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DOCTORAL DISSERTATION

# Investigating both ends of the driver age spectrum: assessment of driving behavior and evaluation of traffic safety interventions

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

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# EXECUTIVE SUMMARY

The aim of this doctoral thesis was to investigate both ends of the driver age spectrum (i.e., both older and younger drivers). Regarding older drivers, the aim was to investigate driving behavior under neutral and distracting circumstances by investigating specific driving measures and the role of functional abilities in driving. Regarding both older and younger drivers, the aim was to investigate the immediate and extended effects of traffic safety interventions on (socio-cognitive determinants of) behavior.

The focus is on car driving since driving a car is related to autonomy and offers a flexible way of moving. As a consequence, mobility has been mainly based on private car traffic in industrialized countries. However, driving a car is a complex, goal-directed task that places high demands on functional (i.e., visual, cognitive, and motor) abilities. As a result, among all the means of transport used by humans, road transport is the most dangerous one. Human behavior plays a role in 96% of the traffic accidents (whether or not in combination with the road vehicle and traffic environment). One contributing factor to traffic accidents is driver distraction, defined as the diversion of attention away from activities critical for safe driving toward a competing (driving- or non-driving related) activity. Since traffic accidents bring along large social and economic costs, and are a serious challenge to public health, the European Commission has set the goal to halve the number of fatalities in traffic by 2020 compared to 2010.

Compared to other age groups, both older and younger drivers have elevated fatality rates. While their types of traffic accidents differ, they both have accidents due to age and (lack of) driving experience. Due to the old age, older drivers’ cognitive abilities important for driving are decreasing, while due to the young age, younger drivers’ cognitive abilities are not yet fully developed. Although age plays an important role, driving experience is even more important: Drivers who make more kilometers, regardless of age, have reduced accident rates per kilometer compared to those making fewer kilometers.
Although older drivers have ample driving experience (e.g., 40 years), their driving experience decreases with age, since older drivers have the tendency to restrict their total kilometers driven to times and places that they feel the safest. Young drivers have not yet acquired a lot of driving experience (i.e., few months/years), because they have their drivers’ license since a short period.

In order to decrease the number of traffic accidents, a careful assessment of driver fitness is necessary. Driver fitness encompasses both medical fitness and driving ability. Although there are clear procedures to obtain a driver's license in industrialized countries, there are not always clear procedures once one has obtained a driver's license. Since medical fitness and driving ability can change over a lifetime, it is necessary to regularly assess driver fitness. However, assessing driver fitness and knowing certain deficits is not enough. Interventions, like education and training, are necessary to promote safe driving. In addition, they are necessary to keep drivers safe drivers for as long as possible, since mobility is important for quality of life. This lifelong learning implies the systematic acquisition, renewal, upgrading, and completion of knowledge, skills and attitudes that are necessary in response to the constantly changing conditions of modern life. Driver education needs to focus on both lower and higher levels of the Goals for Driver Education matrix. It is important to evaluate their effects in order to know whether these interventions reached their objectives. Since each age group is heterogeneous in composition, the same intervention will not necessarily produce desired effects for all drivers.

In order to investigate driving behavior and effects of traffic safety interventions for both ends of the driver age spectrum, six studies were conducted which are described in six chapters.
Since there is still no instrument that adequately distinguishes between safe and unsafe drivers, the relations between specific measures of older drivers' driving behavior and demographic measures as well as functional ability measures were investigated in **chapter 1**. Moreover, the explained variance of these relations was verified to determine the strength of these relations. Since the lack of an adequate instrument is possibly due to the approach that has been used so far to investigate the relation between driving behavior and functional abilities, as the majority of studies have used summarized measures of driving behavior, specific measures of driving behavior of older drivers were assessed. Results indicated that the importance of functional abilities depends on the specific driving measure under investigation. Although demographic variables, like age, explain only a very small proportion of the variance in measures of driving behavior (i.e., between 3% and 15%), the amount of the variance explained in measures of driving behavior by functional abilities is also rather limited (i.e., between 7% and 36%).

Since cognitive abilities like attention seem to be important for some specific measures of driving behavior while driving under neutral circumstances, it was investigated whether they are also important for some measures of driving behavior while driving under distracting circumstances. More specifically, in **chapter 2,** it was investigated whether attention capacity moderates the effect of visual and cognitive distraction on specific measures of driving behavior. In addition, the main effects of distraction and the main effects of attention on measures of driving behavior of older drivers were investigated. Finally, it was investigated how people rated their performance during distraction. There was a moderating trend effect of attention capacity on a measure of lateral control: whereas lateral control improved in those with higher attention capacity, it deteriorated in those with lower attention capacity for the ride with distraction. Both types of distraction had adverse effects on measures of driving behavior of older drivers. There was especially an adverse effect of distraction on driving measures with a high demand on both vehicle handling and information processing (e.g., complete stops at stop signs), but not on driving measures with a low demand on vehicle handling and/or information processing (e.g., mean driving speed and following distance). In general, drivers drove slower when distracted. In addition, higher attention capacity was related to a lower number of accidents. Despite the decrease of driving performance with distraction, participants rated their driving performance during distraction quite high.

Although cognitive abilities seem to be important for some measures of driving behavior, there is debate about the effect of cognitive training on driving behavior. Possibly, this depends on the type of training. In general, adaptive training leads to larger training gains than non-adaptive training since adaptive training ensures an adequate level of difficulty that does not over- or underchallenge participants. Therefore, the effect of an adaptive vs. a non-adaptive cognitive training on cognitive abilities and specific measures of driving behavior was investigated in **chapter 3**. Regarding cognitive ability, the cognitive training had a positive effect on the trained cognitive ability (i.e., working memory): participants who followed adaptive training (i.e., task difficulty adapted to the participant) had largest improvements, participants who followed non-adaptive training (i.e., task difficulty fixed at a low level) had smaller improvements and participants who followed no training only had minimal improvements. Important to notice is that for attention, all groups (i.e., adaptive training group, non-adaptive training group, no training group) improved, regardless of (type of) training, indicating a general test-retest effect. For response inhibition, group means were in the same direction, but results were only marginally significant. Regarding driving behavior, the cognitive training had a marginally significant positive effect on some driving measures (i.e., driving speed and reaction to stop signs), but effects were rather small.

Since it is assumed that a more direct training of driving behavior has more influence on driving behavior compared to a more indirect training, the effect of a driving simulator based training on specific measures of driving behavior was investigated in **chapter 4**. Driving multiple times in a simulator improved performance on some driving measures like lateral control. However, in order to improve on other driving measures, like giving right of way, driving-specific feedback was necessary. Taking together, driving simulator based training had medium to large effects on several driving measures.

Although it is important to focus on traffic safety interventions for older drivers to keep them safe drivers for as long as possible, it is also important to focus on traffic safety interventions for younger people. It is important to focus on those who obtained their driver’s license recently since the first few months of independent driving pose the greatest risk of collision for novice drivers. In addition, traffic safety-related attitudes evolve over time and individuals are highly susceptible to attitude change during late adolescence and early adulthood. Therefore, the effect of a post-license education program for young novice drivers on socio-cognitive variables for driving-related risk behaviors (i.e., speeding and drink driving), on risk detection, and on risk-related knowledge was investigated in **chapter 5**. Immediately after session attendance, positive effects on socio-cognitive variables were rather limited and small. Moreover, the program had counterproductive effects on some socio-cognitive variables (e.g., decreased risk perception of drink driving). The program had no effect on risk detection. Even though we found a large effect on risk-related knowledge, the levels of risk-related knowledge still remain low after session attendance. Two months after session attendance, only the effect on risk-related knowledge sustained.

It is also important to focus on traffic safety interventions for those who still need to obtain their driver’s license, since safety related attitudes are formed at a young age. Although these people are new-comers as car drivers, they are not new to the roads. They already have extensive experience in other traffic roles (e.g., pedestrian, cyclist). Therefore, the effect of a pre-license education program for high school students on socio-cognitive and behavioral variables was investigated in **chapter 6.** In addition, the impact of the program on participants’ cognitive and emotional state was investigated. Finally, it was investigated whether this impact on participants’ cognitive and emotional state influences the program’s impact on socio-cognitive and behavioral variables. Immediately after session attendance, the program had small positive effects on the socio-cognitive and behavioral variables. These effects differed in function of education type. While students of general and occupational education were both significantly more traffic safety supportive after session attendance, no such effect could be established for students of technical education. Two months after session attendance, there were small to medium positive effects on most of the socio-cognitive and behavioral variables. These positive effects differed in function of gender. Both male and female students were significantly more traffic safety supportive after session attendance. However, the program had more effect on males than on females. Immediately after session attendance, the program had a positive effect on participants' cognitive and emotional state. This impact on participants' cognitive and emotional state was relevant for determining the effect of the program on the socio-cognitive and behavioral variables: less aroused participants became traffic safety supportive to a lesser extent than participants declaring they were more aroused by the program.

