Crick, 1991; Pollatsek, Fisher & Pradhan, 2006; Scialfa et al., 2011). Our results add to the existing hazard perception literature by showing for the first time that increased inhibitory control is related to improved hazard detection. That is, people with an enhanced ability to inhibit responses were faster in releasing their foot from the accelerator and showed a faster braking time when they encountered hazards. Furthermore, they made fewer collisions than people with decreased response inhibition. Visual search of the environment is an important skill for hazard perception and it has been shown that young novice drivers do not scan the roadway environment efficiently (Pradhan et al., 2005; Underwood, Chapman, Brocklehurst, Underwood & Crundall, 2003). However, in the present study the importance of visual search in explaining differences in crashes and hazard detection cannot be fully determined since detection was measured relatively indirect by the release of the accelerator (relative to the occurrence of the road hazard). Direct measurements of eye scanning are actually incorporated in a study we are currently running.

With the inclusion of a visuospatial working memory measure this study extended on previous research (Adrian et al., 2011; Mäntylä et al., 2009) that only included verbal working memory measures. Visuospatial abilities are important for driving as shown for instance, for elderly drivers, where decrements of safe driving were associated with declines in visuospatial abilities (Anstey et al., 2012). In addition, working memory training was shown to lead to an improvement of simulated driving performance (Cassavaugh & Kramer, 2009). The results from Cassavaugh & Kramer (2009) match the hypotheses we initially posted (i.e., increased working memory performance reduces risky driving). This study, however, included a different target group (i.e., older adults) and did not include visuospatial working memory. Interestingly the current study showed an unexpected pattern of results as visuospatial working memory performance was positively associated with yellow light running and decreased following distance inside the city center. We may only speculate about these results. Three possible explanations will be discussed below.

A first interpretation originates from literature where distraction while driving, which reduces available working memory resources, causes drivers to adopt compensatory strategies that allow drivers to safely execute the driving task while temporarily deprived from spare resources (e.g., maintain longer following distances; Young, Regan & Lee, 2009). Similarly, for young novice drivers with decreased working memory performance, increasing the following distance might help compensate the lack of resources to deal with the increased driving environment complexity inside the city center (e.g., pedestrian crossings, traffic density). Second, working memory performance has been postulated to be positively related to sensation seeking (Romer et al., 2011, 2009), a known predictor of risky driving behavior (Dahlen, Martin, Ragan & Kuhlman, 2005). As a result, young novice drivers with increased visuospatial working memory performance might encompass higher levels of sensation seeking that, for instance, could make them more inclined to run yellow lights. Third, in accordance with prior research (Anstey et al., 2012) the current data suggests a relation between visuospatial working memory performance and processing speed. Participants with increased visuospatial working memory performance (split by average) processed go-cues ('X' or 'O') in the stop signal task faster as reflected by decreased reaction times on these trials (392.15 vs. 431.44ms; F 4.602 p .039). Research already indicated that visual processing speed positively predicts driving capabilities (Ball, Edwards & Ross, 2007; Mathias & Lucas, 2009). Interestingly, the decision to cross a yellow light as well as following a leading vehicle require spatial orienting of attention (i.e., towards the yellow light/leading car), which could be more exact due to enhanced processing speed, and thus not necessarily involve more risky driving. Spatial attention and working memory are indeed related (Awh, Vogel & Oh, 2006), and in a previous study attentional orienting was important for gap acceptance while turning left at an intersection (Jongen, Brijs, Brijs, Lutin, Cattersel & Wets, 2012). For our original hypothesis, this implies that variables such as compensatory strategies, sensation seeking and processing speed might moderate or confound the relation between cognitive control (i.e., visuospatial working memory performance) and risky driving. Future studies, including those variables, will be necessary to test these hypotheses.

Some of the results reported here are in line with the maturation theory on adolescent risk taking (Steinberg, 2008) which stresses the importance of neurocognitive development to explain risk taking. From 11 years on, the prefrontal cortex and parietal lobes undergo a period of prolonged development until the age of 30 (Casey et al., 2011). This development is reflected by advances of cognitive control that lead to capable self-control of behavior and emotions across an array of situations and social contexts (Dahl, 2008; De Luca & Leventer, 2008; Crone, 2009; Keating & Halpern-Felsher, 2008). When adolescents gain cognitive control they should be less negatively influenced by emotions and their social environment, which allows them to engage in strategic, self-regulated, and goal oriented processing (McCloskey, Perkins & Van Divner, 2009), and makes them less inclined to take risks (Steinberg, 2008). Although this theory mainly predicts a negative relation between cognitive control and risky driving behavior *within subjects* (i.e., when cognitive control increases due to maturation), it can similarly be expected that higher levels of cognitive control *between subjects* will predict decreases in risky driving. Indeed, response inhibition and verbal/updating working memory performance related negatively to lane keeping variability (i.e., smaller SDLP). Furthermore, response inhibition related negatively to efficient hazard perception (i.e., faster reaction times and fewer collisions). It should be noted that a relation between cognitive control and risky behavior is not limited to either young novice drivers or risky driving. It also applies to other target groups (e.g., elderly drivers; Adrian et al., 2011) and other types of risk behavior (e.g., disturbances in eating behavior and alcohol use; Rosval, Steiger, Bruce, Israël, Richardson and Aubut, 2006; Houben, 2011b). Nonetheless, some findings contradict the maturation theory as visuospatial working memory performance related positively to yellow light running and negatively to following distance inside the city center. However, as stated in the discussion, these measures might not necessarily reflect risky driving.

Important, and supported by the explained variance in the regression models (9.4%-42.7%), it would be an oversimplification to expect cognitive control to be the only determinant of driving behavior. Other factors explain the remaining variance (e.g., sensation seeking). Crone and Dahl (2012) already argued in a recent review that cognitive control might only be part of a greater picture. Social and affective processes may moderate the relation between cognitive control and risky driving.

Taken together, the findings show that cognitive functioning in young novice drivers relates to risky driving and might partially explain their overrepresentation in car accidents. These findings can be applied to traffic safety. Driving learner programs, such as GDL, include several restrictions to reduce collision risk for young novice drivers (Masten, Foss & Marshall, 2011; Vanlaar, et al., 2009). These results imply that some novice drivers might require different restrictions. For instance, due to a slower response to hazards, and because hazards are less visible at night, drivers with decreased response inhibition might require extended periods of restricted nighttime. With the inclusion of cognitive control tests, driver-learning programs could be tailored to the specific needs of young novice drivers. The results also apply to cognitive control training, a hot topic nowadays based on the assumption that improved cognitive control leads to increased behavioral control and therefore decreased risky behavior. Research indeed showed that cognitive control functions are flexible and can be altered by training, leading to improvements in performance (Cassavaugh & Kramer, 2009; Jolles, Grol, Van Buchem, Rombouts & Crone, 2010; Klingberg et al., 2002). Training of cognitive control can also transfer to everyday behavior. For example, response inhibition as well as working memory training led to decreases in alcohol intake (Houben, Nederkoorn, Wiers & Jansen, 2011a; Houben et al., 2011b). Due to the inclusion of multiple driving parameters, this study sheds a different light on cognitive control training to reduce risky driving. For instance, visuospatial working memory training may have undesirable effects since it could increase yellow light running which is a traffic violation. Nonetheless, training programs are often applied before thoroughly determining underlying mechanisms of the risk behavior. To positively influence traffic safety, the exact relations between cognitive control and risky driving parameters need to be investigated in order to develop efficient learner and training programs.

5. Limitations

The power of this study was reduced due to the low sample size (n 38). This also reduces the generalizability of the results as smaller samples less accurately represent the population from which they are drawn due to an increased estimation error (VanVoorhis & Morgan, 2007). Nonetheless, significant relations were shown, as well as the unique contribution of different variables in predicting driving performance.

Related to simulator validity, an important question is whether driving performance in the simulator transfers to driving performance on the road. On the one hand, simulated driving might overestimate risky driving behavior, because accidents can never have equally severe consequences as real crashes, and participants might therefore not attain equal degree of motivation in a simulated environment. On the other hand, however, simulators might underestimate risk behavior by overestimating driver performance given that much of the daily distractions that are present in real traffic (e.g., passengers, phone calls) were not present in our study (Fillmore, Blackburn & Harrison, 2008). Recent reviews and studies evaluating simulator validity have however already provided positive evidence for simulator validity in domains such as speed, lateral position, brake onset, divided attention, driving errors, risky traffic behavior assessment and hazard perception (Fisher, Rizzo, Caird & Lee, 2011; Shechtman, Classen, Awadzi & Mann, 2009; Underwood, Crundall & Chapman, 2011).

Important to note, cognitive control is not uniquely defined. First, the exact selection of functions that are said to be cognitive functions may differ between authors. Second, some authors have described cognitive control as a unitary concept while others describe it as non-unitary (i.e., involving distinct subcomponents) (Baddeley, 1986; Best & Miller, 2010; Buckner, 2004; Tamnes et al., 2010). An intermediate framework states that cognitive control can be seen as a construct consisting of interrelated but distinct components (Best & Miller, 2010; Miyake et al., 2000). This view was supported by brain research indicating that response inhibition and working memory share common neural components, which may provide a basis for an interrelationship between the two, but also show distinct components (McNab et al., 2008).

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Footnotes

[1] Piloting showed that the original ITI and stimulus duration parameters lead to no or minimal failed inhibitions whereas the probability for Fillmore et al. (2006) was .3. This difference could be attributed to the drug history of the test sample (i.e., former cocaine users who made fewer errors in response to doses of cocaine) in the study by Fillmore et al. (2006). Both changes increased task difficulty and thereby the number of failed inhibitions on no-go trials.
[2] Given the automatic adaptation, participants make mistakes in 50% of the trials. Pilot testing showed that, due to this continuous adaptation, the majority of subjects in the pilot test experienced the task as frustrating and/or tiring.
[3] The lack of red light running might be explained by the minimal inclusion of red lights in the driving scenario (i.e., only 3). Jongen et al. (2011) included 10 red lights and did report red light running in a sample of young novice drivers (i.e., two age groups: 17-18 and 22-24 years old). For future studies, it would be preferable to balance the number of yellow and red lights.

CHAPTER 4

Accident analysis and prevention, Accepted for publication

Investigating risky, distracting, and protective peer passenger effects in a dual-process framework.

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In the following chapter, I was involved in the analyses and dissemination (presentation at conferences and writing of the paper).

Abstract

Prior studies indicated higher collision rates among young novice drivers with peer passengers. This driving simulator study provided a test for a dual process theory of risky driving by examining social rewards (peer passengers) and cognitive control (inhibitory control). The analyses included age (17-18 yrs, n 30; 21-24 yrs, n 20). Risky, distracting, and protective effects were classified by underlying driver error mechanisms. In the first drive, participants drove alone. In the second, participants drove with a peer passenger. Red-light running (violation) was more prevalent in the presence of peer passengers, which provided initial support for a dual process theory of risk driving. In a subgroup with low inhibitory control, speeding (violation) was more prevalent in the presence of peer passengers. Reduced lane-keeping variability reflected distracting effects. Nevertheless, possible protective effects for amber-light running and hazard handling (cognition and decision-making) were found in the drive with peer passengers. Avenues for further research and possible implications for targets of future driver training programs are discussed.

Keywords: Young novice drivers, driving simulation, peer passengers, dual processes.

1. Introduction

Young novice drivers have a higher risk of collisions when they drive with peer passengers (Lee & Abdel-Aty, 2008; Simons-Morton et al., 2011). Furthermore, the risk of a fatal collision increases with the number of peer passengers (Chen, Baker, Braver, & Li, 2000; Tefft, Williams, & Grabowski, 2013) and, for male drivers with male passenger (Ouimet et al., 2010). Although the effect of peer passengers on non-fatal collisions is less established (Durbin, McGehee, Fisher, & McCartt, 2014), injury risk also increases with peer passengers (Durbin et al., 2014; Orsi, Marchetti, Montomoli, & Morandi, 2013).

1.1. A dual process theory of risky driving

A dual process theory of risky driving provides a theoretical framework for the peer passenger effect by considering the imbalance between the development of the social-affective brain and the cognitive control system (Cascio et al., 2014; Lambert, Simons-Morton, Cain, Weisz, & Cox, 2014). A maturational gap between these brain systems causes this imbalance. The brain's socioemotional reward system shows early adolescent remodeling while the cognitive control system (e.g., inhibitory control, working memory, mental flexibility, and planning) matures more gradually. Neurocognitive evidence indicates that these cognitive functions improve until young adulthood (Albert, Chein, & Steinberg, 2013; Bugg & Crump, 2012; De Luca & Leventer, 2008; Glendon, 2011). Adolescents and young adults were found to be prone to risk taking in response to highly social-affective situations when impulses were not appropriately inhibited by cognitive control (Albert et al., 2013; Figner, Mackinlay, Wilkening, Weber, 2009). This was observed, even when probabilities of negative outcomes were known (Smith, Chein, & Steinberg, 2014).

Jongen, Brijs, Komlos, Brijs, and Wets (2011) provided initial support for a dual process theory of risky driving by showing that a momentary reward increased risky driving (i.e., speeding and red-light running) in young novice drivers, while cognitive control interacted with driving performance (i.e., lower inhibitory control related to reduced lane-keeping variability). However, they did not include a full test of a dual process theory of risky driving, which would include cognitive control and a social-emotional reward context, for example a peer passenger manipulation (Lambert et al., 2014). Cascio et al. (2014) included peer passengers and found that increased inhibitory control overrode risky driving tendencies when a cautious peer was present. However, their study only included red-light running, therefore including only a limited reflection of the complex driving environment.

1.2. Confounding factors

According to Orsi et al. (2013), several factors might confound the peer passenger. First, within-group differences are expected to exist in young novice drivers (i.e., aged 17-25). Although recent analysis indicated that young adults displayed the highest levels of risk taking behavior (e.g., alcohol and drug use), young adults are probably less driven by situational conditions involving peers when compared with younger adolescents (Willoughby, Good, Adachi, Hamza, & Tavernier, 2013). Indeed, as the cognitive control system matures into young adulthood, resistance to peer influence gradually grows (Figner et al., 2009). Therefore, it was hypothesized that age would relate negatively to risky driving, with the younger segment of the range showing riskier driving when accompanied by peer passengers.

Second, novice drivers lack driving experience. As some aspects of driving are not fully automated and require a greater investment of attention, novice drivers lack spare resources to deal with the increased complexity of the driving task when adding a peer passenger (Orsi et al., 2013; Ross et al., 2014), possibly leading to increased risky driving.

Third, driver and passenger sex influence the outcome of the peer-passenger effect. Males drivers, compared with female drivers, were found to weigh the benefits of risk taking more heavily than the costs (Gardner & Steinberg, 2005) and to engage more in risky driving when accompanied by peer passengers (Curry, Mirman, Kallan, Winston & Durbin, 2012). When considering passenger sex, male peer passengers were found to increase risky driving (e.g., speeding, tailgating) (Conner, Smith, & McMillan, 2003; Simons-Morton, Lerner, & Singer, 2005). Collision outcome was also found to be more severe in the presence of male passengers, probably due to increased risky driving (Orsi et al., 2013).

1.3. Peer passenger effects: mixed results

Previous studies indicated effects of peer passengers beyond risky driving. The risk-increasing effect of peer passengers can be caused by an increased tendency of risky driving or by the presence of distracting effects (Buckley, Chapman, & Sheehan, 2014; Orsi et al., 2013). Several studies indicated increased risky driving behaviors in young drivers when accompanied by peer passengers. For example, a stronger tendency for red-light running was established in a driving-related version of the videogame Chicken' (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011). Other research found that increased risky driving was mainly present with risk-prone peer passengers. For instance, Shepherd, Lane, Tapscott, and Gentile (2011) reported increased scores on a risk index that combined collisions and maximum speed during a simulated drive that included risk-prone peer passenger. Drivers in these cases may be encouraged to drive faster and not to worry about collisions.

Studies also described the distracting effects of peer passengers (Durbin et al., 2014; Heck & Carlos, 2008). It was stated that the presence of peer passengers might prevent drivers from devoting sufficient attention to the driving task, either by inducing visual (e.g., eyes off road) or cognitive (e.g., conversation) distraction (Durbin et al., 2014; Orsi et al., 2013). These distracting effects can differ for males and females. Male drivers tend to be more externally distracted, whereas female drivers tend to be more internally distracted, by peer passengers (Curry et al., 2012). Whatever the cause, distracting effects are unwanted because inattention often precedes collisions in young novice drivers (Durbin et al., 2014).

In addition to both risky and distracting effects on young novice drivers' driving behavior, protective effects of peer passengers were found. To illustrate, Engström, Gregersen, Granström, and Nyberg (2008) investigated effects for three different age groups (18-24, 25-64 and > 65 years) using the Swedish national collision database and exposure data. Albeit weaker for the youngest group, they found a protective effect of passengers on collision statistics that became more pronounced with an increase of passengers. Furthermore, the above mentioned study from Shepherd et al. (2011) found that verbal persuasion by peer passengers led to safer driving in a high-risk condition. In this condition, the passengers encouraged drivers to drive slower and avoid collisions. Ouimet et al. (2013) included measures of risky driving and distraction to test the effects of risk averse or prone male confederate passengers on young male novice drivers. The study found that the mere presence of a passenger caused distractive effects, as indicated by fewer eye glances towards hazards and reduced horizontal eye movements. Protective effects were also found as passenger presence related with waiting for a greater number of vehicles to pass before initiating a left turn. Counterintuitively, protective effects were even higher for risk-accepting passengers, when compared to the risk-averse passengers. With a risk accepting passenger, drivers maintained longer headway with the lead vehicle and engaged in more eye glances at hazards.

1.4. Driver error

Driver error contributes to 70-75% of driver collisions and is therefore directly related to traffic safety (Allahyari et al., 2008; Stanton & Salmon, 2009). With respect to young novice drivers, driver error was found to be the most significant cause for events immediately preceding collisions (Curry, Hafetz, Kallan, Winston, & Durbin, 2011). Furthermore, individual differences in cognitive ability may lead to different types and rates of errors committed in similar circumstances (Allahyari et al., 2008), which can be relevant due to biological maturation. Finally, young novice drivers are more prone to errors in distracting situations when compared with older, more experienced drivers. (Romer, Lee, McDonald, & Winston, 2014).

Stanton and Salmon (2009), described a classification with five psychological mechanisms underlying driver errors. These mechanisms are: action, cognition and decision-making, observation, information retrieval, and violations. For examples of driver errors in each classification, refer to table 1. In recent descriptions of their model, distraction is described as a contributing factor that increases the likelihood of driver errors (Young & Salmon, 2012; Young, Salmon, & Cornelissen, 2013a). Although a full description of the model[1] is beyond the scope of this article, it was included to classify peer passenger effects on multiple driving parameters, to allow predictions for driving parameters not included in the current study.

Table 12: Examples of driver errors per underlying mechanism (i.e., adapted from Stanton & Salmon, 2009).

Underlying mechanism	Example
Action	Press the accelerator instead of brake, following too close
Cognition and decision-making	Wrongly assume a vehicle will not enter path, misjudge speed of oncoming vehicle
Observation	Fail to observe offside mirror when changing lanes, fail to observe appropriate area
Information retrieval	Misread road sign, only retrieve part of information required
Violation	Intentionally speed, overtake on the inside

1.5. Objectives

A more complete test for a dual process theory of risky driving is warranted. To this end, the study from Jongen et al. (2011) was repeated with the inclusion of a social reward (i.e., peer presence) instead of a monetary reward. The analyses also included possible confounding factors: age, driver experience, and sex. Results from this study were published as a conference proceeding by Jongen, Brijs, Brijs, and Wets (2013). These results were mixed and showed that the influence of peer passengers could be negative (e.g., increased red-light running) or positive (e.g., decreased number of collisions), depending on the specific driving measure. Meanwhile, they found a moderating influence of cognitive control (i.e., inhibitory control) as in a subgroup with high inhibitory control there was no effect of peers on speeding.

Although Jongen et al. (2013) provided support for a dual process theory of risky driving, a sufficient theoretical analysis was required in order to bridge insights from developmental psychology to traffic safety. First, a thorough literature review regarding a dual process theory of risky driving should be included. Second, a detailed description of the rationale and results for the confounding factors was needed. Third, the results were not yet classified into a driver error framework, limiting predictions for future research. Therefore, mixed effects (risky, distracting, and protective) were classified based on underlying mechanisms of driver errors.

2. Methods

2.1. Participants and peer passengers

Fifty young novice drivers were recruited using the inclusion criteria (1) age between 17-18 years or 21-24 years (i.e., delineating adolescence and young adulthood), (2) a provisional or full driving license, (3) and maximum of two years driving experience at the time of testing. The rationale for the chosen time frame is that collision rates are highest in the first 6 months after licensure and then begin to decline in the first six months before normalizing over the next 1.5 years (Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011; Mayhew, Simpson, & Pak, 2003). All participants gave informed consent before taking part in this study. Every driver invited a friend of any sex and in the same age category to allow ecological validity, as opposed to a confederate peer passenger (e.g., Ouimet et al., 2013; Shepherd et al., 2011). The two age groups (n 30 versus n 20, respectively) were matched in terms of driver sex ratios (60% versus 65% male drivers, respectively). Mean age of the peer passengers was 17.77 years for the 17-18 year old group and 21.85 years for the 21-24 year old group. Most of the participants brought a same-sex friend (17-18: 86.7%, 21-24: 75%). Self-reported driver experience was significantly higher for drivers aged 22-24 year (2883 km/year) than for 17-18 years (1627 km/year); F 4.15, p 0.047.