Based on the knowledge obtained by the studies performed in this doctoral thesis, a number of **clinical and policy recommendations for driver assessment procedures** can be formulated.

(1) Demographic variables like age only explain a limited amount of the variance in measures of driving ability. Therefore, screening procedures solely based on age will not be successful in lowering the fatality rates of older drivers. In order to make decisions about driver fitness, it is necessary that the right abilities are assessed. Functional abilities explain a larger amount of the variance in measures of driving ability compared to demographic measures, therefore screening procedures should pay attention to functional abilities. Given the multifactorial nature of driving and the finding that different functional abilities are differently related to different driving measures, it will be necessary to assess several functional abilities, in contrast to assessing a single functional ability. However, a driving assessment program that only includes measures of functional abilities will not be successful in discriminating safe from unsafe older drivers, since functional abilities still only explain a rather limited amount of the variance in measures of driving ability. Possibly, this is why there is currently no instrument that can adequately distinguish between safe and unsafe drivers. In order to obtain reliable assessment results, it will be necessary to incorporate a more context-relevant assessment. Hence, if the purpose is to assess driving ability, a driving test should be conducted. Given that drivers usually have problems with specific

driving situations, it is important to assess specific driving measures in order to obtain a detailed enough view of driving ability.

(2) Despite of the ample driving experience of older drivers, they also experience degrading effects on driving ability due to driver distraction. Although older drivers seem to compensate for the effects of driver distraction by adopting lower driving speeds, it is crucial to eliminate driver distraction as much as possible. Since older drivers still rated their performance during driving with distraction quite high, education programs to increase awareness about adverse effects of driver distraction are recommended.

In addition, a number of **clinical and policy recommendations for traffic safety interventions** can be formulated.

(1) In order for an intervention to be effective, it is recommended to focus on the right target group. Although both ends of the driver age spectrum are a relevant target group due to their increased fatality rates, programs targeting traffic safety views will probably have more effect in other target groups, for example, drivers with Mild Cognitive Impairment or as an alternative sanction for particular groups of traffic offenders, since it can be expected that they have more and larger deficits in (socio-cognitive determinants of) driving behavior.

(2) In addition, one should first conduct a needs assessment to thoroughly investigate the true underlying needs within a specific target group before developing an intervention. For example, if there is a need to improve driving ability in contrast to cognitive ability, a training directly targeting driving ability in contrast to a training indirectly targeting driving ability would be more appropriate. Ideally, the training should be tailored to the individual or a group of individuals with common characteristics, targeting those functions that are hampered. Importantly, program developers should not be overambitious in the number of objectives to be reached, but focus on a suitable amount of objectives.

(3) Moreover, appropriate methods and strategies should be selected based on the available theoretical and empirical scientific evidence. For example, if the goal is to address higher order levels, methods and strategies enhancing lower order levels (i.e., instruction-oriented teaching style) should not be selected. In contrast, methods and strategies enhancing higher order levels (i.e., coaching-oriented teaching style) should be selected.

(4) It is recommended to evaluate interventions, since program effects are sometimes small, or even counterproductive. In addition to effect evaluations, process evaluations are also important to know why an

intervention has or has not beneficial effects. Effects can depend on the background profile of participants (e.g., gender and education) and on the way the program is offered (e.g., emotional and cognitive impact). Regarding the way the program is offered, it can be recommended to practitioners to aim at moderate arousal levels since these can be expected to result in optimal message processing.

Taken together, the studies performed in this doctoral thesis lead to more insights into driver assessment procedures to distinguish safe drivers from unsafe drivers. After detailed driver assessment, it is clear whether people have excessive, limited or no problems with functional abilities or driving ability. In case drivers have excessive problems with functional abilities or driving ability, driving cessation would be appropriate. In that case, it is important to assist drivers in this process, since driving cessation can have a negative impact on people’s quality of life. However, in case people have limited problems with functional abilities or driving ability, it is recommended to follow driver education or training to create safe drivers and to keep them safe drivers for as long as possible, since driver education and training seems to help to attenuate declines in functional abilities or driving ability, which is in favor of the lifelong learning approach.

# NEDERLANDSTALIGE SAMENVATTING

Het doel van deze doctoraatsthesis was om beide uitersten van het bestuurdersleeftijdsspectrum te onderzoeken (nl. zowel oudere als jongere bestuurders). Voor oudere bestuurders was het doel om rijgedrag onder neutrale en afleidende omstandigheden te onderzoeken door specifieke rijmaten en de rol van functionele vaardigheden te onderzoeken. Voor oudere en jongere bestuurders was het doel om de onmiddellijke en latere effecten van verkeersveiligheidsinterventies op (socio-cognitieve determinanten van) gedrag te onderzoeken.

De focus ligt op autorijden, aangezien autorijden gerelateerd is aan autonomie en een flexibele manier van verplaatsen biedt. Hierdoor is mobiliteit vooral gebaseerd op personenwagen verkeer in ontwikkelde landen. Nochtans, het besturen van een wagen is een complexe, doelgerichte taak die verschillende functionele (nl. visuele, cognitieve en motorische) vaardigheden vereist. Hierdoor is van alle transportmiddelen, wegentransport het meest gevaarlijk transportmiddel. Menselijk gedrag speelt een rol in 96% van de verkeersongevallen (al dan niet in combinatie met het voertuig en de verkeersomgeving). Eén van de oorzaken van verkeersongevallen is afleiding. Bij afleiding geeft men minder aandacht aan activiteiten die belangrijk zijn voor veilig rijden omdat men aandacht geeft aan een andere activiteit (al dan niet gerelateerd aan rijden).
Aangezien verkeersongevallen voor hoge sociale en economische kosten zorgen, en een serieuze uitdaging voor de volksgezondheid zijn, heeft de Europese Commissie het doel gesteld om het aantal verkeersdoden in 2020 te halveren vergeleken met het aantal verkeersdoden in 2010.

Ten opzichte van andere leeftijdsgroepen hebben zowel oudere als jongere bestuurders verhoogde ongevallencijfers. Hoewel hun type van ongevallen verschillen, zijn hun ongevallen te wijten aan leeftijd en (gebrek aan) rijervaring. Door de hoge leeftijd van ouderen nemen cognitieve vaardigheden die belangrijk zijn voor veilig rijden af, terwijl door de lage leeftijd van jongeren, de cognitieve vaardigheden nog niet volledig ontwikkeld zijn.
Hoewel leeftijd een belangrijke rol speelt, speelt rijervaring een nog belangrijkere rol: onafhankelijk van de leeftijd hebben bestuurders die meer kilometers afleggen, een lager ongevallenrisico per kilometer vergeleken met bestuurders die weinig kilometers afleggen. Hoewel oudere bestuurders veel rijervaring hebben (ca. 40 jaar), neemt hun rijervaring af met de leeftijd, aangezien ouderen de neiging hebben om het rijden te beperken tot de tijdstippen en locaties waar ze zich het

veiligst bij voelen. Jongere bestuurders hebben nog niet veel rijervaring omdat ze nog maar pas over hun rijbewijs beschikken.

Om het aantal dodelijke slachtoffers in verkeersongevallen te verminderen, is een uitgebreide beoordeling van rijgeschiktheid nodig. Rijgeschiktheid omvat zowel medische geschiktheid als rijvaardigheid. Hoewel er duidelijke procedures bestaan om rijgeschiktheid te meten wanneer men een rijbewijs wil halen in ontwikkelde landen zijn er niet altijd duidelijk procedures om rijgeschiktheid te meten eenmaal men reeds over een rijbewijs beschikt. Aangezien rijgeschiktheid met de leeftijd kan veranderen, is het belangrijk om regelmatig medische geschiktheid en rijvaardigheid in kaart te brengen. Het beoordelen van rijgeschiktheid en op de hoogte zijn van bepaalde gebreken is niet voldoende. Interventies zoals verkeerseducatie en training zijn nodig om van mensen veilige bestuurders te maken. Daarnaast is het belangrijk om bestuurders zo lang mogelijk veilige bestuurders te laten blijven aangezien mobiliteit belangrijk is voor de levenskwaliteit. Dit levenslang leren leidt tot het systematische verwerven, vernieuwen en vervolledigen van kennis, vaardigheden en attitudes die nodig zijn voor de constant veranderende levensomstandigheden.

Verkeerseducatie moet zich richten op zowel de lagere als hogere niveaus van de ‘Goals for Driver Education’ matrix. Het is belangrijk om het effect te evalueren om te weten of de interventies hun vooropgestelde doelen bereikt hebben. Aangezien iedere leeftijdsgroep een heterogene groep is, zal dezelfde interventie niet dezelfde wenselijke effecten voor alle bestuurders hebben.