2.2. Driving simulator

The study was conducted on a fixed-based medium fidelity driving simulator (STISIM M400; Systems Technology Incorporated) with a force-feedback steering wheel, brake pedal, and accelerator. A large, seamless, curved screen with 180° field of view included rear- and side- view mirror images. The projection screen offered a resolution of 1024 × 768 pixels and data were collected at a 60 Hz frame rate. The use of a driving simulator allowed for objective measurement of driving parameters that would not be directly available for an observer while in a safe and controllable environment (Young & Salmon, 2012; Young et al., 2013a). A dual-seat setup was used so that the passenger could sit on a chair next to the driver.

2.3. Driving scenarios

The simulated driving task consisted of two warmup sessions, and two experimental sessions, borrowed from Jongen et al. (2011; see also Jongen et al., 2013). In the experimental sessions, a 28 km daylight driving scenario was presented on a two-lane road with bidirectional traffic and included both inner (50 km/hour) and outer (90 km/hour) city sections. Twelve road hazards (e.g., a pedestrian crossing the road) were calibrated such that collisions could be avoided by braking (when driving up to and at the signed speed limit) or by steering around an obstacle. The possibility of colliding was included because collisions represent the outcome of an unsafe act and thereby provide an indicator of driving safety (Veldstra et al., 2012). Apart from road hazards, other vehicles were presented on the roadway but required no passing or braking on the part of the driver. Participants had to drive through 18 intersections equipped with traffic lights (10 red, 4 green, 4 amber; in randomized order).

2.4. Stop signal paradigm

This study included an inhibitory control as a measurement of cognitive control, similar to Cascio et al. (2014). The stop signal paradigm, adapted from Jongen et al. (2011) and Ross et al. (2015) (for a review, see Verbruggen & Logan, 2008), was used as a standard laboratory measure. Presentation software was used to program the scenario. This task included two practice sessions (40 trials each) and one experimental session (96 trials). In each session, a two-choice reaction time task required participants to press a button (left or right) in response to a stimulus ('X' or 'O') presented centrally on the computer screen. In each trial, after 1000 ms a fixation cross ('+') was presented for 500 ms. After that, the stimuli were presented for 1000 ms and required a response between 150 and 1000 ms after onset. The first practice session served to determine the individual speed level, which was used as a reference for the second practice and the experimental session. These sessions consisted of the same two-choice reaction-time task, but on a randomly selected 25% of trials, an auditory stimulus (1000 Hz, 70 dB, 100ms) was presented in addition to the visual primary task stimulus. Presentation of this tone indicated that the subject should refrain from responding to the stimulus on that trial. Initially, the time interval between the stimulus and the stop signal was set 50ms below participants' individual speed level. Subsequently the interval varied dynamically according to a staircase tracking algorithm, to converge on a stop signal delay with a 50% probability of stopping. The stop signal delay increased by 50ms if the response was withheld and decreased by 50ms when it was not. If the participant waited too long to respond, the following message appeared on the computer screen: “React faster please”.

2.5. Procedure

The procedure was derived from Jongen et al. (2011; see also Jongen et al., 2013). On arrival, participants signed a consent form. Participants drove two warmup sessions to become familiarized with the driving simulator. After the warmup sessions, participants drove the first experimental drive (28 km) without the presence of a peer passenger. For the second experimental drive, participants drove the same scenario but in the presence of a peer passenger. Finally, they completed the stop signal paradigm, measuring inhibitory control.

2.6. Data collection

2.4.1. Driving behavior

The current manuscript extended the dependent driving measures from Jongen et al. (2013). These included the standard deviation of lateral lane position (SDLP; m), speeding (percentage of total driven distance above the posted speed limit), red-light running (number of times), and collisions (number of times). SDLP represents a measure of weaving. Higher values indicate increased weaving (i.e., increased lane-keeping variability). SDLP can be seen as a driving safety index because higher SDLP values could indicate lane crossings (Verster & Roth, 2011). In the computation of SDLP, segments associated with lane changes were excluded.

Additional measures not included in Jongen et al. (2013) were added to the current analyses. First, Jongen et al. (2013) did not include amber-light running. Red- and amber-light running reflect different decision making processes. Amber-light running, although not preferable, is not prohibited by the law. The driver is allowed to drive through the amber light if s/he judges that it is not possible to stop safely. To accomplish this, the driver has to take his or her current speed and the distance to the light into account. In contrast, red-light running represents a blatant disregard of traffic lights and is prohibited by the law. Considering table 1, amber-light running reflects cognition and decision-making, while red-light running indicates a violation. Therefore, the current analyses included amber-lights. The onsets for the amber and red lights were based on headway time, 3.5 s and 12 s, respectively (see figure 2). To accomplish this, the simulator calculated time to stop line (TSL) values during the approach to the intersection of light location (i.e., time for a vehicle to reach the intersection stop line without braking or accelerating) (Ross et al., 2015).

Because collisions are one possible outcome of an unsafe driving maneuver, potentially dangerous near collisions were studied through examination of two hazard-handling related measures, calculated for a selection of eight road hazards, excluding hazards four hazards that followed speed limit signs. More specifically, the initial brake was first calculated in a hazard window starting 100 m before the position of the hazard (i.e., calculated from the beginning of the hazard window; s). Initial brake reactions below 0.10 s were treated as missing values because they reflected braking that was not targeted towards the hazard (e.g., slowing down), which led to two missing values for the drive with peer passengers (i.e., 0 s and 0.01 s). Next, the distance of maximum deceleration was calculated (i.e., relevant to the position of the hazard; m). Increases of the initial brake point and decreases of the distance of maximum deceleration were considered late and less safe hazard-approach responses.

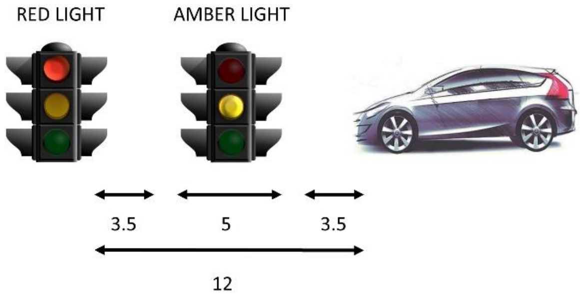

Figure 26: The timing for the onset of the amber and red light, based on the vehicle's headway time.

2.4.2. Inhibitory control

The stop signal reaction time (SSRT) was used as a measure of inhibitory control, with shorter SSRT that indicated higher inhibitory control (Jongen et al. 2011, 2013).

2.5. Data analysis

First, to investigate whether inhibitory control improved between both age groups, an analysis of variance (ANOVA) was conducted. As driving experience was confounded with the age group variable (i.e., the older group had more driving experience), driving experience was excluded from the analyses. Furthermore, since there was not an equal distribution of male and female peer passengers across male and female drivers of the two age groups, and given the current sample size, passenger sex could not be included as a factor in the analyses. With only one significant interaction effect (i.e., speeding*SSRT), analyses were re-calculated using only inhibitory control (i.e., excluding driver sex). Finally, because the measures did not correlate highly (see table 2 for a correlation matrix), separate repeated measures mixed ANCOVA models were calculated with a within-subjects factor of peer passengers (2: no, yes), and a continuous variable (covariate) of inhibitory control (SSRT). Significant interactions between peer passengers and any of the between-subjects factors or covariates were further investigated to assess the main effect of peer passengers. To this aim, the initial ANCOVA model was repeated separately for each group of the covariate (i.e., low and high inhibitory control based on a median split). The significance level for the analyses is alpha ≤ .05.

Table 13: Correlations between dependent driving measures: SDLP: standard deviation of the lateral lane position; Speed: percentage of total driven distance above the posted speed limit; Amber: amber light running; Red: red light running; Brake: initial brake reaction; Deceleration: distance of maximum deceleration; Crash: crashes. Each measures is averaged across the two drives. The Pearson correlation r is indicated together with the significance level.

		SDLP	**Speed**	**Amber**	**Red**	**Brake**	**Decel-eration**	**Crash**
SDLP	**r**	1	-.01	.17	.27	.16	.02	.27
	p		.47	.13	.03	.14	.44	.03
Speed	**r**		1	.45	.31	-.31	.08	.44
	p			< .001	.02	.01	.29	< .01
Amber	**r**			1	.09	-.03	-.11	.30
	p				.26	.41	.22	.02
Red	**r**				1	.04	-.13	.13
	p					.40	.18	.18
Brake	**r**					1	-.31	-.16
	p						.01	.14
Decel-	**r**						1	-.41
eration	**p**							< .01
Crash	**r**							1
	p							

3. Results

3.1. Inhibitory control

SSRT did not differ significantly between 17-18 year olds and 22-24 year olds (210.57 ms versus 209.34 ms, respectively; *F* 0.01, *p* .92).

Table 14: Descriptives: mean (M), median (Mdn), standard deviation (SD), range, minimum and maximum values of driving measures by age group and peer condition. SDLP: standard deviation of the lateral lane position; Speed: percentage of total driven distance above the posted speed limit; Amber: amber light running; Red: red light running; Brake: initial brake reaction; Deceleration: distance of maximum deceleration; Crash: crashes.

		No peers		Peers	
Dependent measures		**17-18 yr**	**21-24 yr**	**17-18 yr**	**21-24 yr**
SDLP	**M**	0.25	0.25	0.24	0.24
	SD	0.06	0.03	0.07	0.04
	Range	0.30	0.11	0.26	0.14
	Min	0.16	0.20	0.12	0.16
	Max	0.45	0.31	0.38	0.30
Speed	**M**	17.66	16.43	21.08	14.85
	SD	13.54	14.31	14.91	11.27
	Range	50.66	50.92	55.19	39.96
	Min	0.12	0.10	0.77	0
	Max	50.78	51.02	55.96	39.96
Amber	**M**	1.47	2.25	1.37	1.60
	SD	1.53	1.74	1.59	1.60
	Range	4	4	4	4
	Min	0	0	0	0
	Max	4	4	4	4
Red	**M**	0.07	0	0.13	0.25
	SD	0.25	0	0.43	0.44
	Range	1	0	2	1
	Min	0	0	0	0
	Max	1	0	2	0
Brake	**M**	4.02	4.29	3.53	3.92
	SD	1.19	1.23	1.36	1.22
	Range	5.20	4.63	5.37	4.83
	Min	1.06	1.27	0.42	1.28
	Max	6.26	5.90	5.79	6.12
Deceleration	**M**	20.64	21.42	24.55	23.05
	SD	4.45	3.96	4.35	4.15
	Range	18.96	12.26	15.73	19.65
	Min	13.12	15.12	17.37	13.41
	Max	32.07	27.37	33.10	33.06
Crash	**M**	3.10	2.20	1.87	1.55
	SD	1.90	1.11	1.72	1.15
	Range	7	4	7	5
	Min	0	0	0	0
	Max	7	4	7	5

3.2. Driving parameters

Table 14 provides descriptives of the dependent driving parameters, by age group and peer condition. Table 15 provides univariate statistical effects from the ANCOVA models for each measure, including estimated marginal means that were controlled for covariates and between-subjects factors, and includes the main effects. The significant interaction will be discussed in text. Table 16 contains an overview of found peer passenger effects.

Table 15: Univariate statistical effects of driving measures: EMM: Estimated marginal mean; $\rho\eta^2$: effect size [SSEffect/(SSEffect+ SSResidual)]. SDLP: standard deviation of the lateral lane position; Speed: percentage of total driven distance above the posted speed limit; Amber: amber light running; Red: red light running; Brake: initial brake reaction; Deceleration: distance of maximum deceleration; Crash: crashes.

Variable		F	p	ρη²
SDLP	Peers (EMM Alone 0.25;With peer 0.24)	4.88	.03	.09
Speed	Peers (EMM Alone 17.17;With peer 18.58)	1.25	.27	.03
Amber	Peers (EMM Alone 1.78;With peer 1.46)	3.91	.05	.08
Red	Peers (EMM Alone 0.04;With peer 0.18)	3.94	.05	.08
Brake	Peers (EMM Alone 4.14;With peer 3.70)	2.60	.11	.05
Deceleration	Peers (EMM Alone 20.95;With peer 23.95)	18.91	< .001	.28
Crash	Peers (EMM Alone 2.74;With peer 1.74)	14.46	< .001	.23

3.2.1. SDLP

SDLP was lower in the drive with peer passengers than in the drive without. No moderation of inhibitory control was found.

3.2.2. Speeding

Although there was no main effect of peer passengers on speeding, there was a significant interaction effect of inhibitory control and peer passengers (F 4.09, $p < .05$, $\rho\eta^2$ .08). The separate analyses for the low and high inhibitory control groups showed that speeding increased in the presence of peer passengers for the low inhibitory control group (estimated marginal mean alone: 13.64% versus peer: 18.42%; F 22.97, $p < .001$), whereas there was no difference in speeding between drives for the high inhibitory control group (estimated marginal mean alone: 20.69% versus peer: 18.74%; F 0.75, p.39).

3.2.3. Traffic lights

The number of red-light running occurrences was higher in the drive with peer passengers than in the drive without. In contrast, for amber-light running, the number of occurrences was lower in the drive with peer passengers than in the drive without. No moderation of inhibitory control was found.

3.2.4. Road hazards

With respect to hazard approach, participants braked earlier, and reached the maximum deceleration while being further away from the hazard in the drive with peer passengers. However, this was not significant for the initial brake. Furthermore, the number of collisions with road hazards was significantly lower in the drive with peer passengers than in the drive without. No moderation of inhibitory control was found.

Table 16: Overview of peer passenger effects. SDLP: standard deviation of the lateral lane position; Speed: percentage of total driven distance above the posted speed limit; Amber: amber light running; Red: red light running; Brake: initial brake reaction; Deceleration: distance of maximum deceleration; Crash: crashes.

	Risky	Distracting	Protective
SDLP		X	
Speed	X (low inhibitory control)		
Amber			X
Red	X		
Brake			X
Deceleration			X
Crash			X

4. Discussion

The current study provided an extension of Jongen et al. (2013), which provided a test of a dual process theory of risky driving through inclusion of peer passengers and inhibitory control. Age and driver sex did not show any significant interaction effects and were therefore excluded from the analyses. In the following discussion, risky, distracting, and protective effects are classified based on underlying mechanisms of driver errors. The results provided initial support for a dual process theory of risky driving.

Considering the lack of age effects, the current design likely included a too narrow of an age range, thereby excluding substantial developmental differences. In further support of that contention, the current study did not show improvements in inhibitory control between the two groups. Although this contradicts results from Jongen et al. (2011) that found improvements in inhibitory control between similar age groups, it coincides with developmental literature indicating that inhibitory control matures at an earlier age compared with other cognitive control functions (e.g., working memory or planning) (De Luca & Leventer, 2008). Alternatively, the sample size may have been too small to differentiate the age effects between your two very close age groups. The fact that no significant interaction effect of driver sex was found was possibly caused by the inability to include passenger sex in the analyses because the effects of peer passengers depend on the composition of the driver-passenger pairs (i.e., male-male, male-female, female-female) (Simons-Morton et al., 2005).

Red-light running was more prevalent in the presence of peer passengers, which supports a dual process theory of risky driving. As mentioned in the methods section, red-light running can be considered a violation. Violations are mostly characterized by a large motivational component and reflect either conscious or unconscious deviations from rules and safe practices (Stanton & Salmon, 2009; Young & Salmon, 2012). As supported by a lower rate of red-light running in the drive without peer passengers, young novice drivers were able to drive in a safe manner. However, when peer passengers were present, young novice drivers engaged in increased risky driving. This is in line with previous research that indicated that the presence of peer passengers increased red-light running (Chein et al., 2011; Gardner & Steinberg, 2005).

The percentage of total driven distance above the posted speed limit, another violation, was greater in the drive with peer passengers, albeit only in a subgroup of drivers. Importantly, and providing further support for a dual process theory of risky driving, inhibitory control partially moderated negative peer passenger effects. More specifically, in a subgroup with low inhibitory control, the percentage of total driven distance above the posted speed limit was greater in the drive with peer passengers. This suggests that adolescents with lower inhibitory control were less successful in regulating the heightened sensitivity to social rewards or pressure. These results coincide with research that showed activity in the inhibitory control network related to overriding risky tendencies in the presence of cautious peers (Cascio et al., 2014). Nevertheless, none of the other interaction effects were significant, indicating a limited role of inhibition the current study. Possibly, reward-seeking behavior mostly relies on inter-individual differences, biasing some individuals more than others towards rewards, irrespective of developmental differences (van Duijvenvoorde et al., 2014).

Although speculative, the reduced lane-keeping variability (i.e., SDLP) in the current study could indicate a distracting effect of peer passengers at the cognitive level, which could be caused by passenger related conversations and/or contemplations (Heck & Carlos, 2008; Lee & Abdel-Aty, 2008; Pradhan et al., 2014). This is supported by previous research that found a decreased lane-keeping variability when drivers had to perform an auditory continuous memory task while driving (Engström, Johansson, & Östlund, 2005) or while talking on a cellphone (Fitch et al., 2013). This would be problematic if distraction disrupted psychological mechanisms (e.g., perception), which thereby increased the rate of driver error and possibly led to increased collision risk (Young & Salmon, 2012; Young et al., 2013a). Therefore, strictly speaking, it could even be possible that the increase in red-light running was caused by the distracting effect of peer passengers, which caused unintentional light running rather than intentional (Stanton & Salmon, 2009).

Protective peer passenger effects were also present, indicated by a decrease in amber-light running and better hazard handling in the presence of a peer passenger. Therefore, protective effects were mainly reflected in decreased driver errors, which included cognition and decision-making (Stanton & Salmon, 2009; Young, Salmon, & Lenné, 2013b). This contradicts research showing that, due to distraction, peer passengers increased driver errors and decreased hazard-handling performance (for a review, see Durbin et al., 2014). Possibly, the peer passenger monitored the road and served as an additional 'risk detector', which thereby improved the driver's ability to detect and respond to amber-lights and road hazards. This is supported by research where passenger conversations were compared with hands-free phone conversations. It was found that in-vehicle conversations did not interfere with driving because much as cell-phone conversations as passengers made references to traffic conditions, adjusted the conversation based on driving difficulty, and helped the driver identify road hazards (Strayer & Drews, 2007).

Although the results provide support for a dual process theory of risky driving, the limited moderating results for inhibitory control could suggest that dual processes are insufficient to fully explain the results. A similar opinion was forwarded in recent literature. Pfeifer and Allen (2012) indicated that the dual process approach oversimplifies research results and overlooks inconsistencies. Others mention a lack of concepts within the theory. For instance, intuitive decision-making based on increased experience (Reyna, Wilhelms, McCormick, & Weldon, 2015) or harm avoidance (Ernst, 2014). However, in agreement with the opinion of Strang, Chein, and Steinberg (2013), theories of dual processes are useful for hypothesis building. Therefore, the current study provides initial support for the usefulness of dual process theories in the applied context of risky driving, and establishes avenues for follow-up research to further pinpoint underlying mechanisms of the driving behavior of young novice drivers in complex social circumstances.

To summarize, the current study provides initial support for a dual process theory of risky driving. Key findings of the study are: 1) risky driving was more prevalent in the drive with peer passengers as evidenced by red-light running (violation);

2) the greater level of speeding (violation) in the drive with peer passengers was moderated by high inhibitory control; 3) distractive effects of peer passengers were reflected in reduced lane-keeping variability (i.e., SDLP); and 4) possible protective effects in the drive with peer passengers occurred for amber-light running and hazard handling (cognition and decision making).

5. Limitations

An important limitation is that the experimental drives were not balanced across conditions, which possibly led to learning or order effects. This procedure was derived from Fillmore et al. (2008) and Jongen et al. (2011). The latter used the same driving scenario, as well as a monetary reward to the second trip (rather than the presence of peer passengers), and found similar results. More specifically, they found a similar decrease in SDLP, which possibly indicated the distracting effects of contemplation on the instructions to obtain the reward. However, although Jongen et al. (2011) found increased speeding and red-light running in the drive that included reward, the decrease in collisions was not found (i.e., amber-light running and hazard approach were not analyzed). Therefore, the decrease in collisions possibly included unique peer passenger effects (i.e., protective effects) rather than being subject to learning effects. Nevertheless, a replication of the current design to include counterbalanced drives is definitely warranted.