Om het rijgedrag en effecten van verkeersveiligheidsinterventies in beide uitersten van het bestuurdersleeftijdsspectrum te onderzoeken, werden zes studies uitgevoerd die beschreven staan in zes hoofdstukken.
Aangezien er nog steeds geen instrument is dat adequaat een onderscheid kan maken tussen veilige en onveilige bestuurders, is zowel de relatie tussen maten van rijgedrag van ouderen en demografische maten als de relatie tussen maten van rijgedrag en maten van functionele vaardigheden onderzocht in **hoofdstuk 1**. Daarnaast is de verklaarde variantie van deze relaties onderzocht om de sterkte van deze relaties te bepalen. Omdat het gebrek aan een adequaat instrument mogelijk te wijten is aan de benadering die tot nu toe vooral gebruikt is, aangezien de meerderheid van de studies gesommeerde maten van rijgedrag gebruikt hebben, werden specifieke maten van rijgedrag onderzocht. Resultaten gaven aan dat het van de onderzochte rijmaat afhangt welke functionele vaardigheid

het meest belangrijk is. Hoewel demografische maten zoals leeftijd slechts een klein deel van de variantie in rijgedrag verklaren (nl. tussen 3% en 15%) was de verklaarde variantie in rijgedrag door functionele vaardigheden nog steeds eerder beperkt (nl. tussen 7% en 36%).

Aangezien cognitieve vaardigheden zoals aandacht belangrijk lijken te zijn voor bepaalde specifieke maten van rijgedrag tijdens rijden onder neutrale omstandigheden, werd onderzocht of ze ook belangrijk zijn voor bepaalde maten van rijgedrag tijdens rijden onder afleidende omstandigheden. In **hoofdstuk 2** werd onderzocht of aandacht capaciteit het effect van visuele en cognitieve afleiding op specifieke maten van rijgedrag modereert. Daarnaast werd het hoofdeffect van afleiding en het hoofdeffect van aandacht op rijmaten onderzocht. Tot slot werd onderzocht hoe deelnemers hun rijprestatie beoordeelden tijdens afleiding. Er was een modererend trend effect van aandacht capaciteit op een maat van slingergedrag: terwijl het slingergedrag afnam bij diegenen met een hogere aandacht capaciteit, nam het slingergedrag toe bij diegenen met een lagere aandacht capaciteit tijdens de rit met afleiding. Beide types van afleiding hadden negatieve effecten op de rijprestatie van oudere bestuurders. Er was vooral een negatief effect van afleiding op de rijmaten die een hoge eis stellen aan zowel voertuighandeling als informatieverwerking (vb. volledig stoppen aan stopborden), maar niet op rijmaten die een lage eis stellen aan voertuighandeling en/of informatieverwerking (vb. gemiddelde snelheid en volgafstand). Bestuurders reden trager tijdens afleiding. Daarnaast was een grotere aandacht capaciteit gerelateerd aan een kleiner aantal ongevallen. Ondanks de daling in rijprestatie tijdens afleiding beoordeelden deelnemers hun rijprestatie tijdens afleiding best hoog.

Hoewel cognitieve vaardigheden belangrijk lijken te zijn voor sommige rijmaten, is er debat over het effect van cognitieve training op rijgedrag. Mogelijk hangt dit af van het type training. Doorgaans zorgen adaptieve trainingen voor grotere vooruitgang dan niet-adaptieve trainingen, omdat adaptieve trainingen zorgen voor een adequaat moeilijkheidsniveau dat niet te moeilijk of te makkelijk is voor deelnemers. In **hoofdstuk 3** werd daarom het effect van een adaptieve vs. een niet-adaptieve cognitieve training op cognitieve vaardigheden en specifieke rijmaten van oudere bestuurders onderzocht. De cognitieve training had een effect op de getrainde cognitieve functie (nl. werkgeheugen). Deelnemers die adaptieve training (i.e., taak moeilijkheid aangepast aan de deelnemer) volgden, hadden de grootste verbetering in werkgeheugen. Deelnemers die niet-adaptieve training (i.e., taak moeilijkheid constant op een laag niveau) volgden hadden een kleinere verbetering in werkgeheugen. Deelnemers die geen training volgden hadden minimale verbeteringen in werkgeheugen. Op een maat voor aandacht vertoonden alle groepen (nl. adaptieve trainingsgroep, niet-adaptieve trainingsgroep, geen training groep) een verbetering, onafhankelijk van het type training, wat mogelijk een test-hertest effect aangeeft. Voor een maat van response-inhibitie waren groepsgemiddeldes in dezelfde richting, maar resultaten waren enkel marginaal significant. De cognitieve training had een marginaal significant positief effect op bepaalde rijmaten (nl. gemiddelde snelheid en reactie op stop borden), maar effecten waren klein.

Aangezien men verondersteld dat een meer directe training van rijgedrag meer invloed heeft op rijgedrag dan een meer indirecte training, werd in **hoofdstuk 4** het effect van een rijsimulator gebaseerde training op specifieke rijmaten van oudere bestuurders onderzocht. Meermaals rijden in een rijsimulator verbeterde prestatie op bepaalde rijmaten zoals slingergedrag. Om prestatie op andere rijmaten te verbeteren (nl. voorrang aan rechts verlenen) was rij-specifieke feedback nodig. Over het algemeen had de rijsimulator gebaseerde training middelmatige tot grote effecten op verschillende rijmaten.

Hoewel het belangrijk is om verkeersveiligheidsinterventies te richten op oudere bestuurders om hen zo lang mogelijk veilige bestuurders te laten blijven, is het ook belangrijk om interventies te richten op jonge mensen. Het is belangrijk om aandacht te schenken aan personen die recent hun rijbewijs hebben behaald, aangezien de eerste maanden zelfstandig rijden cruciaal zijn. Daarnaast evolueren veiligheid-gerelateerde attitudes over tijd en zijn individuen uiterst gevoelig voor attitudeverandering tijdens late adolescentie en vroege volwassenheid. Daarom werd het effect van een inzicht programma voor jonge beginnende bestuurders onderzocht op socio-cognitieve variabelen voor risicogedrag in het verkeer (nl. te snel rijden en rijden onder invloed van alcohol), op risicodetectie, en op risico-gerelateerde kennis in **hoofdstuk 5**. Onmiddellijk na het bijwonen van het programma waren positieve effecten op socio-cognitieve variabelen eerder beperkt in aantal en klein van omvang. Daarnaast had het programma ook ongewenste effecten op sommige socio-cognitieve variabelen (vb., verminderde risicoperceptie van rijden onder invloed van alcohol). Het programma had geen effect op risicodetectie. Hoewel het programma een groot effect had op risico-gerelateerde kennis bleef het kennisniveau relatief laag na het bijwonen van het programma. Twee maanden na het bijwonen van het programma bleef enkel het positief effect op risico-gerelateerde kennis overeind.

Het is ook belangrijk om interventies te richten op bestuurders die hun rijbewijs nog moeten halen omdat verkeersveiligheid gerelateerde attitudes op een jonge leeftijd ontstaan. Hoewel deze personen niet bekend zijn met het besturen van een wagen, zijn ze wel bekend met wandelen en fietsen. Daarom werd het effect van een verkeersveiligheidsprogramma voor leerlingen van het secundair onderwijs onderzocht op socio-cognitieve en gedragsvariabelen in **hoofdstuk 6**. Daarnaast werd de impact van het programma op de cognitieve en emotionele staat van deelnemers onderzocht en werd bekeken of deze impact op de cognitieve en emotionele staat het effect van het programma op socio-cognitieve en gedragsvariabelen beïnvloedde.
Onmiddellijk na het bijwonen van het programma had het programma kleine positieve effecten op de socio-cognitieve en gedragsvariabelen. Deze positieve effecten verschilden in functie van onderwijstype. Terwijl leerlingen van het algemeen secundair onderwijs en het secundair beroepsonderwijs meer verkeersveilig georiënteerd waren na het bijwonen van het programma, werd dit effect niet gevonden bij leerlingen van het technisch secundair onderwijs. Twee maanden na het bijwonen van het programma waren er kleine tot middelmatige positieve effecten op de meeste socio-cognitieve en gedragsvariabelen. Deze positieve effecten verschilden in functie van geslacht. Zowel mannelijke als vrouwelijke leerlingen waren na het bijwonen van het programma meer verkeersveilig georiënteerd, met mannelijke leerlingen in meerdere mate vergeleken met vrouwelijke leerlingen.
Onmiddellijk na het bijwonen van het programma had het programma een effect op de cognitieve en emotionele staat van deelnemers. Deze impact op de cognitieve en emotionele staat van deelnemers was relevant om het effect van het programma op socio-cognitieve en gedragsvariabelen in kaart te brengen: deelnemers die in mindere mate (cognitief en emotioneel) geprikkeld werden, werden in mindere mate verkeersveilig georiënteerd dan deelnemers die in meerdere mate (cognitief en emotioneel) geprikkeld werden.