Second, we did not observe or analyze, the interaction of driver and passenger. Inclusion of interactions would have permitted additional investigation of explicit motivations of peer passengers to take more risks. By analyzing such motivations it would have been possible to determine whether the peer passenger was risk prone or risk averse (Simons-Morton et al., 2011) and, related to the discussion above, whether the increase in violations was intentional or unintentional. For example, unintentional violations may be caused by the distracting effects of peer passengers. Similarly, although red-light running currently was considered a blatant disregard of traffic lights and therefore a violation, it could also be caused by inappropriate cognition and decision-making if they failed to detect the light, possibly due to distraction (Young et al., 2013a; Young et al., 2013b). However, peer passengers can also passively influence behavior (Centifanti, Modecki, MacLellan, & Gowling, 2014). Therefore, additional driving parameters could alternatively reveal the intention of the driver. Going back to the example of the traffic light, acceleration towards the light could indicate an intentional violation.

A third limitation of this study was the sample composition. The inclusion criteria complicated the recruitment of a balanced sample in terms of both driver and passenger sex. Therefore, we were not able to analyze the effect of passenger sex, which limited the conclusions that could be drawn, given that variations in driving performance in function of sex differences have been shown by others (McKenna et al., 1998; Ouimet et al., 2010; Simons-Morton et al., 2005). We were also not able to gain an equal distribution of driving experience between the age groups. As driving experience was confounded with the age variable, it had to be excluded from the analyses. Finally, because it has been found that effects of peer passengers are stronger for males (Ouimet et al., 2013), the inclusion of only males in the current study might have led to a more prominent moderating role of inhibitory control.

Finally, we used a median split to easily interpret the interaction of speeding and inhibitory control. A median split was preferred over a mean split to reduce the possibility that extreme scores may alter the results. Nevertheless, despite the easy interpretation of the results, this approach could have reduced the statistical power of the results and essential information could be lost (Altman & Royston, 2006).

6. Implications

Although a large gap exists between developmental issues and public policies, the insights coming from research on cognitive development can be applied to programs aimed at the reduction of injury risk for adolescents and young adults, such as GDL (Graduated Driver Licensing) (Johnson & Jones, 2011; Spear, 2013). Instead of reducing risks by increasing age restrictions, GDL systems limit risky circumstances. To accomplish this, GDL not only reduces exposure to passenger presence, but also restricts other demanding conditions (e.g., nighttime driving) until driving behaviors become less cognitively taxing with increasing driving experience, similar to the idea of intuitive decision making (Johnson & Jones, 2011). Although this approach has been shown to be effective, it does not eliminate the problem because some drivers will still drive with peer passengers, even when not allowed (Williams, Ferguson, & McCartt, 2007). Therefore, based on the current results, a complementary approach can be provided, that targets peer passengers to serve as additional risk detectors (e.g., improving cognitive and decision-making performance).

With respect to risky driving, one can indeed assume on the basis of other research (e.g., Lenné, Liu, Salmon, Holden, & Moss, 2011; Shepherd et al., 2011) that more safety-related statements, and fewer risk-supportive statements, could reduce violations. A similar approach was suggested by Lenné et al. (2011). They evaluated a pilot program where communication training in male driver passenger pairs improved driving behavior, which allowed the passenger to be a useful resource in the critical learner phase. Interestingly, cognitive control can be trained, which could lead to improvements in driving performance (Cassavaugh & Kramer, 2009). Adding inhibitory control training to existing programs might therefore positively affect the ability of a subgroup of young novice drivers to better resist peer influences. Nevertheless, more research will be necessary because cognitive control might also positively relate to risky driving.

7. Future directions

The current design could be extended in a number of ways: An older control group could be included for additional analysis on the effect of age. The design could include additional cognitive control measures such as planning or working memory that are known to develop at a later age. Additional driving parameters relating to the current but also to additional driver errors could also be included. For example, distraction could be measured with eye glances. Overtaking on the inside would be considered a violation, while misjudged gap selection reflects cognition and decision-making. Finally, misreading a road sign indicates information retrieval (Ouimet et al., 2013, Stanton & Salmon, 2009). Other possible confounding factors, such as personality (e.g., sensation seeking: Mirman, Albert, Jacobsohn, & Winston, 2012), and socio-emotional factors (e.g., mood: Rhodes, Pivik & Sutton, 2015) could potentially benefit additional future analysis. Recordings of the interaction between the driver and the peer passenger could be combined with eye tracking to determine the potential cause of the protective effects. Were peer passengers serving as additional risk detectors, or were protective effects caused by increased exploratory scanning behavior and learning in a social environment (Silva, Shulman, Chein, and Steinberg, 2015)? Future studies could also include brain measurements to fully determine the developmental processes that are at play.

Future research could focus on multiple peer passenger situations. Multiple peer passengers may increase risk-taking tendencies, especially if passengers are risk supportive. To illustrate, multiple peer passengers led to speeding in young male drivers (Ferguson, 2013). Furthermore, multiple passenger situations are expected to be more distracting, and it is those chaotic driving conditions that are most dangerous when combined with a lack of driving experience (LaVoie, Lee, Parker, & Winston, 2013; Foss & Goodwin, 2014).

8. Conclusion

Taken together, the current results provide initial support for a dual process theory of risky driving. The driver error taxonomy from Stanton and Salmon (2009) allowed interpretation of the results in terms of the function of different underlying mechanisms. The results showed that distractive effects of peer passengers were reflected in reduced lane-keeping variability. Risky driving was more prevalent in the presence of peer passengers in the cases of red-light running (violation), and speeding (violation) in a subgroup of drivers with low inhibitory control. Possible protective effects were present in situations where the driver was subject to the risks of making cognitive or decision-making errors (e.g., detecting road hazards). Nevertheless, as inhibitory control only had a limited effect, additional research that takes the current limitations into account and includes an extended design will be necessary. Possible implications for driver programs currently based on developmental research (e.g., GDL) can be made.

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Footnotes

[1] Stanton and Salmon (2009) described a more extended error taxonomy not only containing psychological mechanism classifications but also subdivisions of these classifications as well as external error modes. For example, belonging to the underlying mechanism ‘action’, there is a subdivision of ‘action execution’ with a possible external error mode of ‘wrong action’. A specific example of this error mode is “Press accelerator instead of brake”. Furthermore, they also included a taxonomy of road transport errors. Their work led to a range of possible technologies that could be used to prevent or mitigate driver errors. This taxonomy was later revised and applied to issues such as driver distraction and intersection negotiation. For more information, refer to: Stanton & Salmon, 2009; Young & Salmon, 2012; Young et al., 2013a; and Young et al., 2013b.

PART 2

Young novice drivers with an autism spectrum disorder

"Different, not less" — Temple Grandin

GENERAL INTRODUCTION

“Autism is the most severe developmental disability. Appearing within the first three years of life, autism involves impairments in social interaction, such as being aware of other people’s feelings, and verbal and nonverbal communication. Some people with autism have limited interests, strange eating or sleeping behaviors or a tendency to do things to hurt themselves, such as banging their heads or biting their hands.” (APA, sd).

Autism spectrum disorders according to the DSM-V

Diagnosis of ASD is based on official diagnostic systems, for instance the American Psychiatric Association’s Diagnostic and Statistical Manual of Mental of Disorders (DSM). Recently, the DSM-4 (i.e., from 1994) has been updated to the DSM-5 (i.e., from 2013). The main change in diagnosis of ASD from the DSM-IV to the DSM-V is that the DSM-V removed the ASD clinical subtypes (e.g., Asperger). The DSM-V instead identifies core ASD and non-ASD specific characteristics that both vary within ASD populations. Where the DSM-IV discussed a triad of symptoms that models communication deficits separate from social impairments and required language difficulties, the DSM-V speaks of a two-domain model. In this model, the only core ASD specific symptoms relate to social-communication deficits and restricted and repetitive interests/behaviors (see Fig. 27). Instead of the multiple categories, the DSM-V includes a series of specifiers. The first indicates whether there is a known etiology (e.g., genetic syndrome, or environmental exposure). The second is a severity specifier, indicating the impact on life across the two domains (social communicative and repetitive behaviors), ranging from one to three (i.e., low to high need for support). The third indicates whether they are impaired intellectually. The fourth addresses language impairment (i.e., provided separately for receptive and expressive language). Finally, the fifth indicates whether catatonia (i.e., disturbances in motor behavior) is present (Volkmar & McPartland, 2014).

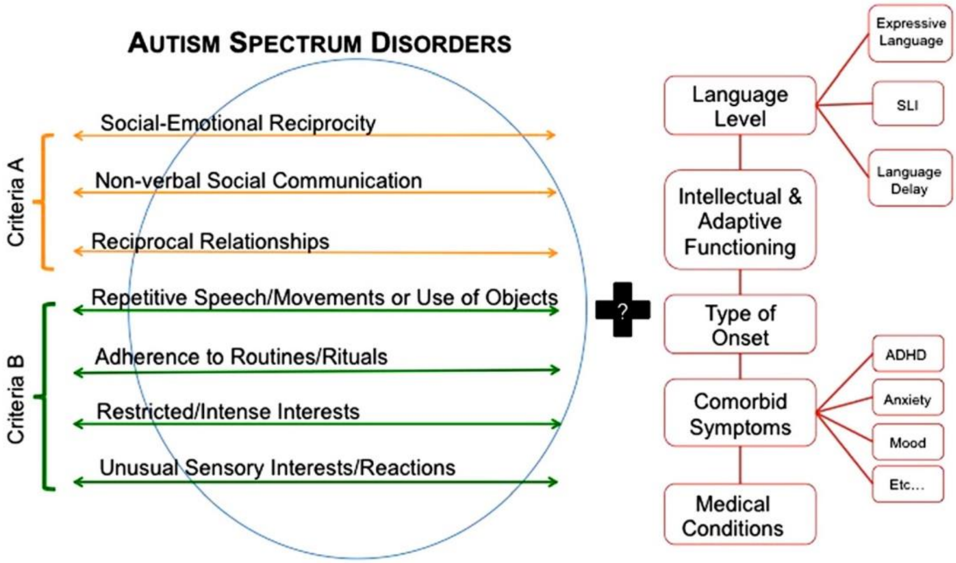

Figure 27: Proposed Diagnostic and Statistical Manual of Mental Disorders, 5th edition (DSM-5) criteria and associated features to be considered when characterizing ASD samples. Source: Grzadzinski et al. (2013).

Autism spectrum disorders and driving

People with ASD experience difficulties in coping with daily life demands (Kretschmer et al., 2014). As driving is an important mean to gain independence and maintain work- and social-related contacts (Ross et al., 2015), the relation between ASD and driving warrants attention.

Learning to drive presents substantial challenges for young novice drivers with autism spectrum disorders

Learning to drive requires a big effort for some young people with ASD. Several factors can be related to the success or failure in learning to drive and to effectively driving after obtaining the license. These factors range from indicators of functional status (e.g., attending regular education, performing a paid job), and previous experience of parents to teach driving skills, to the encouragement from the school. Schools that include car-related goals in the individual study plan also determine the success rate of learning to drive (Huang et al., 2012).

An American survey of parents and educators (Cox et al., 2012) showed that learning the basic skills associated with driving (e.g., controlling speed and maintaining lane position) did not present problems for young novice drivers with ASD. Learning more complex skills (e.g., merging into traffic and multi-tasking) did pose great challenges. The parents gave the following valuable tips: adequate exercise and repetition, dividing the driving task into small subtasks, practice-related activities (e.g., video games or driving a go-cart), starting in a low-risk environment, additional training in multitasking (e.g., speed control during merging), exercising in interpreting the actions of other drivers (e.g., reading nonverbal social cues, especially in ambiguous situations), managing unexpected changes in the driving environment (e.g., GPS use in case of an unexpected diversion), first discuss or visualize any new ride, practice sustained attention to complex traffic situations and, finally, applying patience.

Characteristics of autism spectrum disorders may interfere with driving

Despite a recent upsurge, research investigating driving in ASD drivers has been sparse compared to research investigating attention deficit hyperactivity disorder (ADHD) and driving. Certain characteristics associated with ASD (i.e., including specific and non-specific ones) may interfere with driving. For instance, individuals with ASD are limited in understanding and predicting others' behavior, possibly causing inadequate judgments of other road users' behavior (Ross et al., 2015). Indeed a previous study, using video images, already showed a slowed reaction to road hazards, and especially to social hazards (Sheppard et al., 2010). Cognitive dysfunction, reflected in limited self-monitoring, creativity, mental flexibility and planning abilities, can cause driving to be stressful and dangerous (Ross et al., 2015). This was confirmed by a study from the US where ASD drivers drove more poorly overall and with a secondary WM task they showed a significant performance decrement compared to a control group (Cox et al., 2016). Furthermore, as emotional regulation issues are also at risk of impairment (Mazefsky & White, 2014), and evidence suggests that young adults with ASD are at increased risk for anxiety (van Steensel et al., 2011; Vasa & Mazurek, 2015), it is possible that they might become apprehensive toward driving, or drive recklessly in emotionally laden situations. This is supported by research where young drivers with ASD show sympathetic symptoms (i.e., related to heart rate and skin conductance) and increased gaze focus during simulated driving, possibly indicating stress and anxiety (Reimer et al., 2013; Wade et al., 2014). Furthermore, Chee and colleagues (2014) found reports of drivers that were anxious towards driving. The latter group was comprised of unlicensed drivers and learner drivers. On the other hand, as safe driving depends on motivational factors, youth with ASD might follow traffic rules more strictly and adopt cautious driving styles, leading to decreased crash risks compared to non-autistic peers

(Ross et al., 2015). The latter was supported by a survey (Huang et al., 2012) indicating that young drivers with ASD received less fines and were less involved in accidents compared to neuro-typical young drivers. Furthermore, their parents indicated that they followed the rules more strictly and were less reckless during driving. This rule-bounded rigidity however might be problematic when unexpected events occur (e.g., a road obstacle requiring full-line-crossing).

Autism spectrum disorders and virtual reality driving simulation training

VRDS offers a safe environment to assess and provide targeted intervention for individuals who are in the process of obtaining a driver’s license (Adler et al., 1995; Brooks et al., 2013; Hoffman et al., 2002). Applied to the needs of adolescents and young adults with ASD, the use of VRDS allows: a controlled and safe environment, naturalistic settings, repetition, modified scenarios to foster generalization of learned skills, a primarily visual world, preferred computer interactions, reduced boredom and fatigue, individualized approach, and the inclusion of eye-tracking (Bölte, 2004; Parsons et al., 2004; Strickland, 1997). The latter allows the inclusion of feedback on gaze guidance, which provides important training benefits as eye gaze patterns indicate driver's competence and gaze training increases driver's competence (Malik et al., 2009; Pradhan et al., 2007). VRDST has already shown to successfully improve driving performance. For instance, VRDST improved driving performance in elderly drivers (e.g., Casutt et al., 2014), as well as visual search for hazards in young novice drivers (Vlakveld et al., 2011). Furthermore, VRDST proved to be useful for other populations. For instance, improved driving performance, accompanied by a reduction in road rage and risky driving, in military personnel recovering from traumatic brain injury (Cox et al., 2010).

RESEARCH QUESTIONS

The current thesis aimed to investigate driving behavior in young novice drivers with ASD by:

1. Investigating difficulties that may occur when learning to drive in young novice drivers with ASD
    a. Do Flemish driver instructors report difficulties when teaching young novice drivers with ASD how to drive?
2. Investigating whether the performance of young novice drivers with ASD can be enhanced by VRDST
    a. Will the driving performance of US young novice drivers with ASD be improved after VRDST?
    b. Will VRDST focusing on driving-relevant cognitive control functions improve that ability?
    c. Can VRDST be enhanced by adding automated feedback and/or eye-tracking?
3. Investigating indications of apprehensive driving and methods to alleviate apprehensive driving in young novice drivers with ASD
    a. Do US young novice drivers with ASD report more negative attitudes and less positive attitudes towards driving?
    b. Can these attitudes be improved by VRDST?

CHAPTER 5

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Exploring the driving behavior of youth with an autism spectrum disorder: a driver instructor questionnaire.

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In the following chapter, I was involved in the design and methodological execution, data collection, analyses, and dissemination (presentation at conferences and writing of the paper).

Abstract

Youth with an autism spectrum disorder (ASD) depend to a great extent on friends and family for their transportation needs. Although little research exists, Cox et al. (2012) surveyed parents/caregivers of youth with ASD (previously) attempting to learn to drive. This study serves as an extension by surveying driver instructors. Several questions queried advice for teaching youth with ASD how to drive, and for improving the current driving education to better fit the needs of youth with ASD. Furthermore, respondents were asked to indicate whether specific characteristics, often associated with ASD, have an impact on driving ability. A total of 52 driver instructors reported potential problems when teaching youth with ASD to drive. Advice for teaching youth with ASD to drive mainly focused on a need for structure, clarity, visual demonstration, practice, repetition and an individualized approach. Results however also showed that the relation between ASD and driving performance might not always be negative but can be positive. Practical implications are provided.

1. Introduction

Driving allows autonomy and permits maintenance of social- and work-related contacts (Cox, Reeve, Cox, & Cox, 2012; Reimer et al., 2013). Nevertheless, youth with an autism spectrum disorder (ASD) depend to a great extent on friends and family for their transportation needs (Feeley, 2010). Driving is a complicated task with subtasks running in parallel. During driving one might also encounter sudden changes (e.g. traffic jams, road blocks and detours). Driving thus relies heavily on driving experience, perceptual and cognitive abilities (Ross et al., 2014).

Certain characteristics, associated with ASD, might interfere negatively with driving. For instance, visual information processing problems can lead to atypical processing of road hazards (Sheppard, Ropar, Underwood, & van Loon, 2010). Furthermore, individuals with ASD are limited in understanding and predicting others' behavior (Zalla, Sav, Stopin, Ahade, & Leboyer, 2009), possibly causing inadequate judgments of other road users' behavior. A limited ability to plan and execute actions in response to environmental changes can cause a slowed driving style (Glazebrook, Elliott, & Szatmari, 2008; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Executive dysfunction, reflected in limited self-monitoring, creativity, mental flexibility and planning abilities, can cause driving to be stressful and dangerous (Hill, 2004; Van Eylen et al., 2011). Mental inflexibility does not mean that youth with ASD are incapable of rule-learning, rather, switching between rules, or situations without specific instructions, can be problematic (Van Eylen et al., 2011; Brady et al., 2013). Their rule-bounded rigidity might be problematic when unexpected events occur (e.g., a road obstacle requires full-line-crossing). On the other hand, as safe driving depends on motivational factors (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002), youth with ASD might follow traffic rules more strictly and adapt cautious driving styles, leading to decreased crash risks compared to non-autistic peers (Porter, 2011).

Although little research exists on the relation between ASD and driving, Cox and colleagues (2012) surveyed parents/caregivers of youth with ASD attempting, or previously attempting, to learn to drive. Questions addressed reasons for the driving status, driving experiences, the relation between ASD and driving, as well as teaching strategies (i.e., effective and ineffective) for learning youth with ASD to drive. Results showed that, in comparison to relatively easy driving skills (e.g., maintaining lane position), complex driving skills, such as merging into traffic or multi-tasking, were reported as most problematic for youth with ASD. Parents, and others involved in driving instruction (e.g., driver instructors), should be aware of certain ASD specific difficulties: interpreting the behavior of other road users, dealing with unexpected situations, and sustaining attention. This study, which is part of the ongoing “Yes I drive!” project, extends on Cox et al. (2012) by surveying driver instructors. Driver instructors are important sources of information and might be complementary to the opinion of parents/caregivers, by more objectively reflecting the teaching process.

2. Methods

2.1. Survey development

The introduction of the survey enclosed basic ASD information, aiding driver instructors to identify learner drivers with ASD; the remainder consisted of demographic questions, as well as open and closed questions addressing the relation between ASD and driving. Respondents were asked to respond to all questions with the answer that best suited their professional opinion. They were able to skip questions for which they did not have an answer. First, it was determined whether they encountered youth with ASD (e.g., ‘How often do you provide driving lessons to youth with ASD?’). After which their advice on teaching youth with ASD to drive was queried (e.g., ‘How can the current driving education be improved to better fit the needs of youth with ASD?’). Closed questions, describing possible perceptual, motor and cognitive problems related to ASD, were based on existing literature and the questionnaire by Cox et al. (2012). Respondents were asked to indicate whether they thought specific characteristics, often associated with ASD, have an impact on driving ability (e.g., ‘difficulties with motor planning’). The response scale consisted of five answering categories ranging from no impact to high impact. Examples were provided for each question.

2.2. Recruitment and Respondents

A web-based link was sent to driving schools in Flanders (i.e., the Dutch-speaking region of Belgium). From 144 driver instructors, 98 completed the questionnaire (dropout rate 44%). About 50% had experience with ASD, and were willing to complete the questionnaire. The final sample therefore consisted of 52 driver instructors (40 males), aged 31 to 65 (*M* 50.10, *SD* 9.10) with driver instructor experience ranging from 1 to 37 years (*M* 15.79, *SD* 10.31).

3. Results

3.1. Open questions

Conventional content analysis provided coding schemes for the open ended questions (i.e., coding themes were derived directly from the responses; Hsieh & Shannon, 2005).

3.1.1. What stands out when youth with ASD learn how to drive?

Personality: A recurring remark was a lack of initiative, interaction and/or empathy in youth with ASD. Some driver instructors however reported high motivation and perfectionism. Finally, some reported that youth with ASD can be overly busy whereas some reported extremely silent. Emotion: Some reported that youth with ASD are unconfident and extremely cautious, whereas others reported that that they are overconfident and incautious. A display of emotional reactivity, when youth with ASD received negative feedback, when sudden changes were encountered and when confronted with other drivers' traffic violations, was reported. Cognition: Typical cognitive characteristics of ASD were reported (i.e., problems with multi-tasking and self-regulation, slowed information processing, too focused on details). Difficulties with judging and reacting to traffic situations were also reported. Finally, it was reported that youth with ASD display abstract and rigid reasoning, and interpret conversations, instructions and logic literally. Learning: As reported, difficulties with complex situations and generalization of skills might be alleviated by providing structure, clarity, repetition, demonstration, and visualization. Some driver instructors also recommended shorter lessons, and/or a slower lesson pace, as youth with ASD usually need more time and might be quickly tired. Motor performance: Reports were made of rigid movements, motor tics and motor coordination difficulties.

3.1.2. Do you experience strong assets of youth with ASD while driving?

Yes/no: Some driver instructors merely responded with 'yes' or 'no'. Personality: Some driver instructors considered perfectionism, conscientiousness, motivation and interest as strong assets of youth with ASD. A persistent and grateful personality was also reported. Emotion: Some driver instructors indicated that youth with ASD have a sensitive personality with an ability to relate to other road-users. One driver instructor reported the necessity of a personal bond with the learner driver in order to experience such strong assets of youth with ASD. Cognition: Youth with ASD were given credit for their concentration, memory, intelligence, perceptiveness, and the ability to notice details. Learning: Some driver instructors mentioned that youth with ASD are quick, systematic learners (i.e., structure is important) that require little explanation. They were also reported as being rule-bound, displaying thorough knowledge of traffic rules and correctly executing learned materials.

3.1.3. What are needs of youth with ASD when learning how to drive?

Instructor: It was advised not to dwell on the diagnosis but to treat them equal to other learner drivers. Concerning interaction with the learner driver, some driver instructors advised to nuance, display tranquility, patience and bi-directional trust, and avoid staring. An individualized approach and adapted communication (i.e., scarcity in words, neutral intonation, avoiding closed questions) were also considered important. Lessons: Again, reports were made of an increased number of lessons with a shorter duration, including additional rest periods, as well as structure, visualization, demonstration and repetition. Changes in teaching strategies were discouraged. The importance to focus on one task at a time, provide directed and concrete instructions, formulate specific goals, create familiarity (i.e., same instructor and vehicle) and reduce uncertainty (i.e., discuss possible scenarios), were reported. The use of motivational strategies, while avoiding negative criticism, was also advised. Environment: It was reported that, ideally, lessons should start at a practice court after which it is necessary to include plenty of practice in real traffic environments. A visit to the exam center before the actual examination was considered useful. Others: An automatic gear was reported to reduce driving task complexity. Psychological tests were reported to be helpful for determining whether youth with ASD are capable of learning to drive.

3.1.4. How can the current driver education program be improved in order to better fit the needs of youth with ASD?

I don't know: Some driver instructors merely responded with 'I don't know'. Instructor: The need for ASD-specific driver instructor courses was recurrently mentioned. As for teaching style, it was reported to base this on tranquility, patience, kindness, and coaching. Some driver instructors stressed cooperation, with for instance, parents, mentors or the educational system, as this should increase motivation and trust, and provide knowledge of diagnosis and severity. Lessons: Switches between instructors were discouraged while driving lessons tailored to the needs of the learner was encouraged. Again, an increased number of lessons with a shorter duration was recommended in which instructors provide structure and repetition, a combination of theory and practice, content beyond basic teaching packages, and an increase of practical exercises. Exams: Also suggested was the need for adapting driving exams, and cooperation with official test centers (e.g., hire professionals for teaching or exam admission). Others: It was recommended to start with driving simulation, and to drive with an automatic gear. Some driver instructors opted to provide learners with financial aids to pay for increased time and effort from the instructors.

3.2. Closed questions

Respondents indicated whether specific characteristics, often associated with ASD, impact driving ability (Table 17). Items were all scored above average (> 3). The most problematic items were 'Difficulty with concentration/attention' (e.g., allocate attention to relevant sources), 'Difficulty with emotional self-regulation' (e.g., stress due to a busy traffic environment) and 'Difficulty with unexpected routine changes' (e.g., a detour on a normally familiar route). The least problematic were 'Difficulty with motor planning' (e.g., sequence of actions necessary to start to drive) and 'Difficulty with sensory overstimulation' (e.g., due to neon signs).

Table 17: Responses to the closed questions (1 = no impact, 5 = high impact).

Question	1	2	3	4	5	Total responses	M	SD
Difficulty with motor planning	0	18	13	15	4	50	3.10	0.99
Difficulty with multitasking	0	7	20	13	10	50	3.52	0.95
Difficulty with concentration/attention	0	4	10	24	14	52	3.92	0.78
Difficulty judging other's behavior	0	4	14	20	12	50	3.80	0.82
Difficulty with emotional self-regulation	0	4	11	15	22	52	4.06	0.98
Difficulty generalizing information	0	8	15	18	10	51	3.59	0.98
Difficulty with unexpected routine changes	0	4	11	17	17	49	3.96	0.96
Difficulty breaking traffic rules	0	12	12	15	9	48	3.44	1.07
Difficulty with other's braking traffic rules	0	8	7	19	12	46	3.76	1.04
Difficulty with sensory overstimulation	0	16	11	17	3	47	3.15	0.98

4. Discussion

This study surveyed driver instructors regarding the driver behavior of youth with ASD. Flemish driver instructors who encountered learner drivers with ASD acknowledged potential problems. When considering the open questions, the need for structure, clarity, visual demonstration, practice and repetition, and an individualized approach were recurrently noted. This coincides with literature describing benefits of structure, overview, clarity, imagery, concreteness, etc., for people with ASD (Cox et al. 2012; Van Eylen et al., 2011; Vermeulen, 2013). Responses were not always consistent, rather often contradicting each other. For instance, perfectionism was rated beneficial as well as detrimental for driving performance. The relation between ASD and driving performance might thus even be positive. This diversity between learner drivers supports the current classification of autism as a "spectrum" disorder with ASD specific and non-ASD specific characteristics (e.g., intelligence) varying from person to person, accounting for the variation in the capabilities and limitations of people with ASD (Grzadzinski, Huerta, & Lord, 2013; Vermeulen, 2013). Strikingly, for the closed questions querying the impact of possible perceptual, motor and cognitive problems related to ASD, driver instructors never indicated a lack of impact on driving. This is different from the perspective of parents/caregivers in the study from Cox et al. (2012) where a lack of impact was provided in each of the ratings, of the impact of specific characteristics associated with ASD, on their son/daughter's driving skills. This study entailed some limitations. First, while this survey extended on Cox et al. (2012) by assessing the perspective of driving instructors, it will also be of interest to survey youth with ASD themselves and thereby get insights in their own perspectives of the matter. Second, there is a chance of misclassification and of under- or over-diagnosis by the driver instructors. More research on the relation between driving and ASD is therefore warranted. Third, although the closed questions queried the potential impact of difficulties often related to ASD, the questions did not query whether the driver instructors observed those difficulties in youth with ASD, nor did the questions specifically queried the relative impact of those characteristics for ASD. Therefore, driver instructors might have answered those questions generally, which might have caused the lack of impact for each item.

5. Conclusion and implications

Similar to Cox et al. (2012), the results indicate that learning to drive presents a substantial challenge for youth with ASD. This survey provides relevant information for future research concerning the relation between driving and ASD. The results also entail some practical implications. For instance, financial aids and driver instructor courses might improve the accessibility of driving lessons for youth with ASD. Furthermore, although not specifically queried, driver instructors indicated driving simulation as a mean to familiarize ASD learner drivers with driving. Driving simulation has been proven to be a valid, safe and efficient method to assess and train drivers in a controlled manner, including a wide range of road and traffic conditions (Mayhew, et al., 2011; Reimer, et al., 2013; Rosenbloom & Eldror, 2014). But research addressing driving simulation as a tool specifically for youth with ASD is still lacking. Another study (i.e., in the data collection phase) from the ongoing "Yes I drive!" project however will investigate hazard perception, and the underlying mechanisms (i.e., executive functioning and action observation), in youth with ASD, using a driving simulator, an eye tracker, and computer tasks (e.g., a computerized stop signal task). In the near future, the "Yes I drive!" project will also entail the development of driver training packages for youth with ASD.

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CHAPTER 6

Submitted to Journal of autism and developmental disorders

Can youth with an autism spectrum disorder use virtual reality driving simulation training to evaluate and improve driving performance- an exploratory study.

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In the following chapter, I was involved in the analyses and dissemination (writing of the paper).

Abstract

Objective: Investigate how novice ASD drivers differ from experienced neuro-typical drivers and whether Virtual Reality Driving Simulation Training (VRDST) improves driving performance. Procedure: 51 novice ASD drivers (μ age = 17.96 years, 78% male) were assessed at pre- and post-training for driving-specific executive function (EF) abilities and tactical driving skills and randomized to Routine Training (RT) or one of three types of VRDST (8-12 sessions). All participants followed DMV guidelines for behind-the-wheel training necessary for a full driver's license. Results: Compared with experienced drivers, ASD drivers showed worse baseline EF and driving abilities. At post-assessment, compared with RT, VRDST significantly improved driving and EF performance. Conclusion: This study demonstrated the feasibility and potential efficacy of VRDS to train novice ASD drivers.

Key words: Autism, Asperger, driving, virtual reality, driving simulation, driving safety

1. Introduction

1.1. Virtual Reality Driving Simulation Training

VRDST, which involves real-time interaction with a driving console and a virtual world (see Fig. 28), offers a safe environment to assess and provide targeted interventions for individuals who are in the process of obtaining a driver's license (Adler, Resnick, Kunz, & Devinsky 1995; Brooks, Mossey, Collins, & Tyler 2013; Hoffman, Lee, Brown, & McGehee 2002). Applied to the needs of adolescents and young adults with an autism spectrum disorder (ASD), the use of VRDST allows for repetition in a controlled and safe environment, naturalistic settings in a primarily visual world, modified scenarios to foster generalization of learned skills, an individualized approach, preferred computer interactions, reduced boredom and fatigue, and the inclusion of eye-tracking (Bölte 2004; Parsons, Mitchell, & Leonard 2004; Strickland 1997). The latter allows feedback on gaze, which provides important training benefits because eye gaze patterns indicate, and gaze training increases, drivers' competence (Malik, Rakotonirainy, & Maire 2009; Pradhan, Pollatsek, & Fisher 2007).

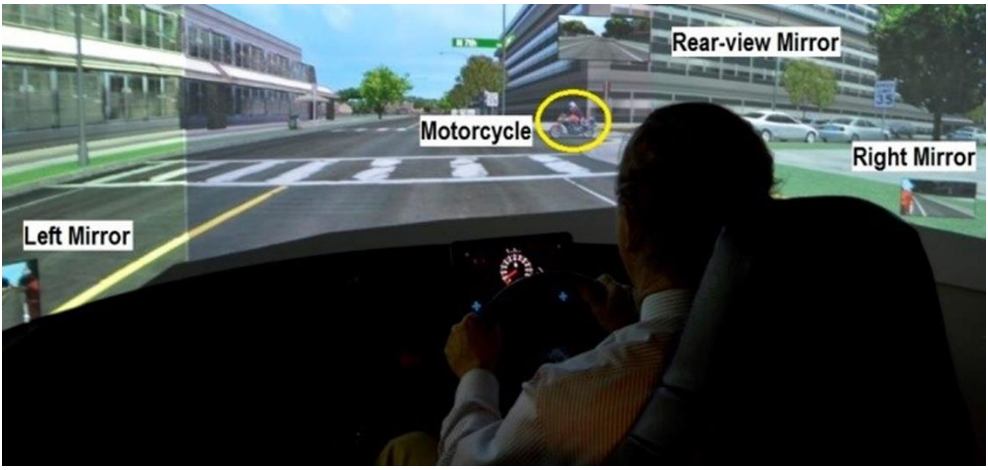

Figure 28: Simulator Displaying a Road Hazard (Motorcyclist Emerging from Behind Traffic) Requiring a Defensive Maneuver.

VRDST has already shown successful improvement in driving performance and prediction of future driving mishaps (collisions and citations for moving vehicle violations). For example, VRDST improved driving performance in elderly drivers (Casutt, Theill, Martin, Keller, & Jäncke 2014) and novice drivers learning to drive (Cox, Moncrief, Wharam, Mourant, & Cox 2009), and improved visual search for hazards in young novice drivers (Vlakveld et al. 2011). Furthermore, VRDST proved useful for patient populations. For instance, VRDST improved driving performance in individuals recovering from stroke (Akinwuntan et al. 2005) and military personnel recovering from traumatic brain injury (Cox et al. 2010) who also experienced a reduction in road rage and risky driving. Performance on virtual reality driving simulation can predict future driving mishaps of both novice drivers (Cox et al. 2015b) and senior drivers (Cox, Taylor, & Kovatchev 1999). Consequently, employment of virtual reality driving simulation holds promise in the identification of driving challenges specific to those with ASD and training of both general driving skills and targeted ASD-specific driving challenges.

1.1. Driving with autism spectrum disorder

Only a limited number of studies have used driving simulators to assess driving skills in ASD, and on-road studies have never been reported. This gap in the research is surprising given the critical role that motor vehicle driving plays in adolescent development and functional independence. For individuals with and without ASD, acquiring a driver's license is associated with increased participation in full-time academic programs, plans to attend college, and a history of paid employment (Huang et al. 2012). The recent upsurge in research on motor vehicle driving for individuals with ASD reflects an improved understanding of this disorder's lifetime course and changing functional impairments across development (Classen & Monahan 2013; Classen, Monahan, & Hernandez 2013; Cox, Reeve, Cox, & Cox 2012; Huang, Kao, Curry, & Durbin 2012; Reimer et al. 2013; Sheppard, Ropar, Underwood, & van Loon 2010). While many individuals with ASD have secured a driver's license and are able to safely operate a motor vehicle, emerging research indicates that the acquisition of safe driving skills is often difficult for this population (Classen et al. 2013; Cox et al. 2012; Huang et al. 2012; Ross et al. 2015b). Therefore, individuals with ASD are less likely than their peers to acquire a driver's license, or if they do acquire a license, they obtain it significantly later (Cox et al. 2012; Daly, Nicholls, Patrick, Brinckman, & Schultheis 2014).

Difficulties in learning to drive may be caused by the negative interference of characteristics that are often associated with ASD. For example, executive functioning difficulties, reflected in limited self-monitoring, creativity, mental flexibility, and planning abilities, could cause driving to be stressful and dangerous (Ross et al. 2015b). Previous research indicated that including executive functioning is warranted in research of this nature. First, executive functioning has been related to driving performance in adolescents and young adults with ASD (Cox et al. 2016). It has also been related to driving performance in other populations, such as neuro-typical adolescents and young adults (Lambert, Simons-Morton, Cain, Weisz, & Cox 2014; Mäntylä, Karlsson, & Marklund 2009; Ross et al. 2015a), the elderly (Aksan, et al. 2012; Freund, Colgrove, Petrakos, & McLeod 2008), and adults with ADHD (Reimer, Aleardi, Martin, Coughlin, & Biederman 2006). Second, executive functioning training has been shown to transfer to driving performance. For example, computer-based cognitive training was found to be predictive of improvements in driving simulator performance in elderly drivers (Ball, Edwards, Ross, & McGwin 2010; Cassavaugh & Kramer 2009).

Adolescents with ASD may be less likely to identify socially relevant road hazards such as pedestrians (Sheppard et al. 2010) and are less likely to monitor all relevant visual fields while driving (Reimer et al. 2013). Another experimental study using eye-tracking technology found that when young male adults were distracted by a mobile phone, both the ASD and control groups increased their gaze focus to the road ahead, therefore paying less attention to the overall driving environment. However, the ASD group especially paid less attention to traffic (Reimer et al. 2013). A study from Wade et al. (2014) replicated these results. They found that the gaze from a group of adolescent ASD drivers was higher in the vertical direction and toward the right in the horizontal direction during simulated driving.

There are a few initial studies that provide indications that adolescents and young adults with ASD face additional difficulties learning to drive. First, it was found that adolescents with ASD showed difficulties with shifting attention, sequential task performance, and the integration/coordination of visuomotor responses. When driving a simulated drive, they performed worse on lane maintenance, visual scanning, speed regulation, signaling, and adjusting to stimuli when compared with healthy controls (Classen et al. 2013; Monahan, Classen, & Helsel 2013).

To further complicate the matter, great variability is present among the ASD population. The relationship between ASD and driving might not always be negative and could even be positive, such as when a tendency for perfectionism could be considered beneficial when learning to drive (Ross et al. 2015b). Developing effective driver-training programs is critical to improving functional outcomes and promoting independence of adolescents and young adults with ASD.

There was no available literature on using VRDST to improve the driving performance of novice drivers diagnosed with ASD, so this preliminary study first investigated how novice ASD drivers differed from “safe” drivers by incorporating unique driving specific measures of executive functioning. VRDST options were next explored to move novice ASD drivers closer in performance to routine drivers.

1.2. Hypotheses tested

This study investigated four main hypotheses. (1) To replicate previous findings comparing novice ASD to novice neuro-typical drivers (Cox et al. 2016), this study first tested whether novice ASD drivers differed from experienced drivers, and by how much, on general (tactical) driving skills and driving-specific executive function (EF) abilities. It was hypothesized that novice drivers with ASD would perform worse on general driving and working memory than experienced drivers. (2) The second hypothesis was that VRDS training would lead to improved general driving performance on a virtual reality driving simulator. (3) It was hypothesized that VRDS training focused on driving-relevant EF would improve that ability. (4) The final hypothesis asserted that VRDS training could be enhanced by adding non-human automated feedback and/or eye-tracking feedback.

2. Methods

2.1. Overview

In this multi-center study, a total sample of 51 individuals (U.Va., n 25, *M* age 17.83, 87.5% male, and U.I., n 26, *M* age 18.08, 73.1% male) were randomized to one of four conditions (Routine Training or one of three variations of VRDST) for three months. All participants had earned their learner's permit but not their full driver's license. Driving-specific EF and general tactical assessments occurred at baseline and after three months of training.

2.2. Facilities

The commercially available Driver Guidance System (DGS-78) VRDS is a realistic driver's cockpit with side- and rear-view mirrors and air conditioning. The driver's view is projected onto a 2.44 m (8 ft) diameter, 210° curved screen (Fig. 1). Performance on this simulator differentiated novice drivers with and without ASD (Cox et al. 2016), as well as drivers with astigmatism for whom astigmatism was or was not corrected (Cox, Banton, Record, & Grabman 2015a). Performance also predicted future driving mishaps during the first six months of independent driving (Cox et al. 2015b), and training on the simulator improved on-road driving of neuro-typical novice drivers (Cox et al. 2009).

The VRDS has two assessment capabilities: EF abilities and general tactical skills (Cox et al. 2016). *Executive function testing* consisted of EF tests that were modeled after traditional neuropsychological tests, e.g., dual tasking, response inhibition, and working memory (see Table 18 for a description). Tests included driving-relevant stimuli, responses, and context. This allowed for enhancement of ecological validity. All tests used the same environment, thus reducing re-adaptation from one test to another. The participant drove down the middle lane of a three-lane highway with the simulator maintaining a constant distance from a lead car at 56.33 km/h (35 mph). To equate task instructions, all participants heard the same instructions, delivered at the same point in the task, by the simulator's synthetic voice. Details of this testing method have been published previously (Cox et al. 2016, Cox et al. 2015a).

Table 18: VRDS executive function tests with task description and selection of primary and secondary variables. **Filtered: mean reaction time scores were only included if a minimum number of trials were responded to, otherwise "-3" was applied for that *z*-score as a conservative method to avoid extreme scores.

Task	Description	Primary	Secondary
Dual Tasking	The lead car's brake lights come on 8 times (4 times for 3 seconds and 4 times for 1-second) and passes over 8 potholes (4 black "deep" and 4 grey "filled" potholes). The participant is to brake to all brake lights and steer around all potholes as quickly as possible.	# of brake lights braked to + # of potholes steered around	Braking and steering reaction times filtered** for inattention errors
Response Inhibition	Same as Dual Tasking but inhibit specific response types (no braking response to brief brake lights or steering response to grey potholes, continue to brake to long brake lights and steer around black potholes)	# of correct braking responses + # of correct steering responses	Braking and steering reaction times filtered** for inattention errors
Working Memory	Same as Response Inhibition with the addition of remembering 1 to 3 road signs recently passed in the order that they appeared	# of signs recalled in correct order	Correct responses to the Response Inhibition component

All three EF abilities tested have been linked previously to driving (Cascio et al. 2014; Cassavaugh & Kramer 2009; Cox et al. 2016; Ross et al. 2014 & 2015a). Dual tasking refers to the simultaneous execution of tasks. Response inhibition assesses the ability to suppress the processing, activation, or expression of information (or action) that would otherwise interfere with the attainment of a desired cognitive or behavioral goal (Dempster 1992; Hofmann, Schmeichel, & Baddeley 2012). Working memory is a limited capacity system responsible for the temporary storage, rehearsal, updating, and mental manipulation of information for use in guiding behavior (Baddeley 2007). The working memory test was a complex span task modeled after the automated operation span task (Conway et al. 2005; Unsworth, Heitz, Schrock, & Engle 2005) and provided an index of overall working memory function. All of the EF tests placed demands on the same stimulus modality – visual. EF composite scores were created for the primary variables of all three tests (see Table 18). Scores were first converted to *z*-scores to allow a common metric and then were summed. Thus, the composite score was an overall reflection of EF driving abilities. A composite score of "0" was average, while a negative composite score was below average.