Op basis van de verworven kennis in het kader van deze doctoraatsthesis kunnen een aantal **klinische aanbevelingen en beleidsaanbevelingen voor het in kaart brengen van rijgeschiktheid** geformuleerd worden.

(1) Demografische variabelen zoals leeftijd voorspellen slechts een beperkte hoeveelheid van de variantie in rijvaardigheid. Hierdoor zullen screening procedures die enkel en alleen op leeftijd gebaseerd zijn niet succesvol zijn in het verminderen van verkeersongevallen

van ouderen. Om beslissingen te maken over rijgeschiktheid is het van belang de juiste vaardigheden te meten. Functionele vaardigheden verklaren een grotere hoeveelheid van de variantie in rijvaardigheid, daarom zouden screening procedures aandacht moeten geven aan functionele vaardigheden. Gegeven de multifactoriële eigenschap van rijden en de bevinding dat verschillende functionele vaardigheden verschillend verbonden zijn aan verschillende rijmaten, zal het nodig zijn om meerdere functionele vaardigheden in kaart te brengen in tegenstelling tot het in kaart brengen van één enkele functionele vaardigheid. Echter, een programma dat rijvaardigheid in kaart brengt met enkel maten van functionele vaardigheden zal niet succesvol zijn in het maken van een onderscheid tussen veilige en onveilige bestuurders aangezien functionele vaardigheden slechts een beperkte hoeveelheid van de variantie in rijvaardigheid verklaren. Mogelijk is dit een verklaring voor het gegeven dat er momenteel nog steeds geen instrument is dat adequaat een onderscheid kan maken tussen veilige en onveilige bestuurders. Om betrouwbare resultaten te verkrijgen, zal het nodig zijn om een meer context-relevante meting te gebruiken. Indien rijvaardigheid gemeten dient te worden, zal het nodig zijn om een rijtest af te nemen. Aangezien bestuurders doorgaans problemen hebben met enkele specifieke verkeerssituaties, is het belangrijk om specifieke rijmaten te meten om een gedetailleerd beeld van rijvaardigheid te verkrijgen.

(2) Ondanks de uitgebreide rijervaring ervaren oudere bestuurders ook negatieve effecten op rijvaardigheid door afleiding. Hoewel oudere bestuurders lijken te compenseren voor de effecten van afleiding door trager te rijden, is het belangrijk om afleiding zo veel als mogelijk te elimineren tijdens het rijden. Aangezien oudere bestuurders hun prestatie tijdens rijden met afleiding nog steeds hoog inschatte, zijn educatieve programma's om bewustzijn over deze nadelige effecten van afleiding op rijden te verhogen aanbevolen.

Daarnaast kunnen enkele **klinische aanbevelingen en beleidsaanbevelingen voor verkeersveiligheidsinterventies** geformuleerd worden.

(1) Om succesvolle verkeersveiligheidsinterventies te ontwikkelen, is het aanbevolen om te focussen op de juiste doelgroep. Hoewel beide uitersten van het bestuurdersleeftijdsspectrum een relevante groep zijn vanwege hun verhoogde ongevallencijfers, zullen verkeersveiligheidsinterventies waarschijnlijk meer effect hebben in andere doelgroepen, bijvoorbeeld bestuurders met milde cognitieve

achteruitgang of als een alternatieve sanctie voor bepaalde groepen van verkeersovertreders, aangezien het verwacht kan worden dat zij meer en grotere beperkingen in (socio-cognitieve determinanten van) rijgedrag hebben.

(2) Daarnaast zou men eerst een behoefteanalyse moeten uitvoeren om de echte noden binnen een bepaalde doelgroep te ontdekken, vooraleer men de interventie begint te ontwikkelen. Bijvoorbeeld, als er een nood is om rijvaardigheid te verbeteren in tegenstelling tot cognitieve vaardigheid, zou een training direct gericht op rijvaardigheid in tegenstelling tot een training indirect gericht op rijvaardigheid beter geschikt zijn. Idealiter zou de training op maat van het individu of op maat van een groep van individuen met gemeenschappelijke kenmerken moeten zijn, waarbij enkel een focus is op de functies die verzwakt zijn. Het is belangrijk dat programma ontwikkelaars niet overambitieus zijn in het aantal doelstellingen dat behaald moeten worden, maar eerder focussen op een gepast aantal doelstellingen.

(3) Bovendien moeten gepaste methoden en strategieën geselecteerd worden op basis van beschikbaar theoretisch en empirisch wetenschappelijk bewijs. Bijvoorbeeld, als het doel is om hogere orde vaardigheden te verbeteren, zouden er geen methoden en strategieën geselecteerd moeten worden die lagere orde vaardigheden verbeteren (vb. onderwijsstijl gebaseerd op instructies), maar methoden en strategieën die hogere orde vaardigheden verbeteren (vb. onderwijsstijl gebaseerd op ondersteuning).

(4) Het is aanbevolen om interventies te evalueren, aangezien programma effecten soms klein of zelfs nadelig kunnen zijn. Naast effect evaluaties, zijn procesevaluaties ook belangrijk om te weten waarom een interventie gewenste effecten heeft of niet. Effecten kunnen afhangen van het achtergrondprofiel van deelnemers (vb. geslacht en educatie) en op de manier waarop het programma aangeboden is (vb. emotionele en cognitieve impact). Gerelateerd aan de manier waarop het programma aangeboden is, is het aanbevolen om te focussen op middelmatige niveaus van prikkeling, aangezien verwacht kan worden dat deze resulteren in optimale informatieverwerking.

Samenvattend: de uitgevoerde studies in deze doctoraatsthesis leiden tot meer inzichten over het in kaart brengen van rijvaardigheid om veilige bestuurders te onderscheiden van onveilige bestuurders. Nadat de rijvaardigheid op een gedetailleerde manier in kaart gebracht is, is het duidelijk als mensen overmatige, beperkte of geen problemen met functionele vaardigheden of rijvaardigheid hebben. Indien bestuurders overmatige problemen met functionele vaardigheden of rijvaardigheid hebben, is stoppen met rijden op zijn plaats. In dat geval is het belangrijk om oudere bestuurders te begeleiden, aangezien stoppen met rijden een negatieve impact op iemands levenskwaliteit kan hebben. Indien bestuurders beperkte problemen met functionele vaardigheden of rijvaardigheid hebben, is het aanbevolen om training of educatie te volgen om bestuurders veilige bestuurders te maken en om hen zolang mogelijk veilig bestuurders te laten blijven. Training en educatie lijken namelijk te helpen in het voorkomen of tegenwerken van achteruitgang in functionele vaardigheden of rijvaardigheid wat ten gunste is van levenslang leren.

# DOCTORAL THESIS OUTLINE

This doctoral thesis focused on both ends of the driver age spectrum since both older drivers and younger drivers have increased fatality rates.

The thesis is divided into several parts and starts with a **general introduction** that gives some general information about the main topics of this doctoral thesis. First, aspects of traffic safety like the number, causes and circumstances of traffic accidents are highlighted. Then, driver assessment procedures are explained. Finally, aspects of traffic safety interventions like content, implementation and evaluation are described.

In six chapters, the performed studies are described in detail. Each chapter describes the research process:

- Problem discovery by conduction of a literature review and formulation of research questions
- Development of the methodology: identification of the research design, the target group and appropriate research instruments
- Data collection
- Data analysis
- Interpretation of results
- Formulation of recommendations

The outline of these chapters is shown in Figure 1.
First, two cross-sectional studies on the assessment of driving behavior of older drivers are discussed. A driving simulator was used since it allows to investigate specific driving measures and to investigate dangerous situations in a safe environment. Neuropsychological measures were used to assess functional abilities that are important for driving.
The first study is described in **chapter 1** and investigated the relation between measures of driving behavior and functional abilities since at this moment there is still no instrument that adequately distinguishes between safe and unsafe drivers. Since this is possibly due to the approach that has been used so far to investigate the relation between driving behavior and functional abilities, as the majority of studies have used summarized measures of driving behavior, in the present studies specific measures of driving behavior of older drivers were assessed.

The following research questions were formulated:

(1) What is the relation between specific measures of driving behavior and demographic measures and functional abilities?
(2) What is the importance of demographic measures and functional abilities for predicting measures of driving behavior?

Since cognitive abilities seem to be important for some specific measures of driving behavior while driving under neutral circumstances, it was investigated whether cognitive abilities are also important for measures of driving behavior while driving under distracting circumstances. More specifically, in this second study which is described in **chapter 2,** it was investigated whether attention capacity moderates the effect of distraction on specific measures of driving behavior.

The following research questions were formulated:

(1) What is the effect of visual distraction (experiment 1) and cognitive distraction (experiment 2) on specific measures of driving behavior?

(2) Does attention capacity moderate the effect of visual distraction (experiment 1) and cognitive distraction (experiment 2) on specific measures of driving behavior?

(3) How do people rate their performance during driving with and without visual distraction (experiment 1) en cognitive distraction (experiment 2)?