Tactical testing followed the framework from Michon (1985) that involved maneuvering a vehicle through time and space while negotiating different road and traffic environments and situations (Dickerson & Bédard 2014). It is analogous to an on-road test of driving skills, but performed in a safe and reliable, yet challenging, virtual world. The tactical test involved driving on a standardized route that included 4.2 km (2.6 mi) of rural, 6.4 km (4 mi) of highway, and 3.2 km (2 mi) of urban roads. Drivers negotiated realistic roads with anticipated and unanticipated signal, traffic, and hazard demands. To avoid practice effects, a different tactical course was used for the pre- and post-assessments, but both were similar in mileage and degree of challenge.

Table 19: Tactical variables.

Category	Variables
Braking	Crash (# collisions > 8.05 km/h (5 mph)), Bump (# collisions ≤ 8.05 km/h (5 mph)), Rolling Stop (> 0 and < 8.05 km/h (5 mph) across stop line)
Speed	Tailgating (following within 4.57 m (15 ft) of lead car), Deceleration Smoothness (Braking), Speeding (driving > 8.05 km/h (5 mph) and < 32.19 km/h (20 mph) over posted speed limit), Reckless Driving (driving > 32.19 km/h (20 mph) over limit), Speed Variability (*SD* speed)
Steering	Off Road (seconds off road), Off Path (missed turns), Off Road Resets (10 seconds), Crossing Midline (penetration into oncoming lane), Swerving (*SD* lane position)
Judgement	Number of Lane Changes, Excessively Slow Driving (> 32.19 km/h (20 mph) below limit)

Ninety-eight performance variables, which included swerving, rolling stops, speeding, and collisions, were monitored throughout the routes. Fifteen of these variables were selected for inclusion in a tactical driving composite score (see Table 19; Cox et al. 2015b; Cox et al. 2016). Variable selection was based on a previous assessment of the relationship between variables and crash history of neuro-typical experienced drivers, as well as prior experience with patient groups that involved the selection of variables that readily distinguished between groups while being related to traffic safety. The tactical composite score was calculated similarly to the EF composite score but incorporated tactical variables. Past research has demonstrated the usefulness of a tactical composite score as a valid overall measure of driving performance. For example, it predicted future driving collisions of seniors (Cox, Taylor, & Kovatchev 1999), differentiated drivers with and without ADHD (Cox, Merkel, Hill, Kovatchev, & Seward 2000), and predicted on-road driving performance (Cox et al. 2010) and future driving mishaps of novice drivers during their first six months of independent driving. (Cox et al. 2015). The tactical composite score was the primary VRDS outcome variable.

2.3. Driver training

Routine training (RT) involved giving participating families the state-specific DMV training manual and instructing them to follow the training program detailed in the manual. This included a tracking sheet to document supervised on-road driving experience. *Standard VRDST* involved a minimum of eight and a maximum of twelve one-hour sessions, depending on how quickly the participant progressed through the VRDST modules (see Table 3 for average number of sessions)[Table 3 located before *Comparison Group* heading, a few pages down, after the paragraph beginning "Requiring a learner's permit…"]. Within a training session, the focus alternated between EF driving deficits identified during the baseline assessment and tactical driving skills. Training was a mastery-based program, meaning a participant did not progress to a subsequent stage of training before mastering the earlier training module. During each session, the trainer would first "get behind the wheel" to demonstrate the task to the participant, and then monitor participant performance while providing continual positive verbal feedback.

The training stages were as follows:
1. Review Pre-Assessment, Identify Deficits
2. Maintaining Lane Position on Straight Roads, Curvy Roads, and in Turns
3. Braking, Stopping, and Speed Maintenance
4. Refining Lane and Speed Maintenance with Executive Functioning Tests
5. First Generalization of Skills on a Rural and Urban Route with No Traffic
6. Use of Mirrors and Turn Signals
7. Hazard Detection
8. Multi-Tasking
9. Navigating Traffic
10. Second Generalization of Skills on a Rural and Urban Route with Traffic.

To ensure treatment fidelity across sites and trainers, a structured trainer manual was developed that detailed each step of the training procedure. This manual is available upon request.

Automatic VRDST was identical to Standard VRDST, only now the simulator's computerized voice provided real-time auditory feedback (e.g., "too fast", "did not stop", "wide turn", "tailgating") when the participant transgressed tactical thresholds. These thresholds included

- Driving too fast (against normative population and for specific road segment [e.g., open road with no instructions to change lane or other deceleration instructions]),
- Driving too slow (for specific road segment and against normative population),
- Swerving,
- Rolling stops,
- Missed stops,
- Not using turn signals (lane change and turning),
- Position in lane (for specific road segment and against normative population),
- Turning too wide (for specific road segment and against normative population),
- Turning too tight (for specific road segment and against normative population),
- Tailgating, and
- Bumps/crashes.

Eye-tracking VRDST (Mobile Eye XG, Applied Science Laboratories; Bedford, MA) was incorporated into Standard VRDST in various ways. First, videos were produced by a member of the research team, three per module, of the eye-view while the driving tasks were performed. This largely replaced the trainer demonstration from Standard VRDST. These videos were produced using the eye-tracker; two display options modeled exactly where the participant should look while driving. After viewing the model video, the participant wore the eye-tracker "glasses" during his/her drives, producing his/her own video for review (see Fig. 29). Once a segment was completed, the trainer and participant would review performance. This was particularly helpful around intersections. For example, the trainer could clearly see if a failure to stop was because the participant never scanned for a stop sign or checked the state of the stoplight, or if s/he had checked and either ignored or misinterpreted the sign.

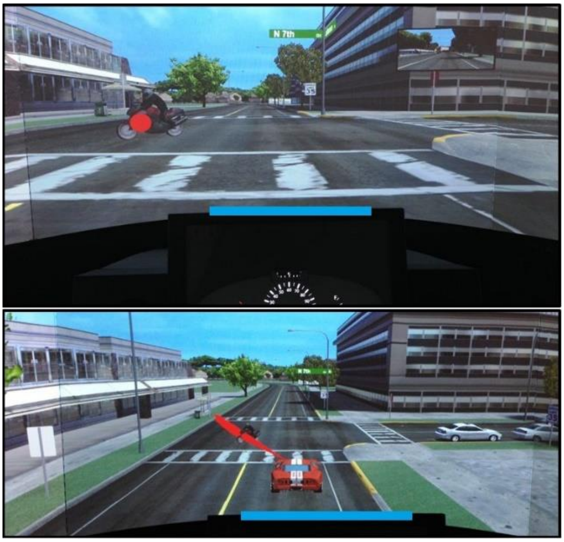

Figure 29: Two types of eye-tracking feedback: driver view (top red dot) & aerial view (bottom red line). The thin light blue horizontal bar above the dashboard represents the position of the integrated eye-tracker.

2.4. Procedure

2.4.1. Assessment phase

Interested adolescents and their parents came to the driving laboratory and were escorted to a private room, then were verbally informed about the study and consented/assented once all questions had been addressed. Informed consent was obtained from all individual participants included in the study. Participants were then screened for inclusion/exclusion criteria. Parents completed a short demographic survey that included specific questions about their child's diagnosis, including the presence of comorbid disorders such as depression or anxiety, as well as the SRS-2, BRIEF, and BASC-2. Parent responses one the SRS-2 were used to confirm a diagnosis of ASD, requiring a score >1.5 standard deviations beyond the norm mean. While parents completed the questionnaires, participants were assessed on the VRDS with both EF and tactical tests. Post-assessment was identical to pre-assessment in terms of the VRDS testing, except a different tactical course was used for the pre- and post-assessments (see Fig. 30).

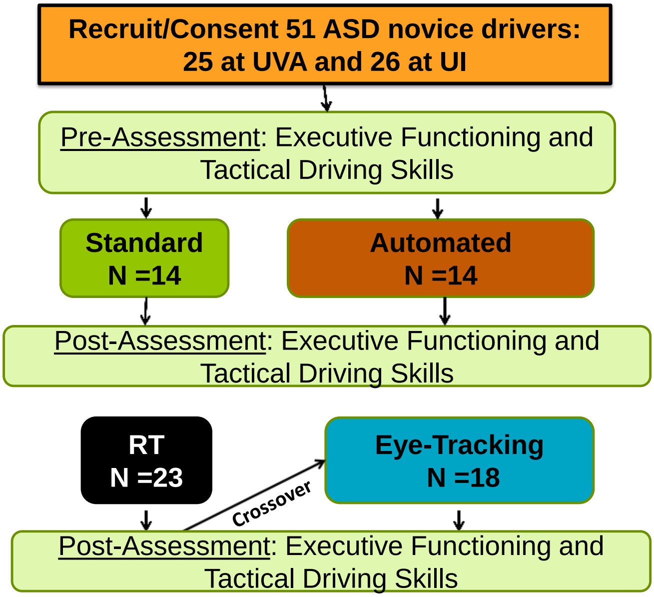

Figure 30: Study flow chart.

2.4.2. Training phase

In this exploratory quasi-experimental design, the initial 28 participants were randomized to either Standard or Automated VRDST during the first year. This allowed for determination of the optimal training condition on which to add eye-tracking the following year. Automated VRDST was not found to be superior to Standard, so eye-tracking was added to Standard VRDST. During the second year, 23 participants were recruited and assigned to the RT group. After completing pre-assessment, three months of RT, and post-assessment, 18 of these 23 participants were subsequently crossed over to Eye-Tracking VRDST. The post-assessment of RT served as the pre-assessment for Eye-Tracking.

This design allowed identification of whether automated feedback was beneficial via analysis of the previous years' data before moving on to the addition of eye-tracking. It also minimized the amount of time RT participants had to wait before receiving training while controlling for season of training and on-road driving (summer). Participant recruitment took place during the spring of 2013 and 2014, and training took place during the summer and fall of each year because the availability of adolescents was highest and weather and road conditions were similar across sites.

2.5. Participants

This multi-center study recruited participants from the catchment areas surrounding the UVa and the UI through newspaper and internet advertisements, flyers, and public announcements. Participants had to meet the following inclusion criteria:

- Diagnosed with ASD (including Asperger's, Autistic Disorder, PDD, or PDD-NOS) by a licensed clinician,
- Parents rating child > 1.5 standard deviations above normative mean on screening questionnaires,
- Have a valid learner's permit,
- Aged 15.5-25 years,
- Able to operate the driving simulator without simulation sickness,
- Able to attend up to 14 study visits (two assessment visits, and up to twelve training sessions) in a three-month period,
- Parent or legal guardian able and willing to provide in-car driving training at home.

No participants were disallowed because of the following exclusion criteria:

- Not able to understand written and spoken English,
- Diagnosis of Intellectual Disability (ID) or Mental Retardation (MR),
- Brain injury,
- Diagnosed genetic disorder or chromosomal abnormality (e.g., Down Syndrome, Prader-Willi Syndrome, Fragile X, Angelman Syndrome),
- Severe physical, medical, or psychiatric condition that impairs driving ability (e.g., muscular dystrophy, psychosis).

Table 20: Demographic data.

Group	*N* assigned/ completed	Mean Age (years)	% Male	Mean # of VRDS sessions
RT	23/19	17.96	73.9	NA
Standard	14/14	17.93	85.7	10.15
Automated	14/13	17.86	85.7	9.69
Eye-Tracking	18/17	18.05	72.7	9.39

Requiring a learner's permit assured basic levels of driving knowledge and intellectual capabilities. Requiring on-road training opportunities served multiple purposes, including allowing transfer of training from the virtual to the physical world and partially satisfying the DMV requirements toward securing an independent driver's license. Five participants dropped out of the study due to scheduling difficulties or family events; one participant dropped out due to simulation sickness. Groups did not differ on demographic variables (Table 20).

Comparison Group. Because ASD novice drivers have already been compared to neuro-typical novice drivers (Cox et al. 2016), this study compared novice ASD drivers to DMV normative drivers in terms of magnitude of difference. These DMV normative drivers were licensed (N = 333), between the ages of 25 and 75, came to the DMV for general business purposes (e.g., registering a car), and drove the VRDS located in the DMV service center. The age range of 25-75 was taken as a conservative normative group because the accident rate per miles driven is relatively flat (Massie, Campbell, & Williams 1995). The ASD drivers were compared to this group rather than a neuro-typical novice driver group for several reasons. The comparison of ASD to neuro-typical novice drivers has previously been reported (Cox et al. 2016). It is very difficult to age match the ASD novice drivers to neuro-typical novice drivers because the ASD group is generally older than the typical novice driver. Neuro-typical novice drivers are a high-risk group and it is preferential to not have the ASD novice drivers emulate a high-risk group. Additionally, the ASD novice drivers have to "stack up" to routine safe drivers, and any deficits relative to this group need to be identified and significantly rectified before assuming independent driving.

3. Results

3.1. Hypothesis 1: Novice drivers with ASD perform worse on general tactical driving and working memory than experienced drivers

Using the DMV normative comparison group's means (M) and standard deviations (SD), z-scores were calculated for the individual EF and tactical variables. These were then summed into composite scores. Independent sample t-tests were executed. If the Levene's test indicated that the variances were not equal, the corrected parameters were reported. In addition to testing the hypothesis, exploratory analyses were conducted on individual performance variables to inform on what differentiated ASD drivers that should be considered in future training programs.

Consistent with the hypothesis, ASD drivers differed from the normative drivers in terms of overall tactical composite score (t -4.54, $p < 0.001$) and EF composite score (t -2.85, $p < 0.01$), (see Table 21 and 22). Exploratory analyses indicated that in terms of driving skills, ASD drivers performed worse on nearly every individual tactical driving variable. However, both groups had a similar number of rolling stops at stop signs and demonstrated similar control of the accelerator (speed variability).

Table 21: M/SD and Md comparing ASD to normative sample in terms of tactical composite and individual variable scores, one-tailed tests.

	ASD		**Normative**			
Variables	***M/SD***	**Md**	***M/SD***	**Md**	***t***	***p***
Composite Score	-29.71/44.10	-16.26	-0.76/21.38	1.58	-4.54	< .01
Excessively Low Speed	-1.45/3.41	-0.39	-0.18/1.41	0.17	-2.59	< .01
Off-Path Resets (Missed Turns)	-1.54/2.52	-1.20	0.01/0.97	0.49	-4.29	< .01
Number of Lane Changes	-3.63/6.42	-1.61	0.39/1.30	0.33	-4.40	< .01
Off-Road Resets	-3.70/8.55	0.10	-0.06/1.24	0.10	-3.01	< .01
Crossing Midline	-1.19/1.73	-0.60	0.06/0.97	0.36	-4.95	< .01
Swerving	-1.53/2.26	-0.95	-0.20/1.00	-0.16	-4.08	< .01
Time Off-Road	-6.44/8.54	-4.19	-1.26/20.13	0.23	-1.79	.04
Rolling Stops	0.08/0.59	0.17	0.02/1.06	0.17	0.44	.33
Deceleration Smoothness	-0.88/4.32	0.51	0.08/1.02	0.30	-1.57	.06
Crashes	-4.75/10.54	-2.81	-0.05/1.08	0.31	-3.15	< .01
Bumps	-2.92/5.12	-1.39	0.02/0.99	0.57	-4.05	< .01
Tailgating	-1.32/1.71	-1.12	0.22/1.07	0.26	-6.16	< .01
Speeding (8.05 km/h (5mph) > limit)	-0.17/1.16	0.36	0.10/0.94	0.48	-1.15	.06
Reckless Driving (32.19 km/h (20mph) > limit)	-0.39/1.81	0.27	0.04/0.91	0.27	-1.63	.06
Speed Variability	0.12/1.59	0.03	0.06/1.24	0.01	0.28	0.39

ASD drivers performed worse on the composite EF variables (t = -2.85, p < 0.01). Specifically, ASD drivers performed worse on the number of correct responses for both dual tasking and response inhibition and the secondary variable of foot/leg reaction time during both dual tasking and response inhibition. ASD drivers did not differ in terms of primary or secondary measures of working memory.

Table 22: M/SD and Md comparing ASD to normative sample in terms of executive function composite and individual variable scores, one-tailed tests.

	ASD		Normative			
Variables	***M/SD***	**Md**	***M/SD***	**Md**	***t***	***p***
Composite Score	-1.20/2.89	-0.55	0.20/1.92	0.43	-2.85	< .01
Dual Processing - # Correct Responses**	-0.48/1.34	0.16	0.08/0.92	0.36	-2.34	.01
Dual Processing - Arm/Hand Reaction Time*	0.07/1.82	0.09	-0.01/0.95	0.11	0.34	.37
Dual Processing - Foot/Leg Reaction Time*	-0.86/1.57	-0.36	0.03	0.13	-3.71	< .01
Response Inhibition - # Correct Responses**	-0.34/1.26	-0.08	0.05/0.96	-0.08	-1.73	< .05
Response Inhibition - Arm/Hand Reaction Time*	-0.26/1.87	-0.26	0.03/1.04	0.00	-1.08	.14
Response Inhibition - Foot/Leg Reaction Time*	-0.70/1.73	-0.63	0.01/0.11	0.11	-2.74	< .01
Working Memory - # Signs Recalled in Correct Order**	-0.38/1.52	0.31	0.07/0.92	0.31	-1.68	< .05
Working Memory - Arm/Hand Reaction Time*	-0.15/1.35	0.02	-0.02/0.94	0.04	-0.81	.21
Working Memory - Foot/Leg Reaction Time*	-0.28/1.36	0.02	0.06/0.92	0.10	-1.43	.08
Working Memory - Correct Responses*	-0.23/1.21	-0.11	0.01/1.00	0.18	-1.34	.09

**Primary variable, included in composite score
*Secondary variable, not included in composite score

3.2. Hypothesis 2: VRDST leads to better general tactical driving performance

To evaluate the effects of VDST on tactical driving performance, the pre- and post-assessment scores were transformed to *z*-scores based on the mean and standard deviation from the ASD group on both assessments and then summed to produce the tactical composite scores. Transformation to *z*-scores for the normative group was not possible because the unique post-assessment tactical drive differed from the pre-assessment drive and no DMV normative data existed for this drive. For these composite scores, a 1x4 ANCOVA (between-subjects factor: group) determined the difference between the groups (RT, Standard, Automated, Eye-Tracking) on the post-assessment while controlling for baseline. The results were Bonferroni-corrected.

Table 23: M/SE of the groups at tactical post-assessment, controlled for baseline.

	RT	**Standard**	**Automated**	**Eye-Tracking**
	M/SE	M/SE	M/SE	M/SE
Composite Tactical Score	-3.53/1.01	2.38/1.22	1.60/1.34	-0.8/1.09
Excessively Low Speed	-0.12/0.21	-0.4/0.26	0.29/0.27	-0.05/0.22
Off-Path Resets (Missed Turns)	-0.06/0.22	0.28/0.27	-0.47/0.28	0.18/0.23
Number of Lane Changes	-0.20/0.19	0.28/0.23	-0.28/0.25	0.21/0.21
Off-Road Resets	-0.13/0.23	0.17/0.28	-0.25/0.29	0.16/0.24
Crossing Midline	0.49/0.22	-0.27/0.27	0.13/0.28	-0.41/0.24
Swerving	-0.59/0.18	0.47/0.22	0.43/0.23	-0.09/0.20
Time Off-Road	-0.33/0.21	0.07/0.25	0.09/0.25	0.23/0.22
Rolling Stops	-0.17/0.22	-0.04/0.27	-0.81/0.28	-0.17/0.23
Deceleration Smoothness	0.31/0.18	0.01/0.22	-0.40/0.24	-0.05/0.19
Crashes	-0.39/0.22	0.20/0.27	0.11/0.28	0.16/0.23
Bumps	-0.33/0.20	0.19/0.24	0.28/0.26	0.03/0.21
Tailgating	-0.33/0.22	-0.13/0.26	-0.12/0.28	0.54/0.23
Speeding (8.05 km/h (5 mph) > limit)	-0.48/0.19	0.31/0.24	0.51/0.25	-0.09/0.20
Reckless Driving (32.19 km/h (20 mph) > limit)	-0.45/0.19	0.22/0.23	0.30/0.24	0.11/0.20
Speed Variability	-0.60/0.20	0.68/0.24	0.50/0.25	-0.22/0.21

The general tactical composite score improved differentially across groups (F 5.70, $p < 0.010$), and a significant covariate (F 54.83, $p < 0.001$, β 0.50) indicated that better baseline performance was associated with better post-assessment performance. Contrasts revealed that both Standard and Automated VRDST were superior to RT. Exploratory analyses indicated specific variable scores differed significantly across groups, albeit this differed per measure (see Table 23 and 24). In terms of overall performance, Standard and Automated VRDST were superior to RT, primarily due to better steering (less crossing midline and swerving) and speed control (less tailgating, speeding, and reckless driving).

Table 24: Significance levels comparing the groups at tactical post-assessment, controlled for baseline, one-tailed tests, *Significant comparison of alpha .05, **Significant comparison of alpha .01 (non-significant comparisons are not included).

	F	p	Contrast */**
Composite Tactical Score	5.70	< .01	RT – Standard* RT – Automated*
Excessively Low Speed	0.53	.66	/
Off-Path Resets (Missed Turns)	1.49	.23	/
Number of Lane Changes	1.55	.21	/
Off-Road Resets	0.64	.59	/
Crossing Midline	3.07	.04	RT – Eye-tracker*
Swerving	6.43	< .01	RT – Standard** RT – Automated**
Time Off-Road	1.24	.30	/
Rolling Stops	1.91	.14	/
Deceleration Smoothness	1.84	.15	/
Crashes	1.40	.25	/
Bumps	1.46	.23	/
Tailgating	2.78	< .05	RT – Eye-tracker*
Speeding (8.05 km/h (5 mph) > limit)	4.04	.01	RT – Automated*
Reckless Driving (32.19 km/h (20 mph) > limit)	2.73	.05	/
Speed Variability	6.85	< .01	RT – Standard** RT – Automated** Standard – Eye tracker*

3.3. Hypothesis 3: VRDST focusing on driving-relevant executive functioning improves that ability

The same EF tests were used at both pre- and post-assessments, so *z*-score transformations were again based on the normative sample to investigate the group effect relative to the normative sample. Scores from participants who used double feet (i.e. right foot on accelerator and left foot on brake pedal) to respond or who performed poorly (>3 *SD* below mean) were replaced with "-3". As with hypothesis 2, for both primary and secondary variables, post-assessment scores were entered into a 1x4 ANCOVA with baseline scores serving as the covariate to determine whether post assessment EF was related to baseline performance. Because there was no automated feedback during EF training, Standard and Automated VRDST subjects were combined into a single group. VRDST was not associated with better improvement on EF than RT (*F* 1.04, *p* 0.36). A priori power analysis (Faul, Erdfelder, Lang, & Buchner 2007) demonstrated that a reasonably larger sample size would not find a significant effect.

A significant covariate ($F = 17.13$, $p < 0.01$, $\beta = 0.50$) indicated that better baseline performance was associated with better post-assessment performance. As Table 25 and 26 indicates, few group differences were found for the improvement of driving-relevant EF. Standard and Automated VRDST were superior to RT when considering the secondary variable of working memory - arm/hand reaction time.

Table 25: M/SE for the composite executive function score and the primary and secondary executive function variables at post-assessment, controlled for baseline.

	RT	**Standard/ Automated**	**Eye-Tracking**
	M/SD	M/SD	M/SD
Composite Score	0.39/0.42	1.17/0.36	0.74/0.44
Dual Processing - Correct Responses**	-0.53/0.25	-0.04/0.23	-0.53/0.24
Dual Processing - Arm/Hand Reaction Time*	-0.57/0.29	-0.49/0.27	-0.60/0.29
Dual Processing - Foot/Leg Reaction Time*	-0.31/0.22	-0.70/0.20	-0.85/0.22
Response Inhibition - Correct Responses**	-0.22/0.29	0.62/0.27	0.01/0.29
Response Inhibition - Arm/Hand Reaction Time*	-0.86/0.29	-0.38/0.29	-0.14/0.31
Response Inhibition - Foot/Leg Reaction Time*	-0.76/0.31	-0.72/0.29	-0.82/0.30
Working Memory - Signs Recalled in Correct Order**	-0.52/0.29	-0.05/0.26	-0.53/0.28
Working Memory - Arm/Hand Reaction Time*	-0.66/0.29	0.33/0.27	-0.04/0.29
Working Memory - Foot/Leg Reaction Time*	-0.53/0.26	-0.32/0.24	-0.44/0.26
Working Memory - Correct Responses*	-0.56/0.29	0.11/0.26	-0.19/0.28

Table 26: Significance levels of the composite executive function score and the primary and secondary executive function variables at post-assessment, controlled for baseline. One-tailed tests, *Significant comparison of alpha .05, **Significant comparison of alpha .01 (non-significant comparisons are not included).

	F	p	**Contrast */***
Composite Score	1.04	.36	/
Dual Processing - Correct Responses**	1.42	.25	/
Dual Processing - Arm/Hand Reaction Time*	0.04	.96	/
Dual Processing - Foot/Leg Reaction Time*	1.68	.19	/
Response Inhibition - Correct Responses**	2.52	.09	/
Response Inhibition - Arm/Hand Reaction Time*	1.43	.25	/
Response Inhibition - Foot/Leg Reaction Time*	0.30	.97	/
Working Memory - Signs Recalled in Correct Order**	1.05	.36	/
Working Memory - Arm/Hand Reaction Time*	3.02	< .06	RT – Standard + Automated*
Working Memory - Foot/Leg Reaction Time*	0.18	.84	/
Working Memory - Correct Responses*	1.51	.23	/

3.4. Hypothesis 4: VRDST can be enhanced by adding automated feedback and/or eye-tracking

There were no significant contrasts across the three VRDST groups. Only the Standard and Automated groups were significantly superior to RT on the tactical simulator tests. Additionally, Standard VRDST demonstrated the greatest improvement in both primary and secondary EF (see Table 25 and 26).

4. Discussion

As hypothesized, this study demonstrated that ASD novice drivers differed from experienced drivers without ASD on the tactical test, which was a drive through a virtual world negotiating common routine and unanticipated traffic and road demands. This replicated findings that compared novice ASD to novice neuro-typical drivers (Cox et al. 2016). However, in the current study the tactical composite score of -29.71 is nearly six standard deviations below normative data, making our ASD novice drivers extremely deficient in general driving skills. Tactical skills are based heavily on driving experience (Dickerson & Bédard 2014) and predicted future collisions of novice drivers (Cox et al. 2015b).

It was hypothesized that ASD novice drivers would perform worse than experienced drivers without ASD on driving-specific tasks of EF, both because of their youth and because of their diagnosis. Given that EF typically does not mature until around age 25 (Lambert et al. 2014) and that ASD can be associated with deficits in EF (Ross et al. 2015b), differences were anticipated from a presumed neuro-typical and older sample. When considering a composite score of EF, the data did confirm such differences. Where our ASD drivers differed from experienced drivers on tactical driving skills by almost 6 standard deviations, in terms of EF this difference was less than 1standard deviation. However, these findings were not consistent with Cox et al. (2016), where ASD drivers differed from non-ASD novice drivers in terms of Working memory but not dual processing and Response Inhibition. Compared to these previous findings, current significant findings may reflect maturation differences between the ASD and experienced driver groups.

Standard and Automated VRDST differentially improved tactical performance relative to RT, suggesting that VRDST can improve basic driving skills. Two prior studies support the significance of this by demonstrating that tactical test composite scores both predicted future collisions of senior drivers (Cox et al. 1999) and future driving mishaps of newly licensed drivers (Cox et al. 2015b). The lack of significance for Eye-Tracking VRDST may be due to the absence of modeling in this condition or the sometimes obtrusive or irritating nature of wearing eye-tracking glasses. It was not surprising that VRDST did not differentially improve EF since minimal initial deficits in this parameter were detected. Additionally, there was no automated feedback and little eye-tracking during this training. Further, only 20-25% of eye-tracking training time focused on EF parameters.

The very significant covariates for post training assessments indicate that those who performed well initially performed better after training. This suggests that very poor baseline performance may indicate a driving candidate who might not improve significantly. If follow-up research confirms this, then initial poor VRDS performance may suggest that further training might not be worth pursuing.

While a pioneering effort, this study could have been improved in a variety of areas. A larger sample could have been recruited. Greater emphasis and documentation of on-road training during the two-month training interval could have been encouraged and analyzed. A control group of neuro-typical drivers would have allowed for the differentiation of the effects of ASD from that of being a novice driver; having normative data for the post assessment tactical score would have allowed determination of how much training moved the ASD sample toward safer driver performance.

Despite these limitations, this study demonstrated the feasibility of VRDST for novice drivers with ASD and identified areas of future research. In addition to correcting the above issues, applying a fixed treatment protocol (e.g., eye-tracking) to all participants appears counter-productive. For example, some participants substantially benefited from eye-tracking feedback, while others did not have difficulty with gaze direction or duration and persisting with such training may have been counterproductive. Some participants appreciated the computer-generated automated feedback; others found the voice aggravating and preferred a human instructor, which interfered with skill acquisition. Consistent with the training manual where participants spend as little or as much time training on specific skill as needed, use of eye-tracking and automated feedback could also be personalized. VRDST holds significant promise to aid individuals with ASD in improving tactical driving performance, but further research needs to focus on how best to generalize VRDST skills to real world driving.

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CHAPTER 7

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Measuring the attitudes of novice drivers with ASD as an indication of apprehensive driving: Going beyond basic abilities.

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In the following chapter, I was involved in the analyses and dissemination (presentation at conferences and writing of the paper).

Abstract

Problem: Earning a driver's license can be a significant accomplishment in the process of achieving autonomy. For some individuals with ASD, apprehension about driving can significantly interfere with the acquisition and application of driving privileges. It is important to acknowledge, quantify, and alleviate such apprehension in order to remove such a barrier to autonomy. Methods: The Parent-Report Driving Attitude Scale (PR-DAS) was developed to provide an indication of novice drivers' attitudes toward driving. The PR-DAS has nine items reflecting positive attitudes towards driving and nine items reflecting negative attitudes. Responses to the 18-item PR-DAS were compared for 66 parents of ASD novice drivers and 166 parents of neuro-typical novice drivers. Following this baseline assessment, the ASD novice drivers completed three months of driver training, 60 parents repeated the PR-DAS. Results: ASD novice drivers had significantly less positive ($p < .001$) and more negative attitudes ($p < .001$) toward driving than neuro-typical novice drivers. Compared to ASD novice drivers undergoing routine on-road driver training, those who additionally received driving training in a safe/low-threat high fidelity virtual reality driving simulator (VRDS) demonstrated a significant increase in positive attitudes ($p < .001$) and reduction in negative attitudes (*p* .001). Conclusion: Novice ASD drivers showed more negative and less positive attitudes towards driving, indicating apprehensive driving, which could interfere with safe driving. Training in the safe VRDS environment, however, resulted in improved attitudes toward driving.

Keywords: Autism spectrum disorder, driving, anxiety, attitudes, driving training, virtual reality

1. Introduction

Achieving an independent driver's license has profound life-long consequences that range from positives such as attaining independence for securing and maintaining work and social relationships (Reimer et al., 2013), to negatives such as collisions that have immeasurable personal and societal costs (WHO, 2013). Controlling a vehicle can be a daunting multi-tasking challenge for some novice drivers (Ross et al., 2014), especially for novice drivers with ASD. Certain characteristics associated with ASD may interfere with driving. For instance, a limited ability to plan and execute actions in response to environmental changes can cause a slowed driving style (Ross et al., 2015). These difficulties may contribute to apprehension toward the prospect of independent driving, discouraging the pursuit of licensure and potentially interfering with both the learning and application of safe driving skills.

Evidence suggests that young adults with ASD are at increased risk for anxiety in general (van Steensel, Bögels, & Perrin, 2011; Vasa & Mazurek, 2015). This increased level of anxiety can interfere with daily life functioning (MacNeil, Lopes, & Minnes, 2009), potentially further contributing to apprehensive driving.

Little research specifically targeting apprehensive driving in ASD has been done, and the scant research that exists mainly provides indications of elevated anxious arousal. Anxious arousal is defined by somatic tension and physiological hyperarousal, including a set of somatic symptoms such as shortness of breath, pounding heart, or sweating (Moser, Moran, & Jendrusina, 2012; Nitschke, Heller, Palmieri, & Miller, 1999). Reimer and colleagues (2013) reported that when young male adults were distracted by a mobile phone while driving, both the ASD and control groups increased their gaze focus to the road ahead, paying less attention to the overall driving environment. In addition, young adults with ASD had an increased heart rate, possibly indicating stress and anxiety. Wade and colleagues (2014) reported similar results; finding that the gaze from a group of adolescent ASD drivers was higher in the vertical direction and towards the right in the horizontal direction during simulated driving. The ASD group also demonstrated higher skin conductance levels (SCL) and skin conductance response rates (SCR). In contrast to anxious arousal, anxious apprehension is defined by worry, a concern for the future, and verbal rumination about negative expectations and fears. It is often characterized by symptoms such as muscle tension, restlessness, and fatigue (Moser et al., 2012; Nitschke et al., 1999). To the best of our knowledge, the only indication of anxious apprehension for driving comes from a study by Chee and colleagues (2014) that used Q-methodology to understand the viewpoints of 50 young adults with ASD towards driving. Although there were reports of drivers who were confident about their driving, or simply preferred different modes of transportation, one group (n 9) was anxious towards driving. The latter group was comprised of unlicensed drivers and learner drivers. As this study was not directly aimed at novice drivers with ASD, driving experience was not controlled for and 58% of the sample actually consisted of non-drivers. The current endeavor aimed to extend this study by measuring attitudes towards driving in a larger sample of novice drivers with ASD.

One issue with using self-report measures is that cognitive and emotional abilities change rapidly during adolescence. These changes possibly lead to blockages in affect processing, or alexithymia (i.e., including a reduced ability to identify and describe feelings), which has been found to be a stable personality trait in late adolescence (Karukivi, Pölönen, Vahlberg, Saikkonen, & Saarijärvi, 2014; Meganck, Markey, & Vanheule, 2012). Furthermore, alexithymia has been well-documented to be elevated in ASD, where it has been related with increased self-reported anxiety and parent-reported emotional difficulties for young people with ASD (Mazefsky & White, 2014; Milosavljevic et al., 2015). Therefore, it might not be prudent to use a self-report measure as indication of apprehensive driving. Indeed, preliminary research already indicated that caution must be exercised in the interpretation of self-report measures in adolescents with ASD (Mazefsky, Kao, & Oswald, 2011). Consequently, a measure such as the Driving Attitude Scale Parent-Report (DAS-PR; Cox et al., In preparation), assessing both positive and negative attitudes towards driving, could provide an insightful indication of apprehensive driving.

One possible way to desensitize apprehensive driving in ASD is exposure to low-risk virtual reality driving simulator (VRDS) training. A driving simulator allows important improvements in driving knowledge, skills, and abilities through the correction of poor and risky driving behaviors in a safe and controlled environment (Akinwuntan, Wachtel, & Rosen, 2012). Therefore, VRDS training could possibly increase positive and decrease negative attitudes towards driving, reducing apprehensive driving.

It was hypothesized that

1. ASD novice drivers will demonstrate less positive attitudes and more negative attitudes on the DAS-PR relative to a normative control group of novice drivers.
2. The gradual and systematic introduction of driving demands in a non-threatening VRDS environment will desensitize drivers to the driving process and result in less negative and more positive attitudes towards driving.

2. Methods

2.1. Subjects and Procedures

For the first hypothesis, two recruitment methods were used. First, 50 youth ages 16-25 (*M* age 17.9 years, 81% male) diagnosed with ASD, who had secured a learner's permit but not an independent license, consented/assented to participate in a study investigating the benefits of 8-12 one-hour sessions of VRDS training. Parents completed the DAS-PR at the time of consenting (baseline). As there were no significant contrasts across three different VRDS training groups, these were merged for the current research purposes[1]. The remainder of the sample was collected at the Universities of Virginia (n 24, *M* age 17.83, 87.5% male) and Iowa (n 26, *M* age 18.08, 73.1% male). Second, to compare the attitudes of novice drivers with ASD at baseline to a control group of neuro-typical novice drivers, parents of 186 neuro-typical novice drivers) completed the DAS-PR. Consent to the questionnaire by parents of neuro-typical parents was deemed unnecessary by IRB as this was voluntary and anonymous. For the second hypothesis, parents of the individuals in the VRDS training study completed the DAS-PR again three months later.

2.2. DAS-PR

The DAS-PR involves parents rating their adolescent or young adult's attitudes on a 0 (Not At all) to 3 (A Lot) scale with eighteen items, nine positive and nine negative (see Attachment 1). In order to cover a broad range of attitudes towards driving, the scale measures attitudes during three phases: thinking about driving, preparing to drive, and while driving. Questions were written to tap the different ways emotions can be expressed – cognitively, behaviorally, and physically. A higher number of negative attitudes together with a lower number of positive attitudes provides an indication of driving apprehension. The DAS-PR has good internal consistency with a Cronbach's alpha of .85 (see Cox et al. In preparation).

2.3. ASD training

Between the baseline and 3-month assessment, twenty-three subjects were randomized to Routine Training (RT), where novice drivers and parents were instructed to continue with on-road training required by the Department of Motor Vehicles (DMV) to secure a driver's license. All were provided the DMV training manual and a driving log to record their on-road driving. Forty-six subjects were randomized to additionally receive 8-12 sessions of individualized training in a high fidelity VRDS (see Fig. 31). VRDS training progressed in steps, beginning with learning to maintain speed control relative to posted speed limits, to maintaining lane position, to stopping, followed by turning and use of turn signals, the introduction of other traffic, multi-tasking, and hazard detection and negotiation (see Figure 31). VRDS training allowed following a mastery model, where one did not progress to the next level of training until mastery was achieved in the current level. To facilitate generalization from virtual reality to actual driving, subjects and parents were instructed to practice each week's objectives in their own cars on local roads. As systematic desensitization has been proven to be successful in treating anxiety in ASD (Head & Gross, 2008; Lang, Mahoney, El Zein, Delaune, & Amidon, 2011), it was anticipated that such gradual training in a safe environment would reduce driving apprehension.

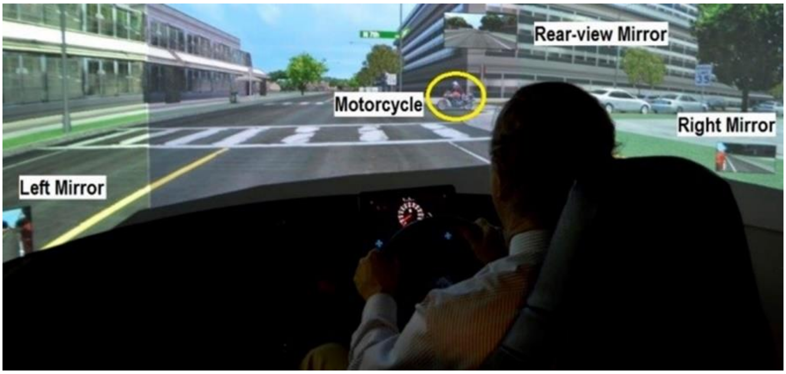

Figure 31: Simulator Displaying a Road Hazard (Motorcyclist Emerging from Behind Traffic) Requiring a Defensive Maneuver. Rear View Mirrors are Located to the Left and Right.

2.4. Data analyses

Respondents with incomplete DAS-PR questionnaires where one or more categories were not answered (i.e. not answering items dealing with on-road driving because that had not yet occurred) were excluded from the analyses. Respondents with random missing values were included but the missing values were replaced by the mean of all other participants on that question. For hypothesis 1, this left a final sample of 232 respondents (ASD 66, control 166). A 2 X 2 ANOVA (within subjects factor valence: positive, negative; between subjects factor group: ASD, control) was used to determine whether ASD novice drivers showed less positive and more negative attitudes toward driving than neuro-typical novice drivers. For hypothesis 2, the ASD sample from (Cox et al., Submitted) was used, which provided a sample of 60 respondents (RT 18, VRDS 42). A 2 X 2 X 2 ANOVA (within subjects factor assessment: baseline, 3-month; within subjects factor assessment valence: positive, negative; between subjects factor training: RT, VRDS) was used to determine whether ASD novice drivers showed reduced negative and increased positive attitudes after a training phase. Furthermore, this determined whether the attitudes of novice drivers with ASD undergoing a systematic, low-threat VRDS training program improved more when compared to RT.

3. Results

3.1. Hypothesis 1, ASD novice drivers will have less positive and more negative attitudes toward driving than neuro-typical novice drivers

A significant main effect of valence (F 57.61, p < .001, $\eta\rho^2$.20) combined with a significant two-way interaction effect of valence*group (F 136.98, p < .001, $\eta\rho^2$ .37) indicated that parents of the ASD novice drivers scored differently on the positive and negative items when compared to the neuro-typical control. Compared to the control, parents of ASD novice drivers reported less positive and more negative attitudes towards driving (*M* ASD: positive 10.73, negative 13.31; *M* control: positive 18.72, negative 6.68, see Fig. 32). Furthermore, the difference between groups in the ratings of positive (F 101.37, p < .001, $\eta\rho^2$.31) and negative items (F 92.41, p < .001, $\eta\rho^2$ .29) were both significant.