In order to make people safe drivers and to keep them safe drivers for as long as possible, traffic safety interventions are necessary. It is important to evaluate these interventions in order to be able to document their effectiveness and to find out what elements did or did not work, so that directions for future improvements can be formulated. Therefore, four studies on the evaluation of traffic safety interventions are discussed.

The first two cross-sectional studies focused on older drivers. Although older drivers already have their driver's license, this is no guarantee for safe driving. Interventions are necessary in response to the constantly changing conditions of modern life.

Although cognitive abilities seem to be important for some measures of driving behavior, there is debate about the effect of cognitive training on driving behavior. Possibly, this depends on the type of training. In general, adaptive training leads to larger training gains than non-adaptive training since adaptive training ensures an adequate level of difficulty that does not over- or underchallenge participants. Therefore, in **chapter 3**, the effect of an adaptive vs. a non-adaptive cognitive working memory training on cognitive abilities and specific measures of driving behavior was investigated.

The following research questions were formulated:

(1) What is the effect of an adaptive vs. a non-adaptive cognitive working memory training on cognitive abilities?

(2) What is the effect of an adaptive vs. a non-adaptive cognitive working memory training on specific measures of driving behavior?

Since it is assumed that a more direct training of driving behavior (e.g., driver training) has more effect on driving behavior compared to a more indirect training (e.g., cognitive training), in **Chapter 4**, the effect of a driving simulator based training on specific measures of driving behavior was investigated. More specifically, the merits of driving-specific feedback were investigated.

The following research question was formulated:
(1) What is the effect of a driving simulator based training on specific measures of driving behavior?

The last two longitudinal studies focused on young people, more specifically on those who obtained their driver's license recently and those who still need to obtain their driver's license. Both studies used a questionnaire based on the Theory of Planned Behavior in order to investigate intervention effects on socio-cognitive (and behavioral) variables.

In **chapter 5** the effect of a post-license education program for young novice drivers was investigated since the first few months of independent driving pose the greatest risk of collision. In addition, traffic safety-related attitudes evolve over time and individuals are highly susceptible to attitude change during late adolescence and early adulthood.

The following research questions were formulated:
(1) What is the immediate effect of the program On the Road on socio-cognitive variables, risk detection and risk-related knowledge?
(2) What is the extended effect of the program On the Road on socio-cognitive variables, risk detection and risk-related knowledge?

In **chapter 6** the effect of a pre-license education program for high school students was investigated since safety related attitudes are formed at a young age. Although these people are new-comers as car drivers, they are not new to the roads. They already have extensive experience in other traffic roles (e.g., pedestrian, cyclist).

The following research questions were formulated:
(1) What is the immediate effect of the program Traffic Informers on socio-cognitive and behavioral variables?

(2) What is the extended effect of the program Traffic Informers on socio-cognitive and behavioral variables?
(3) Does the program have an immediate effect on participants' cognitive and emotional state?
(4) Does this effect on participants' cognitive and emotional state influence the program's impact on socio-cognitive and behavioral variables?

After these six chapters, there is a **general discussion**. First, main findings and clinical and policy recommendations are formulated. Then, strengths and limitations of the conducted studies are discussed together with some future research suggestions.
The doctoral thesis ends with some **final conclusions**.

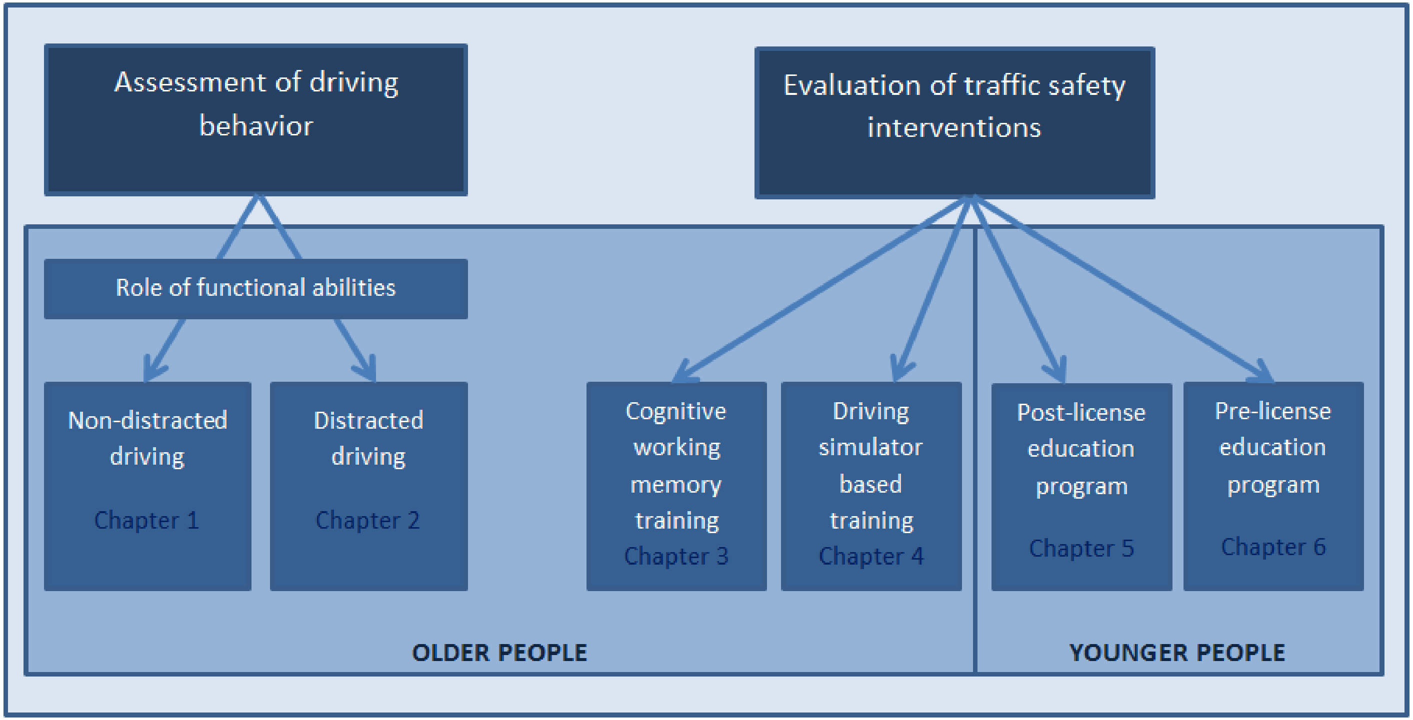

**Figure 1.** Visualization of the chapters in the doctoral thesis

# GENERAL INTRODUCTION

## 1.1. Demographic changes in the population

It is important to pay attention to older people, since there is a demographic shift towards an ever-increasing number of older citizens in industrialized countries. This increase is a consequence of the baby boom between 1946 and 1964 that occurred after World War II, and a consequence of the increased life expectancy due to improvements in healthcare (i.e., medicine, nutrition). In Figure 1, the population pyramid of the Flemish district in Belgium in 2013 is displayed. Since the pyramid comes in at the bottom, the population is older on average, has long life expectancy and a low birth rate. In 2013, the life expectancy of Flemish citizens was approximately 81.30 years.

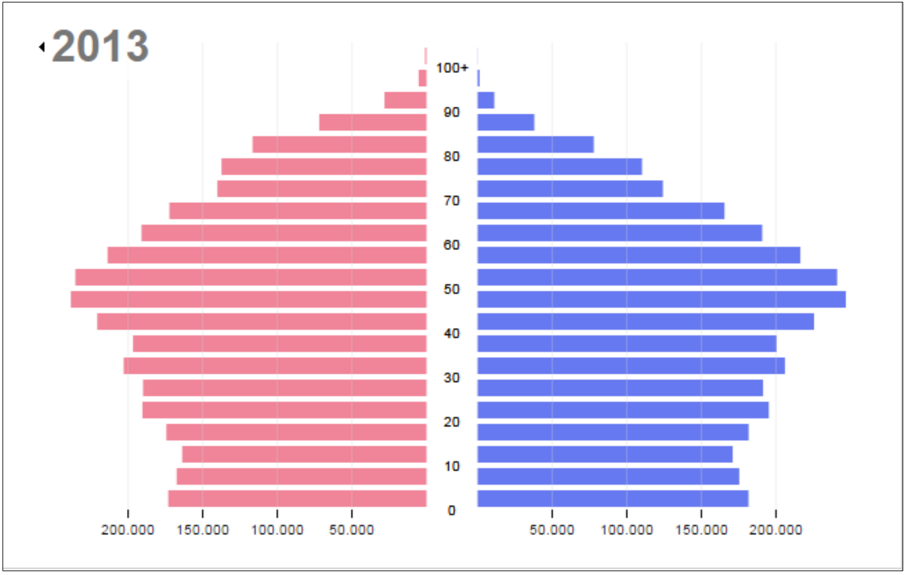

**Figure 1.** Population pyramid of the Flemish district in 2013. Pink bars represent the number of female citizens, blue bars represent the number of male citizens (FPS Economy SMEs, Self-Employed and Energy).