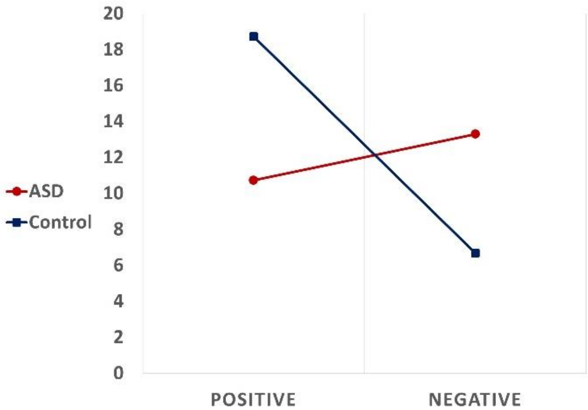

Figure 32: Positive and Negative Attitudes towards Driving for the ASD and Control Group. Summed ratings 0 (Not At all) to 3 (A Lot) are depicted on the y-axis.

3.2. Hypothesis 2, ASD novice drivers undergoing a systematic, low-threat VRDS training program will experience a reduction in negative and an increase in positive attitudes on the DAS-PR

The three-way interaction of assessment*valence*training was not significant (F 2.33, p .13, $\eta\rho^2$ .04). Therefore, analyses were conducted per training group, thereby investigating whether attitudes improved in both groups (i.e., VRDST and RT) while excluding the non-significant three-way from the model, allowing more statistical power (i.e., possibly, the small sample size of the RT group caused non-significant effects). The main effect of assessment (F 0.25, p .62, $\eta\rho^2$ .01) combined with the two-way interaction of assessment*valence (F 1.23, p .28, $\eta\rho^2$ .07) indicated that even though attitudes improved in the RT group (*M* Baseline: positive 9.78, negative 14.00; *M* 3-month: positive 11.58, negative 12.97), the improvement was not significant. For the VRDS group, there was no significant main effect of assessment (F 0.07, p .79, $\eta\rho^2$ < .001). Nevertheless, a significant interaction of assessment*valence (F 23.19, p < .001, $\eta\rho^2$ .36) indicated that positive attitudes increased and negative attitudes decreased after the VRDS training period (*M* Baseline: positive 11.38, negative 12.63; *M* 3-month: positive 15.06, negative 9.17, see Fig. 33). The change in attitudes was significant for both positive (F 31.80, p < .001, $\eta\rho^2$ .44), and negative (F 12.16, p .001, $\eta\rho^2$ .23) items.

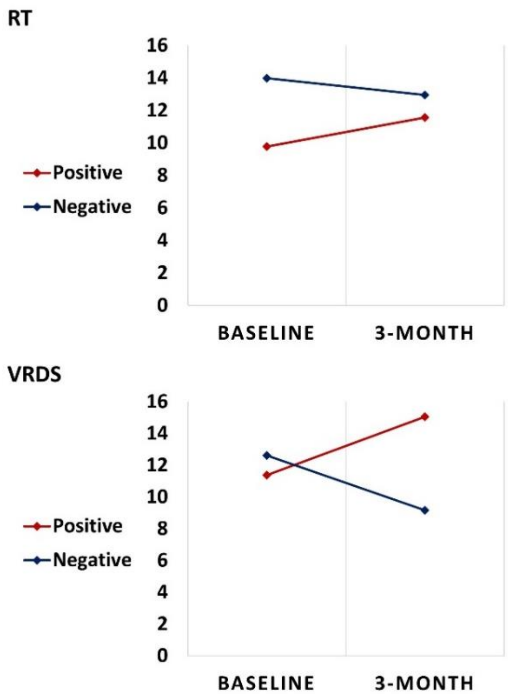

Figure 33: Positive and negative attitudes toward driving for the RT and VRDS groups at baseline and after a 3-month follow-up. Summed ratings 0 (Not At all) to 3 (A Lot) are depicted on the y-axis.

4. Discussion

As hypothesized, at baseline, the parents of ASD novice drivers reported less positive and more negative attitudes on the DAS-PR relative to a normative control group. This extends on previous research findings indicating anxious arousal while driving (Reimer et al., 2013; Wade et al., 2014), and confirms research indicating apprehension for driving (Chee et al., 2014). Using the Q-methodology, Chee and colleagues (2014) revealed 18% of their ASD sample reported significant driving anxiety. Using a cut-off of 1.5 standard deviations beyond the normative sample, we found 53% and 48.5% of our ASD novice drivers at baseline had less positive and more negative attitudes toward driving, respectively. After VRDS training, this improved to 34.8% and 36.2% for positive and negative items. This suggests that for some drivers with ASD, problems with learning to drive and subsequent independent driving can go beyond general abilities and include driving apprehension, even after VRDS training.

These findings are problematic as anxiety can lead to avoidance behavior and maladaptive coping (Hendriks, 2013). Avoidance behavior might only reinforce anxious beliefs because the absence of a feared outcome could be attributed to the avoidance. Although such behavior appears safe, it could result in dangerous behaviors such as rapidly switching lanes to avoid a possibly threatening situation (Possis et al., 2014). Furthermore, for individuals who continue to drive despite feelings of anxiety, the consequences can extend from subjective fear and avoidance to problematic driving behavior (e.g., disorientation, slowing for green lights, driving far below the speed limit, hostile reactions) (Clapp et al., 2011).
Another troublesome consequence of driving apprehension is that worry makes it difficult to maintain task-relevant goals; therefore, more investigation is needed (Proudfit, Inzlicht, & Mennin, 2013). More specifically, worry draws on working memory resources that would otherwise be available for the task at hand (Moser, Moran, Schroder, Donnellan, & Yeung, 2013). Indeed, apprehension has a domain-general impact on working memory, especially in situations of low load (Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013). This could be problematic because it has been found that driving performance depends on available working memory capacity (Chan, 2015; Ross et al., 2014). Furthermore, a recent study from Cox and colleagues (2016) proposed working memory as a key mechanism for possible difficulties drivers with ASD face during driving. ASD drivers, compared to a control group, not only demonstrated poorer driving performance at baseline, but also showed decreased driving performance when a working memory task was added. Therefore, the impact of apprehension on working memory could be more pronounced in novice drivers with ASD.

These results indicate that future efforts should be guided towards the assessment and alleviation of driving apprehension in novice drivers with ASD. Important in this respect, the second hypothesis was also confirmed parents of novice drivers with ASD reported less negative and more positive attitudes towards driving after a period of VRDS training. This coincides with a review indicating promising results of driving simulator training to reduce the symptomatology of collision-related post-traumatic stress disorder (Wiederhold & Wiederhold, 2010). It is not clear from the current study whether the effects will have a lasting benefit once the participant transfers to independent real-world driving. Therefore, future research could add an extra phase of on-road training once the driver feels secure enough to transfer to the actual road-environment. This would allow comparison of the effects of VRDS training alone versus combined with on-road training.

Although the current study extended previous research by measuring driving apprehension, it lacked the measurement of anxious arousal. While the two are often highly correlated, they are characterized by different brain patterns (Moser et al., 2012; Nitschke et al., 1999) and disjunction between them can occur (Corbett & Simon, 2014). For instance, children with ASD were found to show a lack of correspondence between apprehension and arousal in various circumstances (Lanni, Schupp, Simon, & Corbett, 2012). Future studies should include measures of arousal during driving (e.g., heart rate and skin conductance) to fully assess indications of driver anxiety in novice drivers with ASD. This will also help to determine whether VRDS training would additionally improve signs of anxious arousal during driving.

Finally, although the questionnaire was able to distinguish between novice drivers with and without ASD based on their attitudes, the questionnaire was not designed to include specific components that are relevant for ASD. There are unique processes for how anxiety is presented in ASD (e.g., social confusion, rigidity), and those that are shared/not-unique (e.g., negative bias, automatic thoughts) (Ollendick & White, 2012). For further use in ASD populations, it might be useful to update the original DAS-PR with items specifically related to ASD.

5. Conclusion

According to their parents, novice ASD drivers exhibited more negative and less positive attitudes towards driving indicating apprehensive driving, which could interfere with safe driving. Training in the safe VRDS environment resulted in improved attitudes toward driving. Future research efforts could combine measurement of anxious apprehension with online anxious arousal measurements to further examine characteristics of ASD that could interfere with driving.

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Footnotes

[1] In the study from Cox et al. (Submitted), participants were randomly allocated to one of four groups (i.e., 1) RT, VRDS: 2) human, 3) automated, 4) automated plus eye tracking). Each VRDS training group received the same 8-12 hours of driving simulator training, only the method of feedback delivery differed (i.e., human, automated, automated plus eye tracking). As the analyses including the four different groups did not deliver significant group differences

(assessment*training: F 0.96, p .79, $\eta\rho^2 < .01$; assessment*valence*training: F 1.10, p .36, $\eta\rho^2$ .06), the VRDS training groups were merged to increase the power of the analyses.

MAIN FINDINGS

NEURO-TYPICAL YOUNG NOVICE DRIVERS

The current thesis aimed to investigate the influence of the imbalance between the development of the cognitive control and the social-affective brain systems. The first goal was to investigate effects of distraction on driving behavior and relate this to the developing cognitive control system. **It was shown that driving behavior depends on cognitive resources**. In a first study, the interaction between verbal WM load and WM capacity on driving performance was measured to determine whether individuals with higher WM capacity were less affected by verbal WM load, leading to a smaller deterioration of driving performance. Driving performance of 46 young novice drivers (17–25 years-old) was measured with the LCT. Participants drove without and with verbal WM load of increasing complexity (auditory-verbal response N-back task). Both visuospatial and verbal WM capacity were investigated. Dependent measures were MDEV, LCI and PCL. Driving experience was included as a covariate. Regarding research question 1a "Is driving performance impaired when young novice drivers combine driving with secondary tasks?", **performance on each dependent measure deteriorated with increasing verbal WM load**. Meanwhile, higher WM capacity related to better LCT performance. Importantly, this study was the first to show that **the relation between verbal WM load and driving performance is moderated by WM capacity**. Young novice drivers with **higher verbal WM capacity were influenced less by increasing verbal WM load**. This was reflected by a smaller decrease of lane change initiations, as well as a smaller decrease of correct lane changes, when verbal WM load increased. In addition, people with high (versus low) verbal WM capacity also showed a smaller increase in the percentage of incorrect responses on the verbal WM load task. The availability of extra WM capacity allowed prioritization of task-relevant stimuli and minimized distraction. Regarding research question 1b "Do increased cognitive capacities moderate distraction?", **negative effects of distraction were also present in young novice drivers with higher WM capacity, indicating that larger cognitive resources cannot completely eliminate detrimental effects of distraction**. Research question 1c "Can the effects of distraction while driving already be identified in early attention allocation processes?", was answered in a second two-phase study including an older sample. Here, it was investigated whether well-known EEG markers of spatial orienting, identified in strict lab-conditions can also be observed in a more complex spatial cueing task simulating a traffic situation with inclusion of distraction. A spatial cuing task was translated to a simulated driving environment to enhance ecological validity and to include actual measurement of driving behavior (i.e., lane keeping). Results showed that **typical ERP markers of attention orienting that are usually**

observed in laboratory tasks were also present in more ecologically valid environments. Phase one included 16 participants who performed a dual task consisting of a spatial cueing paradigm and a concurrent verbal memory task that simulated aspects of an actual traffic situation. Orienting-related alpha lateralization, the lateralized event-related potentials (ERPs) ADAN, EDAN, and LDAP, and the P1-N1 attention effect were found. When WM load was high (i.e., WM resources were reduced), lateralization of oscillatory activity in the lower alpha band was delayed. In the ERPs, we found that ADAN was also delayed, while EDAN was absent. Later ERP correlates were unaffected by load. Behaviorally, we observed a load-induced detriment of sensitivity to targets. Phase two, included 22 participants and investigated WM load (memory task) effects on orienting processes by analyzing event-related potentials (ERPs) and behavioral outcomes on a simulated attention task, consisting of 512 intersections. A driving simulator allowed continuous lane-keeping measurement. Again, Typical ERPs were found (cue: contralateral negativity, LDAP; target: N1, P1, SN, and P3). Referring back to research question 1a "Is driving performance impaired when young novice drivers combine driving with secondary tasks?", **with increased WM load, lane-keeping variability reduced while dual task performance degraded** (memory task: increased error-rate; attention task: increased false alarms, smaller P3). Therefore, the current results confirm that **attention orienting depends on available WM capacity**.

Further support for a dual process theory of risky driving was found by including the interplay of cognitive and social-emotional processes while driving. In a first study, addressing research question 2a "Are cognitive control functions related to measures of risky driving?", 38 participants aged 17 to 25 years old, with less than 1 year of driving experience, completed a simulated drive that included several risky driving measures. Higher inhibitory control and verbal WM related to decreased lane-keeping variability. Inhibitory control, but not WM, was also related with better hazard handling as reflected in quicker detection of, and reaction to, and less crashes with road hazards. Increased cognitive control however did not always relate to decreased risky driving. Better visuospatial WM performance related to increased yellow-light running and decreased minimal following distance inside the city center. Variables such as compensatory strategies, sensation seeking, and processing speed might moderate or confound the relation between cognitive control (i.e., visuospatial WM performance) and risky driving. The **findings evidence the role of cognitive control in explaining risky driving in young novice drivers**. This **relationship, however, differed per cognitive function and per driving parameter**. Importantly, and supported by the explained variance in the regression models (10.9%–42.7%), it would be an oversimplification to expect cognitive control to be the only determinant of driving behavior. **Social and affective processes**

may moderate the relation between cognitive control and risky driving. In a second study, including 30 participants, social rewards (peer passengers) and cognitive control (inhibitory control) were examined. Risky, distracting, and protective effects were classified by underlying driver error mechanisms. In the first drive, participants drove alone. In the second, participants drove with a peer passenger. Regarding research question 2b "Is risky driving increased in the presence of peer passengers?", the **effects of peer passengers differed per driver error class**. Further **support for a dual process theory of risky driving was found**. Red light running (violation) increased in the presence of peer passengers. Related to research question 2c "Do increased cognitive capacities moderate the effect of peer passengers on driving?", for speeding (violation), **inhibitory control moderated the risk-increasing effect**. Distracting effects were reflected in reduced lane-keeping variability. Nevertheless, protective effects in the drive with peer passengers were found for amber light running and hazard handling (cognition and decision making). Although the results provide support for a dual process theory of risky driving, the **limited moderating results for inhibitory control could suggest that dual processes are insufficient to fully explain the results**.

YOUNG NOVICE DRIVERS WITH ASD

Research concerning young novice drivers with ASD, a population who due to associated cognitive dysfunction characteristics may experience additional problems when learning how to drive/while driving, **indeed identified potential issues**. With respect to research question 1a "Do Flemish driver instructors report difficulties when teaching young novice drivers with ASD how to drive?", several questions queried advice for teaching youth with ASD how to drive, and for improving the current driving education to better fit the needs of youth with ASD. Furthermore, respondents were asked to indicate whether specific characteristics, often associated with ASD, have an impact on driving ability. **A total of 52 driver instructors reported potential problems when teaching youth with ASD to drive. Advice for teaching youth with ASD to drive mainly focused on a need for structure, clarity, visual demonstration, practice, repetition and an individualized approach. Results however also showed that the relation between ASD and driving performance might not always be negative** but can be positive as well. This diversity between learner drivers supports the current classification of autism as a "spectrum" disorder with ASD specific and non-ASD specific characteristics (e.g., intelligence) varying from person to person, accounting for the variation in the capabilities and limitations of people with ASD. A second study investigated how young novice ASD drivers differ from experienced drivers and whether VRDST improves driving performance. To this end, 51 young novice ASD drivers (M age 17.96 years, 78% male) were assessed at pre- and post-training for driving-specific executive function (EF) abilities and tactical driving skills and randomized to Routine Training (RT) or one of three types of VRDST (8-12 sessions). All participants followed DMV guidelines for behind-the-wheel training necessary for a full driver's license. **Compared with experienced neuro-typical drivers, young novice ASD drivers showed worse baseline EF and driving abilities.** Research questions 2a and 2b "Can the driving performance and driving-relevant cognitive control functions of US young novice drivers with ASD be improved with VRDST?", were answered. **At post-assessment, VRDST significantly improved driving and EF performance, compared to baseline. This study demonstrated the feasibility and potential efficacy of VRDS to train young novice ASD drivers**. Regarding research question 2c "Can VRDST be enhanced by adding automated feedback and/or eye-tracking?", automated feedback and/or eye-tracking was not superior to human feedback. Futhermore, **only the human and automated feedback was superior to routine training to improve driving performance**. Additionally, **human feedback demonstrated the greatest improvement in both primary and secondary executive functioning**. Finally, **for some individuals with ASD, apprehension about driving may significantly interfere with the acquisition and application of driving privileges. It is important to acknowledge, quantify, and alleviate such apprehension in order to remove such a barrier to autonomy**. To address research question 3a "Do US young novice drivers with ASD report more negative attitudes and less positive attitudes towards driving?", a third study made use of the Driving DAS-PR. The DAS-PR was developed to provide an indication of young novice drivers' attitudes toward driving. The DAS-PR has nine items reflecting positive and nine items reflecting negative attitudes towards driving. Responses to the 18-item DAS-PR were compared for 66 parents of young novice ASD drivers and 166 parents of neuro-typical young novice drivers. After the ASD drivers completed three months of various driver trainings, 60 parents of young novice ASD drivers repeated the DAS-PR. **At baseline, the parents of young novice ASD drivers reported significantly less positive ($p < .001$) and more negative attitudes ($p < .001$) toward driving than parents of neuro-typical young novice drivers**. According to the parents , compared to young novice ASD drivers undergoing routine on-road driver training, **those who additionally received driving training in a safe/low-threat high fidelity VRDS demonstrated a significant increase in positive attitudes ($p < .001$) and reduction in negative attitudes (p .001)**. Research question 3b "Can these attitudes be improved by VRDST?", was therefore answered as well and **the usefulness of VRDST was again confirmed.**

IMPLICATIONS

NEURO-TYPICAL YOUNG NOVICE DRIVERS

As for distraction, several recommendations were made based on the current results. First, we considered the relationship between WM capacity and driving performance as measured by an LCT. Even though increased WM capacity might lead to an overall better driving performance and, at least for some driving parameters, to superior coping with distraction, **the degrading effect of distraction by verbal WM load in this study for both low and high WM capacity participants clearly indicates the necessity to eliminate distraction as much as possible**. This would decrease crash involvement of young novice drivers as they are more susceptible to distraction related crashes and are more willing to accept risks accompanying potentially distracting technology (Neyens & Boyle, 2007). One option is to use technologies to detect and prevent distraction (Lerner et al., 2010). For instance, Shabeer and Wahidabanu (2012) describe a system that detects the use of a mobile phone and notifies the nearest police post that can take legal actions. As another example, the Key2SafeDriving device is a cell phone blocker that transmits a disabling signal to a selected cell phone. Incoming calls are directly sent to voicemail. Emergency calls however will never be disabled (NHTSA, 2010). Lastly, most drivers are clueless of the extent to which distractions induced by WM load deteriorate driving performance (Horrey et al., 2008; Council, 2010). Therefore, education, as a way to raise awareness, can also be used to target distraction while driving. One example of an educational training program for young novice drivers and passengers targets risks and distractions by teaching communication skills to both parties (Lenné et al., 2011). Second, Intersection driver-support systems have been used to improve traffic safety, and recently also traffic flow (e.g., Chen et al., 2011; Dotzauer et al., 2015). Still, in-vehicle systems induce WM load, even without using visual stimuli (Becic et al., 2012; Becic et al., 2013; Solovey et al., 2014). As this could increase the tendency to yield, thereby affecting traffic flow, the effectiveness of such systems might be reduced. **Including EEG measurement to intersection driver-support systems would allow to assess the WM load of drivers** (Lei et al., 2009). Previous research already investigated the use of ERPs to measure WM load with the use of a secondary task (Coleman et al., 2015; Lei et al., 2009). For instance, Coleman and colleagues (2015) found an increased P3 latency, together with a reduced P3 amplitude, in a signal detection task when drivers interacted with in-vehicle voice-command systems resembling varying levels of WM load. With respect to yielding situations, the current results suggest that it may be possible to identify WM load based on the driving task, as indicated by a reduced P3 in response to a vehicle owning right-of-way. The use of ERPs in response to the driving task to measure WM load is further supported by previous research indicating a reduction of P3 amplitude, elicited by brake lights of a leading vehicle in a car-following-task, while drivers were talking on the phone (Strayer & Drews, 2007). A major concern however is the practical applicability. The current results were found in a situation with high experimental control, allowing an averaged ERP response, which may not be transferable to actual driving where a single-trial ERP would be required (Welke et al., 2009). Furthermore, although wireless EEG systems are available, further advances in measurement and analysis are necessary to integrate them into driver-support systems (Haufe et al., 2011). Furthermore, in the study by Coleman and colleagues (2015), there was a degradation of signal quality due to increased environmental noise (e.g., computers), making the transfer to an even more noisy context of on-road driving, challenging.

Considering the interplay of dual processes while driving, the results from the current thesis again provided some specific recommendations. Although a large gap exists between developmental issues and public policies, **the insights coming from research on cognitive development can be applied to programs aimed at reducing injury risk for adolescents and young adults, such as GDL**. Instead of reducing risks by increasing age restrictions, GDL systems tries to limit risky circumstances while driving. To accomplish this, GDL for instance not only reduces exposure to passenger presence, but also restricts other demanding conditions (e.g., nighttime driving) until driving behaviors become automatized with increasing driving experience (i.e., similar to the idea of intuitive decision making). Although this approach has been shown to be effective, it does not eliminate the problem as, for instance, some young novice drivers still drive with peer passengers, even when not allowed. Furthermore, it has been found that even though GDL decreases accidents during the learning period by limiting risky circumstances, these effects disappear once the driving license has been obtained (SWOV, 2013). Based on the current results, a complementary approach could be suggested. First, **some young novice drivers might require different restrictions**. For instance, young novice drivers with decreased response inhibition might require extended periods of restricted nighttime driving because they respond slower to hazards, which are less visible at night. With the inclusion of cognitive control tests, driver learning programs could be tailored to the specific needs of young novice drivers. Second, **with respect to peer passengers, they could be approached to serve as additional risk detectors** (i.e., improving cognitive and decision making performance). Interestingly, cognitive control can be trained, leading to improvements in driving performance. The current results therefore also apply to cognitive control training. **Adding inhibitory control training to existing programs might positively affect the ability of a subgroup of young novice drivers to better resist negative peer influences**. Nevertheless, more research will be necessary as better cognitive control may also relate to increased risky driving. For instance, visuospatial working memory training may have undesirable effects because it could increase yellow-light running. Unfortunately, training programs are often applied before the underlying mechanisms of the risk behavior have been thoroughly determined. To positively influence traffic safety, the exact relations between cognitive control and risky driving parameters need to be investigated to develop efficient learner and training programs.

YOUNG NOVICE DRIVERS WITH ASD

For young novice drivers with ASD, recommendations were formulated regarding education and training. First, **financial aids to pay for driver lessons and driver instructor courses to deal with ASD learner drivers could improve the accessibility of driving lessons for youth with ASD**. Second, driver instructors indicated **VRDS as a means to familiarize ASD learner drivers with driving**. Two papers in the current thesis already investigated the applicability of VRDST for driving ability and apprehension. First, regarding driving ability, standard (i.e., human) and automated VRDST differentially improved tactical performance, suggesting that VRDST can improve basic driving skills. Two studies support the significance of this by demonstrating that composite scores for a tactical test predict both future collisions of senior drivers (Cox et al., 1999) and future driving mishaps of newly licensed drivers (Cox et al., 2015). The results from the training indicated that the increase in driving performance mainly occurred for young novice drivers ASD drivers who initially performed better. This suggests that very poor baseline performance may indicate a driving candidate who might not improve significantly. If follow-up research confirms this, then initial poor VRDS performance may suggest that further training may not be indicated. For these candidates, alternative solutions such as for instance assistance with public transportation could be provided. Second, parents reported that apprehensive driving can be an issue for some young novice drivers with ASD. **Future efforts should be guided towards the assessment and alleviation of driving apprehension in young novice drivers with ASD. VRDST proved to be a valuable tool in this respect**. However, as some young novice ASD drivers still showed less positive and more negative attitudes towards driving after VRDST when compared to a control group, the current VRDST on its own was not sufficient to alleviate apprehensive driving. A dual process approach of attitude-related behavior supports the contention that interventions can target the automatic (attitude), or the controlled (coping skills and confidence) responses, or both (Vasey et al., 2012). In case the automatically activated attitudes are not altered, the effect of the intervention could be reduced. To illustrate, for social phobia it was found that a post-treatment implicit measure of attitudes toward public speaking (i.e., the Personalized Implicit Association Test) predicted return of fear (Vasey et al., 2012). Therefore, the still remaining driving apprehension might be caused due to the fact that the current VRDST mainly focused on mastery of skills, thereby targeting explicit processes, while there is evidence available supporting the view that anxiety is based on implicit, and unconsciously operating processes. **To further alleviate apprehensive driving in young novice drivers with ASD, it will be necessary to take such implicit processes into account**.

FUTURE DIRECTIONS

NEURO-TYPICAL YOUNG NOVICE DRIVERS

Regarding the interplay of dual processes while driving, both driving tasks in the chapters including distraction could be considered as rather simplistic driving tasks. **Future studies could include more complex and realistic VRDS scenarios that allow the investigation of a multitude of driving parameters to determine the costs of distraction**. The error classification of Stanton and Salmon (2009) proposing a typology with five psychological mechanisms underlying driver errors (i.e., action, cognition and decision making, observation, information retrieval, and violations) could be useful to categorize driving parameters. Furthermore, **it would be interesting to determine the influence of visuospatial WM capacity on driving performance when combined with visuospatial WM load**. This would allow to formulate additional recommendations for systems that include visual stimuli, such as for instance navigational systems.

The inclusion of eye tracking (e.g., eye glances, Ouimet et al., 2013) would be useful in research considering hazard perception (i.e., with or without distraction), as the detection in the current studies was measured rather indirectly by the release of the accelerator (relative to the occurrence of the road hazard). With respect to distraction, it would allow even more detailed inferences regarding early and late information processing phases. For instance, Recarte and Nunes (2003) used eye-tracking in a two-choice reaction time task and found that verbal WM load mainly impaired visual detection due to late detection and poor identification rather than response selection.

Related to the cognitive functions that were included in the current thesis, **future research should specifically investigate the relation between different working-memory processes and driving parameters**. Similarly, **other cognitive functions such as for instance, planning, prospective memory (PM), task switching, could be investigated**. PM is the ability to remember to carry out intended actions in the future while being engaged in other ongoing activities (Altgassen et al., 2012; Henry et al., 2014; Kretschmer et al., 2014; Williams et al., 2013). For instance, remembering to call a friend on your drive home with both tasks requiring attention. Two subtypes of PM exist, event-based PM (EBPM) and time-based PM (TBPM). The former refers to the execution of intentions at certain events (i.e., prospective cues) while the latter refers to the execution of intentions at certain times. Applied to driving, 'remembering to buy groceries on the way home' (i.e., EBPM: grocery store is a prospective cue), or 'remembering to attend a meeting at 2 PM' (i.e., TBMP) (Altgassen et al., 2012).

Combining the to-be-remembered intention with the ongoing task (i.e., dual-tasking requires more cognitive resources) can produce interference effects, thereby decreasing performance on the ongoing task (Loft et al., 2008). PM would be interesting as this is a complex cognitive function that is supported by several underlying cognitive abilities such as retrospective memory (i.e., involving past intentions), executive functioning (e.g., response inhibition, working memory, planning), theory of mind (TOM) and perspective taking (Altgassen et al., 2014; Ford et al., 2012; Mäntylä et al., 2007; Williams et al., 2013). For instance, due to the dual-task nature of PM tasks, working memory is required to monitor performance in TBPM. More specifically, working memory representations of the ongoing activity need to be maintained and updated, while paying attention to the approaching deadline (Mäntylä et al., 2007). As another example, response inhibition is required for a successful withdrawal from the ongoing activity towards the prospective cue (i.e., EBPM). Related to driving, on the way to an appointment, working memory allows updated representations of the road position while response inhibition allows one to drive by an exit (i.e., the prospective cue) in case of a road detour. Furthermore, as PM requires intention retrieval, or mental state retrieval, theory of mind and perspective taking are necessary in order to imagine the execution of the future PM act (Altgassen et al., 2014; Ford et al., 2012; Williams et al., 2013). For instance, the image of taking an exit while creating the intention to leave the highway at a certain exit (i.e., the prospective cue).

Looking at the additional influence of social-emotional processes, **future studies could include multiple peer passengers**. First, the presence of multiple passengers might increase the amount of immediate social rewards, possibly causing even more increased risk taking tendencies, especially in case passengers are risk supportive. To illustrate, multiple peer passengers in particular led to speeding in young male drivers (Ferguson, 2013). Second, multiple passenger situations will be more distracting, and it is those chaotic driving conditions that are most dangerous in combination with a lack of driving experience (LaVoie et al., 2013; Foss & Goodwin, 2014). Both increased effort to override risk taking tendencies and to resist distraction would require higher levels of cognitive control.

Finally, despite the usefulness of a dual process theory of risky driving for future education and training programs, some important concepts were not included in the current thesis. Personality (e.g., agreeableness, attitudes) and neurobiological (e.g., cortisol stress response) factors however have already been found to relate to risky driving (Brown et al., 2016; Starkey & Isler, 2016). Furthermore, the combination of the importance of all these factors might be different per type of risk-taker (e.g., speeding vs. drinking and driving) (Brown et al., 2016). This will also have an impact on interventions. For instance, for sensation seekers, rather than merely training cognition, it might be good to focus their sensation seeking inclinations from risky driving to less harmful activities such as sports (Romer et al., 2011). Furthermore, while the current thesis focused on a dual process approach of risky driving, the triadic neural systems model potentially provides a more complete account. The triadic approach additionally involves an avoidance system, which is not included in dual process accounts, thereby describing three systems: motivation/approach, emotion/avoidance, and regulation. Within this model, the motivation system is represented by the striatum that is associated with approach. The emotion system, represented by the amygdala, is related to aversive (e.g., fearful) stimuli and plays a significant role in avoidance. The regulatory center is represented by the prefrontal cortex that controles approach and avoidance behaviors. In adolescence, the striatum is mainly responsible for risk seeking and cognitive impulsivity and the amygdala for emotional intensity and lability. Finnaly, social reorientation requires interactions among all three systems. (Ernst, 2014). Future research could address the potential usefulness of a triadic approach in which to frame risky driving. Finally, to truly reduce the accident risk for young novice drivers, studies might need to switch from a driver-centric to a system approach. The former includes a strong focus on individual components that elevate the risk for young novice drivers (e.g., hazard perception, cognitive processes), and often considers studies in isolation. Accordingly, this approach still ignores the complex interaction between different factors. Meanwhile, the latter aims to not only consider individual characteristics, but the other actors in the driving environment too, together with the interactions amongst them, providing a more holistic approach (Scott-Parker et al., 2015).

YOUNG NOVICE DRIVERS WITH ASD

Also for this population, the inclusion of other driving parameters and cognitive functions would provide additional information to base recommendations on. Going back to the PM example, the little research that exists suggests that people with ASD experience difficulties more specifically in complex driving situations, requiring multi-tasking and inducing increased cognitive load (Cox et al., 2012; Reimer et al., 2013). Applied to autonomy, in order to maintain work and social contacts, it is not only necessary to handle the vehicle, but also to navigate through rural, urban, and highway traffic environments while concurrently remembering appointments and obeying a schedule. People with ASD however experience difficulties with coordinating and sequencing activities, and with planning ahead (Altgassen et al., 2009). Following this, PM may be even more interesting to investigate in young novice ASD drivers. Some existing studies state that only TBPM is impaired in young ASD while others claim that both EBPM and TBPM are impaired in ASD (Altgassen et al., 2009; Altgassen et al., 2010;

Altgassen et al., 2012; Brandimonte et al., 2011; Kretschmer et al., 2014; Henry, et al., 2014; Williams et al., 2013). The nature of the included PM tasks may contribute to the contradictory EBPM finding as low complexity lab tasks leave spare cognitive resources to deal with the EBPM task. (Altgassen et al., 2012; Williams et al., 2013). Therefore, it would be most interesting to study PM in a more complex task such as driving. Interestingly, research on PM difficulties in ASD is steadily growing. None of the research on PM difficulties in ASD however includes adults with ASD performing a realistic driving task while also assessing cognitive abilities. Therefore, future studies should investigate the relation between PM, cognitive functioning, and driving.

The two final chapters consisted our research regarding the applicability of VRDST to improve driving performance and driving apprehension in young novice drivers with ASD. With respect to the VRDST, while a pioneering effort, this study could have been improved in a variety of areas. A larger sample could have been recruited. Greater emphasis and documentation of on-road training during the two-month training interval could have been encouraged and analyzed. A control group of neuro-typical young novice drivers would have allowed to distinguish the effects of ASD from that of being a young novice driver: having normative data for the post assessment tactical score would have allowed determination of how much training moved the ASD sample to safer driver performance. In addition, applying a fixed treatment protocol (e.g., eye-tracking) to all participants appears counter-productive. For example, some participants substantially benefited from eye-tracking feedback, while others did not have difficulty with gaze direction or duration and persisting with such training may have been counterproductive. Some participants appreciated the computer-generated automated feedback. Others found the voice aggravating and preferred a human instructor, which interfered with skill acquisition. Consistent with the training manual where participants spent as little or as much time training on specific skills as needed, use of eye-tracking and automated feedback could also be personalized. Such a personalized approach has also been advocated in other domains regarding ASD (e.g., in community settings; Wood et al., 2015), but also in VRDST as Wade et al. (2016) also employed eye-tracking to personalize driving interventions (Wade et al., 2016). Regarding apprehension, it is not clear however whether the effects will have a lasting benefit once the participant transfers to independent real-world driving. Therefore, future research could add an extra phase of on-road training once the young novice driver feels secure enough to transfer to the actual road-environment. This would allow comparison of the effects of VRDS training alone versus such training combined with on-road training. Possibly, such an approach would be more effective in improving driving apprehension. Furthermore, measures of arousal during driving (e.g., heart rate and skin conductance) should also be included to fully assess indications of driver anxiety in young novice drivers with ASD. This will help to determine whether VRDS training would additionally improve signs of anxious arousal during driving. Finally, although the questionnaire was able to distinguish between young novice drivers with and without ASD based on their attitudes, the questionnaire was not designed to include specific components that are relevant for ASD. There are unique processes for how anxiety is presented in ASD (e.g., social confusion, rigidity), and those that are shared/not-unique (e.g., negative bias, automatic thoughts) (Ollendick & White, 2012). For further use in ASD populations, it might be useful to update the original DAS-PR with items specifically related to ASD.

Compared to the research on neuro-typical young novice drivers, research in ASD was not specifically framed in dual process theory. Similar research questions can be applied to young novice drivers with ASD. For instance, how do young novice ASD drivers react to a potential reward while driving? Furthermore, there may be differences in how the symptomology of ASD contributes to the interplay of dual processes while driving. For instance, with respect to monetary rewards, it is possible that young novice drivers with ASD would be more cautious. Effects from a social reward (peers) might also be different. Possibly, young novice drivers with ASD mainly show distractive effects due to fear of negative evaluation (Demurie et al., 2012; Cardoos et al., 2013; White et al., 2015). Furthermore, it is possible that specific ASD characteristics might provide additional difficulties while driving for novices with ASD. For instance, individuals with ASD are limited in understanding and predicting others' behavior, possibly causing inadequate judgments of other road users' behavior (Ross et al., 2015). Indeed a previous study using video images, already showed a slowed reaction to road hazards, and especially to social ones (Sheppard et al., 2010). Cognitive dysfunction, reflected in limited self-monitoring, creativity, mental flexibility and planning abilities, can cause driving to be stressful and dangerous (Ross et al., 2015). Indeed, in a study from the US, young novice ASD drivers drove more poorly overall and with a secondary WM task they showed a significant decrement in performance compared to a control group (Cox, et al., 2015). Finally, as emotional regulation issues are also at risk of impairment (Mazefsky & White, 2014), it is possible that they would show increased aggressive driving in emotionally laden situations. On the other hand, as safe driving depends on motivational factors, youth with ASD might follow traffic rules more strictly and adopt cautious driving styles, leading to decreased crash risks compared to non-autistic peers (Ross et al., 2015). This rule-bounded rigidity however might be problematic when unexpected events occur (e.g., a road obstacle requires full-line-crossing). In sum, it could be expected that young novice drivers with ASD suffer even more from the imbalance of dual processes while driving.

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Veerle Ross graduated in Audio-Visual Education at PIKOH in Hasselt in 2003. In 2007, she graduated with honors in Occupational Therapy. She received an award for her bachelor thesis, i.e., a literature review on the assessment of daily life activities in multiple sclerosis (MS).

After this, she continued her education with a study in psychology. In 2010, she graduated in the top 3% and received a bachelor's degree in Cognitive Psychology. During her master, she performed a scientific research internship at the Transportation Research Institute (IMOB). At IMOB, she investigated the underlying cognitive mechanisms of risky driving in young drivers. In 2011, she graduated magna cum laude with a master's degree in Health and Social psychology and was provided with the opportunity to start a PhD extending on the same topic.

IMOB already investigated specific populations such as elderly, young drivers, and people with MS. Recently, they started to investigate people with an autism spectrum disorder (ASD). Veerle Ross was therefore able to extend her PhD research to ASD. It was for the latter that she obtained FWO funding to conduct a seven-week research stay, from which she spent five weeks in Charlottesville to conduct an internship with Daniel Cox from the University of Virginia, who is known for driving research in populations such as ASD and ADHD.

During the final period of her PhD, she was also involved in the project Yes I Drive, which was aimed to integrate young adults with ASD by investigating their ability to drive. After 4 years of work on her PhD, Veerle Ross obtained a grant from the Marguerite-Marie Delacroix Foundation to investigate the relation between prospective memory and driving in ASD.

Veerle Ross was also involved in other projects related to traffic safety. For instance, a project investigating a reformation of the current Flemish driving education system, Finally, Veerle Ross is involved in several educational activities of the Transportation Sciences program at Hasselt University.

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- **Ross, V.**, Jongen, E., Brijs, T., Brijs, Kris, Ruiter, R., Wets, G. Mixed effects of peer passengers on driving. *European Road Safety Summer School 2015. VSV*. Diepenbeek (Belgium), 26/08/2015.
- **Ross, V.**, Jongen, E., Brijs, T., Vanvuchelen, M. Yes I Drive - Autorijden door jongvolwassenen met een autismespectrumstoornis. *Infobeurs voor (jong) volwassenen met ASS en hun netwerk. Hejmen vzw, Begeleid wonen Leuven vzw, Autiwoonzorg vzw*. Leuven (Belgium), 19/03/2016

PROJECTS

- 2011-2015, IMOB (UHasselt). *Unraveling the underlying mechanisms of risky driving among adolescents and strategies for training by means of simulated driving*. With support from the Special Research fund (BOF) of Hasselt University.
- 2014-2015, IMOB (UHasselt, REVAL (UHasselt), *"YES, I DRIVE": project voor jongvolwassenen met een autismespectrumstoornis (ASS) ter bevordering van het leren autorijden en van het veilig deelnemen aan het gemotoriseerde verkeer.* With support of the King Baudouin Foundation (ICT community for ASD).
- 2015-2016, IMOB (UHasselt). *Naar een hervormde rijopleiding: Studie naar de effectiviteit van modellen en deelcomponenten voor de opleiding rijbewijs categorie B*. With support from Steunpunt.
- 2015-2016, IMOB (UHasselt). *Driving the future: The relation between driving and prospective memory in adults with autism spectrum disorder*. Personal funding obtained from of the Marguerite-Marie Delacroix Foundation.

SUPERVISION OF BACHELOR THESES

- 2012-2013: Thomas Mondelaers, Emoties en agressie in het verkeer: Een vergelijkende studie tussen jonge en oudere bestuurders

SUPERVISION OF MASTER THESES

- 2011-2012: Banfegha Emmanuel Kiwo, The effects of cognitive distraction on young novice driver performance
- 2014-2015: Geenen Michelle, Wordt agressief rijgedrag van mannen, dat voortkomt uit boosheid, beter voorspeld door impliciete of expliciete maten van agressie
- 2015-2016: Yusupova Nodira, Aggression in traffic: effects of frustration in male drivers and underlying mechanisms of aggressive driving
- 2015-2016: Huysmans Eddy, Hoe regelen mensen met een autisme spectrum syndroom hun vervoer om van A naar B te geraken?
- 2015-2016: Baig Muhammad Sulman, Google Streetview: Evaluating the effectiveness for individuals with an autism spectrum disorder (ASD)
- 2015-2016: Reinolsmann Nora, Measuring explicit and implicit aggressive attitudes in young novice drivers – a new approach in driving education

TEACHING ACTIVITIES

- Master of Transportation Sciences, course Behavioral Influence: work sessions (2011-2016)
- Master of Transportation Sciences, course Behavioral Influence: work sessions (2011-2016)
- Master of Transportation Sciences, course Master Thesis: supervision of students (2012-2016)
- Master of Transportation Sciences, course Traffic and Travel Behavior: work sessions and lectures (2012-2016)
- Master of Transportation Sciences, course Internship: supervision of students (academic years 2013-2014)
- Bachelor of Transportation Sciences, course Integrated Project: supervision of students (academic years 2012-2013)
- Bachelor of Transportation Sciences, course Traffic Psychology: lecture (academic years 2013-2016)