There is not only an increase in the number of older citizens, but also an increase in the number of older drivers (Eby, Molnar, & Kartje, 2009). It is expected that by 2030, more than 25% of the car drivers in Belgium will be 65 years or older (Martensen, 2014). Because older people nowadays are increasingly active and travel by car more often, the number of older drivers increases even faster than the number of older citizens. They, for example, visit senior associations and bring their grandchildren to school by car. Although at this moment there are more older male drivers compared to older female drivers, this gap in driver's license holding among males and females is decreasing (Hakamies-Blomqvist, Sirén, & Davidse, 2004). Possibly this is because driving a car is related to autonomy and offers a flexible way of moving. In industrialized countries, mobility has therefore been mainly based on private car traffic. However, driving a car is a complex, goal-directed task that places high demands on functional (i.e., visual, cognitive, and motor) abilities (Groeger, 2000). As a result, among all the means of transport used by humans, road transport is the most dangerous one (Keskinen, 2014).

## 1.2. Number of traffic accidents

Traffic accidents occur due to the interaction between three components: human behavior, road vehicle and traffic environment. According to Sabey and Taylor (1980), human behavior plays a role in 96% of the traffic accidents and in 65% of the traffic accidents human behavior was identified as the sole contributor to traffic accidents. These traffic accidents bring along large social and economic costs, and are a serious challenge to public health (Peden et al., 2004).

Compared to other causes of death like diseases and suicide, traffic accidents are one of the leading causes of death, especially in industrialized countries (ECMT, 2006). However, despite rising motorization, there has been an overall downward trend in traffic accident injuries in these countries since the seventies. This trend is the result of successful traffic safety policies targeting human behavior, the development of safer vehicles and the improvement of the traffic environment (Peden et al., 2004). Yet in recent years, the number of lives saved has plateaued. Therefore, the European Commission has set the goal to halve the number of fatalities in traffic by 2020 compared to 2010 (EC, 2015a). The ultimate goal is to have zero fatalities in traffic.

Although traffic accidents occur in all age groups, in Figure 2 it is clear that middle-aged drivers compared to younger and older drivers have the lowest fatality rates. Therefore, it is important to pay attention to both ends of the driver age spectrum: older drivers and younger drivers. Compared to other age groups, young novice drivers are involved in a disproportionately large number of traffic accidents (Evans, 2004; Hatakka et al., 2003; Kweon & Kockelman, 2003; Rhodes, Brown, & Edison, 2005), since they are at almost twice the risk of being killed in a traffic accident than the average member of the population across the

European countries as a whole (EC, 2015c). In the European Union, 17% of the traffic victims are young adults (as a driver as well as a passenger), while young adults represent only 8.9% of the total population.

By the end of the sixties, the concept of the ‘older driver problem’ was introduced. However, there is some debate about whether older drivers are also a risk group in traffic. Actually, it depends on the way fatality rates are defined. Fatality rates start to increase again from the age of 74 years or older and start to decrease again from the age of 84 years or older, when illustrating fatality rates per 100,000 people in each age group (Figure 2). However, when illustrating fatality rates per 100,000 licensed drivers in each age group, it is clear that there is a U-shaped curve, with highest fatality rates among both young and older drivers. Finally, when illustrating fatality rates per 100 million miles driven, this U-shaped curve is even more pronounced, with drivers being 84 years or older having the highest fatality rates. Taking these ways of illustrating fatality rates together, it can be concluded that drivers with an age of 70 years or older have increased fatality rates compared to all but the youngest drivers (Eby et al., 2009).

Although drivers with an age of 70 years or older have increased fatality rates compared to all but the youngest drivers, older drivers drive less kilometers per year. The Central Bureau of Statistics in the Netherlands indicated in April 2016 that a retired household drives almost halve as much kilometers compared to a non-retired household: 9,300 kilometers per year compared to 17,900 kilometers per year. This decrease in driving experience may exaggerate driver risk per kilometer estimates (Hakamies-Blomqvist, Raitanen, & O’Neill, 2002). Drivers who make more kilometers, regardless of age, have reduced accident rates per kilometer compared to those making fewer kilometers (Hakamies-Blomqvist et al., 2004). When taking this into account, it can be derived from Figure 3, that only older drivers who drive less than 3,000 kilometers per year are high risk drivers (Langford, Methorst, & Hakamies-Blomqvist, 2006).

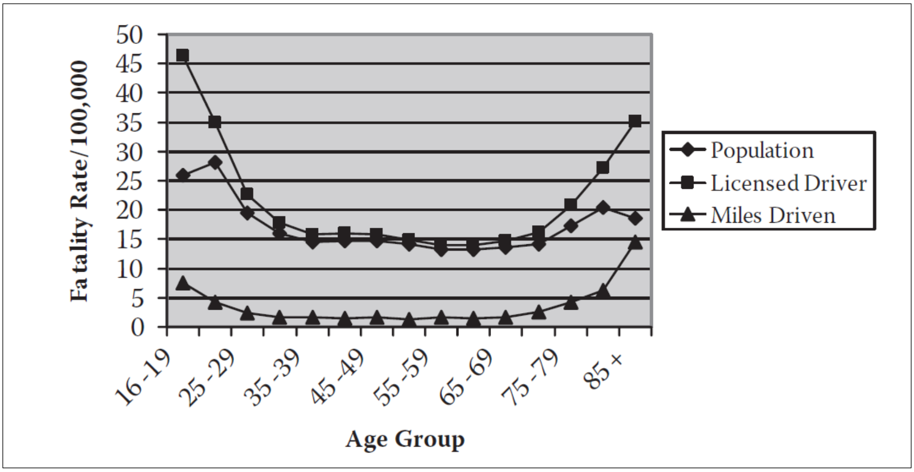

**Figure 2.** U.S. motor vehicle driver fatality rates by age group (data from Insurance Institute for Highway Safety, 2007; FHWA 2008a, derived from Eby et al. (2009)).

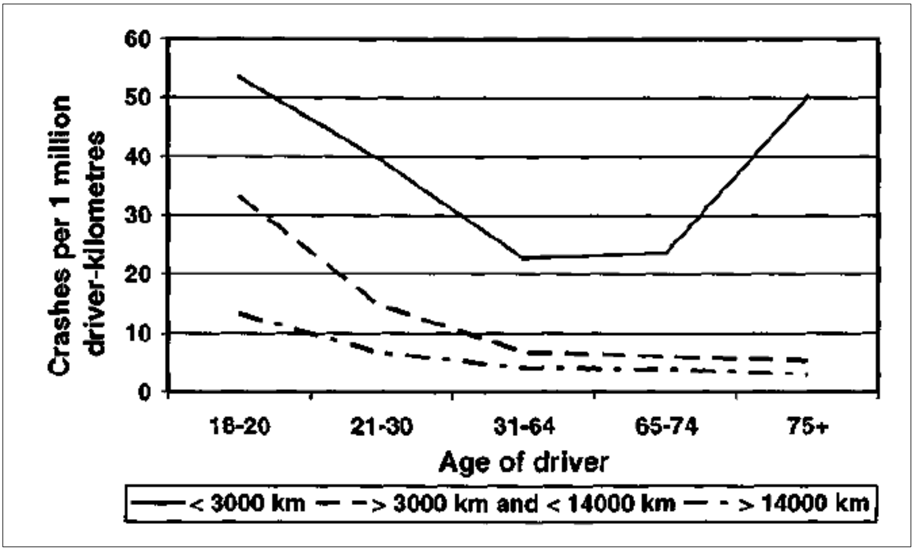

**Figure 3.** Annual crash involvement for different driver ages, controlling for annual mileages (Langford et al., 2006).

## 1.3. Causes of traffic accidents

Older people (65 years or older) mainly have elevated accident rates due to deficits in functional abilities important for driving. Functional abilities are visual, cognitive, and motor abilities. Visual abilities are necessary to perceive information while driving. Examples are visual acuity and contrast sensitivity. Cognitive abilities are necessary to make decisions while driving. Examples are the ability to sustain attention and to temporarily store or manipulate information. Motor abilities are necessary to handle the vehicle during driving. Examples are muscular strength and balance. The task of driving requires the interaction of these abilities: drivers need to receive information, process the information and make proper and timely judgments and responses (Freund, Colgrove, Burke, & McLeod, 2005).

Although deficits in these functional abilities can occur with normal aging, in certain cases, these deficits are due to disorders like dementia. Declines in functional abilities can threaten driver fitness. Driver fitness means that one meets the minimum standards of physical and cognitive driver fitness and has the abilities to drive a car. Driver fitness is therefore a medical decision taking into account medical history (e.g., medication use), functional abilities, and driving ability. Only when one is fit to drive, one can obtain and keep a driver’s license. Unfortunately, driver fitness can change over the course of a driver’s lifetime, which is why driver assessment and interventions are needed regularly. Drivers should continuously reflect upon their competence, since driving circumstances change continuously, (e.g., more drivers, new vehicles and driving environments). If they identify problems, they must take responsibility for solving those problems, for example, by using technical aids, limiting driving or even (temporarily) refraining from driving (Weiße, 2015). In Belgium, a stroke can be a reason for a temporary driving cessation, since the law states that after a stroke one is not allowed to drive for at least six months.

Fortunately, when people are aware of their decreases in functional abilities they can self-regulate their driving behavior. By self-regulating their driving behavior, they can reduce task demands and increase safety margins. For instance, people can adopt lower driving speeds, avoid overtaking, and decide not to drive under bad weather conditions (Fisher, Rizzo, Caird, & Lee, 2011; Meng & Siren, 2012). Unfortunately, these self-regulative behaviors can also increase accident risk. For example, the slowness of older drivers can create problems at intersections where they

encounter younger drivers who drive faster and have higher capacities for action than older people.
As was illustrated in Figure 3, in addition to the decrease in functional abilities, older drivers' accident rates are also elevated due to a decrease in driving experience (Langford et al., 2006). Although older people nowadays make more and longer trips than older people in the past, they make less and shorter trips than younger age groups since older people do not have to make work-related trips anymore. In addition, older drivers have the tendency to restrict their total kilometers driven to times and places that they feel the safest (Ball et al., 1998). As a consequence, their feeling and routine with the dynamic traffic environment decreases. Moreover, older people have increased risk for serious injuries due to their physical frailty. They can become severely injured or even die due to the consequences of a traffic accident that would be much less harmful for a younger person (Hakamies-Blomqvist et al., 2004).

Younger people (15-24 years) mainly have traffic accidents due to immaturity and lack of driving experience (EC, 2015c). Regarding immaturity, areas of the human brain which are dealing with 'executive' functions like planning, inhibition, reasoning and the integration of information, necessary for driving, are still developing at the age when most drivers can obtain a driver's license (ECMT, 2006). This maturation can last until the age of 25 years. Hence, the cognitive capacity of young people is still limited when they already obtain a driver's license (De Luca & Leventer, 2008; Glendon & Bryan, 2011). As a result of this biological immaturity, adolescence is a period of socio-behavioral transition. During this period adolescents are in the middle of a socialization process in which they are getting away from their parents' influence to become independent. They are often more susceptible to the influence of peers, who may not necessarily be good role models for safe driving.

Because young drivers have their drivers' license since a short period, they lack sufficient driving experience. It requires a lot of practice before expert levels of driving are reached (e.g., 100,000 kilometer). Michon (1985) divided the task of driving into three hierarchical levels of skills and control. The first operational level deals with vehicle control and includes variation in speed and frequency of steering movements. The second tactical level is related to maneuvers like overtaking and gap acceptance, while taking into account other road users' behavior and traffic situations. The third strategical level has to do with the planning of a trip, for example choices about mode and route, and goals. In order to drive safely and to limit the risk of having a traffic accident, drivers should be successful at all three levels.

Due to these causes of young driver traffic accidents (i.e., immaturity and lack of driving experience), the literature often speaks of the 'young driver problem' and the 'problem young driver'. While the 'young driver problem' is related to the lack of driving experience, the 'problem young driver' is related to immaturity (Senserrick, 2006).

It can be concluded that for both older and younger drivers, both age and (lack of) experience are related to traffic accidents (Catchpole & Coutts, 2002; Drummond & Yeo, 1992). Due to the young age, younger drivers' cognitive abilities are not fully developed, while due to the old age, older drivers' cognitive abilities are decreasing. Although age plays an important role in accident risk, driving experience is even more important (Maycock, Lockwood, & Lester, 1991; Slootmans, Dupont, & Silverans, 2011). While older drivers have a lot of driving experience (e.g., 40 years), their driving experience now decreases. In case older people drive less than 3,000 kilometers per year, they have elevated accident rates. Young drivers have not yet acquired enough driving experience and it is known that the first few months of independent driving pose the greatest risk of collision for novice drivers (Mayhew, Simpson, & Pak, 2003).

### 1.4. Circumstances of traffic accidents

Younger people have traffic accidents mainly during weekends and on rural roads (EC, 2015c). They usually have single vehicle accidents, and thus merely are a threat to themselves. Their traffic accidents are mainly due to risky driving, e.g., making a traffic offense by not respecting the speed limits.

Older people have traffic accidents mainly during weekdays and on urban roads (EC, 2015b). Risky driving like speeding and yellow light running are uncommon events in older drivers (Eby et al., 2009; West et al., 2010) since they are more aware of the risks that are associated with these kinds of risky driving behaviors, and are more willing to avoid this. Their traffic accidents are mainly due to errors (Eby et al., 2009), and one of the most frequent driving errors at intersections is failure to stop completely at a stop sign (McKnight, 1988; Staplin, Lococo, McKnight, McKnight, & Odenheimer, 1998). Situations mentioned most often in the literature to be difficult for the older driver include responses to signs, signals and road hazards (Bao & Boyle, 2008; Horswill et al., 2009) and gap acceptance while turning left at an intersection, where typically the older driver turns against oncoming traffic with right of way on the main road (Yan, Radwan, & Guo, 2007). As a result, their traffic accidents mainly occur at intersections. Consequently, they usually have multiple vehicle accidents, thereby not only being a threat to themselves, but also posing risk toward other road users.

Although younger drivers mainly have traffic accidents due to risky driving and older drivers mainly have traffic accidents due to errors, this does not mean that older people never expose themselves to risky driving circumstances. For example, a risk that is often taken by drivers of all ages, is driving while being distracted. Although several studies argue that driver distraction is mainly a problem of young novice drivers (Hakamies-Blomqvist, 1994; McEvoy, Stevenson, & Woodward, 2007; Young & Lenné, 2010), data from the Crashworthiness Data System that has detailed data on a representative, random sample of thousands of minor, serious, and fatal crashes in the United States showed no significant differences between young and older drivers (Stutts et al., 2005; Stutts, Reinfurt, Staplin, & Rodgman, 2001). Driver distraction can be defined as the diversion of attention away from activities critical for safe driving toward a competing (driving- or non-driving related) activity (Regan, Hallett, & Gordon, 2011). Distraction can occur due to carrying out additional tasks during driving.

Two important types of distraction are visual distraction and cognitive distraction. Visual distraction means that the driver has the eyes off the road, for example, by looking at a text message on a mobile phone. Cognitive distraction means that the driver has the mind off the road, for example, by conducting a hands-free mobile phone conversation (J. Engström & Markkula, 2007). In the United States-100 Naturalistic Car Study, it was found that 78% of the accidents and 65% of near accidents had one form of inattention or distraction as a contributing factor (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005).

Although distraction is often a contributing factor of accidents, in seldom circumstances, distraction can have beneficial effects. For example, when driving on a monotonous road, distraction can suppress fatigue (Atchley, Chan, & Gregersen, 2014; Chan & Atchley, 2011; Gershon, Ronen, Oron-Gilad, & Shinar, 2009). This indicates that detrimental effects arise when resource demands exceed resource availability or vice versa. Therefore, the relationship between resource demands and resource availabilities can best be represented as an inverted U-shaped curve with moderate levels of resource demands leading to optimal results (Janis, 1967; McGuire, 1968, 1969).

When distraction has adverse effects on driving performance, this is due to a mismatch between resources demanded by the driving task and resources devoted to it. Resource demands may simply exceed resource availability, as our cognitive capacity is limited, causing workload or information overload (Proctor & Van Zandt, 2008). Therefore, especially those with a low cognitive capacity are susceptible to distractor interference (Lavie, Hirst, De Fockert, & Viding, 2004). Both young and older people have lower cognitive capacity compared to middle aged drivers, although due to other reasons. Since resource demands play an important role, distraction mainly affects driving subtasks that require deliberation or active exploration, whereas it leaves reflexive and habitual subtasks largely unaffected. Attentional demand thus increases with driving complexity (Cantin, Lavallière, Simoneau, & Teasdale, 2009; Stinchcombe & Gagnon, 2013; Stinchcombe, Gagnon, Zhang, Montembeault, & Bedard, 2011). This is in line with the complexity hypothesis, indicating that performance is especially impaired when the complexity of the task is raised (Mayr & Kliegl, 1993). Previous research has classified driving complexity according to the Fastenmeier (1995) taxonomy of driving complexity (Patten, Kircher, Östlund, & Nilsson, 2004; Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Stinchcombe & Gagnon, 2013; Stinchcombe et al., 2011; Törnros & Bolling, 2006). This taxonomy consists of two dimensions: information processing and vehicle handling. Consequently, four combinations of demands are possible: low demands on both information processing and vehicle handling, low demands on information processing and high demands on vehicle handing, high demands on information processing and low demands on vehicle handing, and high demands on both information processing and vehicle handling.

In order to prevent detrimental effects of distraction on driving performance, drivers have to learn not to overestimate their own skills and to only undertake those tasks in traffic that they are capable of, an ability sometimes referred to as "calibration" (Kuiken & Twisk, 2001). In order to reach this, driver assessment is necessary to obtain an overview of situations were drivers have difficulties with.

## 2. DRIVER ASSESSMENT

Driver assessment is necessary to detect unsafe drivers. Assessment provides the basis for identifying functional deficits, determining the extent of driving impairment, recommending license actions, and identifying options for driving compensation or remediation (Molnar & Eby, 2008). Driving ability is assessed during the process of licensing. In order to drive a car, one must obtain a driver’s license. Although in each country the licensing system is unique in terms of content and organization, in general two distinct categories of licensing systems can be distinguished: (1) traditional systems consisting of one or two phases, which are implemented in European countries, and (2) graduated licensing systems consisting of multiple phases, which are implemented in Anglo-Saxon countries like the United States, Canada, Australia and New Zeeland (SWOV, 2013; Vanlaar et al., 2009).

In traditional systems with one phase, people can obtain a full driver’s license allowing them to drive independently without restrictions after one phase of theory and training and a driving test (I. Engström, Gregersen, Hernetkoski, Keskinen, & Nyberg, 2003). More and more European countries now adapt systems with two phases. In these systems, people can obtain a provisional or a probationary driver’s license allowing them to drive independently under certain restrictions (e.g., peer passenger restriction) after completion of a first phase of theory and training and a driving test. After a second phase of theory and training, but without further tests, people can obtain a full driver’s license allowing them to drive independently without additional restrictions (I. Engström et al., 2003). In both one-phase and two-phase systems, a probationary period can be included, before obtaining the full driver’s license, where drivers are allowed to drive unsupervised under certain restrictions. In case drivers do not adhere to these restrictions, the probationary period can be extended or the driver can be forced to follow a driver improvement course (I. Engström et al., 2003).

In graduated driving licensing systems, where the basic principle is to allow new drivers to acquire driving experience under low risk situations, often three phases are included. In a first phase, people can obtain a learner’s permit where drivers are allowed to drive under supervision. In a second phase, people can obtain a provisional license where drivers are allowed to drive independently under certain restrictions like a restriction on peer passengers. In a third phase, people can obtain a full license allowing them to drive independently without additional restrictions (Mayhew, Williams, & Pashley, 2014).

European countries do not have a typical graduated licensing system since the licensing age of a full driver’s license is higher compared to Anglo-Saxon countries. Although evaluation studies have shown positive improvements in traffic safety since the implementation of graduated licensing systems, the magnitude of the effect of graduated licensing systems in European countries may be smaller since the 'old' licensing systems in Anglo-Saxon countries were less 'advanced' compared to the European licensing systems. Although graduated licensing systems induced significant reductions in accidents and fatalities, it is important to mention that these improvements were especially visible during the first two phases, and substantially less during the third phase (Williams, Tefft, & Grabowski, 2012). This indicates that graduated licensing systems especially are an exposure measure. To obtain positive effects during the third phase, the integration of a graduated driver education in a graduated licensing system is recommended (Lonero & Mayhew, 2010).

Importantly, licensing systems are not only applicable to novice drivers who want to obtain their driver’s license, but also to drivers who already obtain a driver’s license (e.g., older drivers). Among countries, there are several procedures to assess driver fitness of older drivers. In some Anglo-Saxon countries, the reversed version of graduated licensing systems is used, referred to as ‘graduated delicensing’ (Cobb & Coughlin, 1998). In this system, restrictions are phased in, as drivers age. The goal is to prevent abrupt driving cessation. Hence, the idea is to have a restricted license that allows to continue driving while being exposed less and less to risky driving circumstances. For example speed (i.e., no highway), time of travel (i.e., daytime only), and geographical area of travel (i.e., certain distance from home) can be restricted. The imposition of restrictions occurs in conjunction with a reevaluation of an individual’s license. For example, in Canada, drivers of any age have to renew their driver’s license after some years, however, beginning at the age of 80 years and every 2 years thereafter, older drivers must submit a medical report indicating driver fitness (Nasvadi & Wister, 2009). Based on this report, functional abilities or driving ability can be assessed and restrictions can be introduced as a result of poor test scores. For example, restrictions for nighttime driving may be introduced as a result of poor scores on a visual test (Nasvadi & Wister, 2009; Stutts, Stewart, & Van Heusen-Causey, 2000). These restrictions are an attempt to improve the fit between the skills of the older driver and the demands of the traffic environment, and to delay revoking a license altogether. Nasvadi and Wister (2009) found that drivers with a restricted license continued to drive accident-free for a longer period compared to unrestricted drivers and that drivers with a restricted license retained their license for longer periods.

In Europe, screening procedures for drivers differ across countries (EC, 2016). Several European countries have introduced an age based screening procedure in order to prevent unfit older drivers from taking part in traffic. Although the age at which this procedure starts varies among countries, for the vast majority it starts around 70-75 years. For example, the Netherlands have introduced an age based screening procedure from the age of 75 years. This screening takes place every 5 years and includes a medical check. In case problems with driver fitness are detected, it can be decided to add restrictions to the driver's license (e.g., driving in a limited area) which is visible by a code on the driver's license. Or, in case the problems are too severe, the driver's license can be revoked. Recent research has indicated that, while countries that have age based screening procedures have lower average fatality rates among car drivers, this is not the case for older drivers (Martensen & Diependale, 2014). As a consequence, relative to the other age groups, the older drivers are not less at risk in countries that have aged-based screening. Possibly, a screening procedure creates a false sense of security. For example, a positive evaluation could confirm a driver who might otherwise be doubtful about his or her own driver fitness that there is no need to worry. Hence, when considering the whole driver age spectrum, aged-based screening lower fatality rates, but not among older drivers (Martensen & Diependale, 2014).

As a consequence, these age based screening procedures are not successful in lowering fatality rates of older drivers. In addition, only a very small percentage of the group of older drivers is classified as unfit to drive. Recent statistics of the Central Bureau of Driver Licenses in the Netherlands indicated that 103,168 people of 75 years or older requested an extension of the driver's license and that 99,377 of these people received an extension. Hence, solely 3.7% of the older drivers were classified as unfit to drive. Moreover, age based screening procedures can cause stigmatization where all older drivers are perceived as unsafe drivers. However, aging is a complex process, bringing at all ages a combination of growth and loss. The positive aspects of aging (i.e., driving experience, wisdom, strategic thinking and less risk taking) are under-appreciated (Hakamies-Blomqvist et al., 2004). This stigmatization can create stereotype threat with the possible consequence that people perform bad because they want to contradict the stereotype (Joanisse, Gagnon, & Voloaca, 2013). In addition, such procedures bring along high costs for the driver and the society.

The finding that an age based screening does not lower fatality rates among older drivers is what we could have expected since older drivers are a heterogeneous group. Although unsafe driving increases with chronological age (Anstey & Wood, 2011), age alone, as the mere passage of time, is not an adequate predictor of driving ability (Anstey, Horswill, Wood, & Hatherly, 2012; Barrash et al., 2010). Functional abilities seem to be a more adequate predictor of driving ability. Hence, functional age is more representative for driver fitness than chronological age. Importantly, deficits in functional abilities do not start at the same age and do not occur to the same degree in each individual (Eby et al., 2009; Fildes, 2008; Langford, 2008). As a consequence, it is possible that an 85-year-old driver is in better shape than a 65-year-old driver.

Since not all drivers are aware to what extent their driver fitness has declined, some European countries (e.g., Romania) have screening procedures for all driver ages. However, these procedures also bring along high costs for the driver and the society.

Finally, several European countries have no screening procedures at all. For example, in Belgium and France, drivers have an unlimited driver's license even though it has to be renewed after some years (i.e., Belgium: every 10 years, France: every 15 years). This renewal is an administrative renewal where a declaration of medical fitness has to be signed, but does not require a medical examination. However, in Belgium, general practitioners have the duty to report problems with driver fitness. Therefore, general practitioners are faced with the challenge of balancing their patients' safety against their needs for mobility and independence, as well as the quality and confidentiality of the general practitioner-patient relationship (Eby et al., 2009). In case of (presumption of) decrease in driver fitness, they can refer their patients to the 'Center of driver fitness and vehicle adaptation'. In this center, people need to undergo a comprehensive driving assessment including neuropsychological tests and a driving test on the public road. However, this assessment is very stressful for the driver. In addition, only a very small percentage of the drivers are unfit to drive (i.e., 8%).

Given the logistics and costs of comprehensive driving assessments, there is, since a couple of years, a lot of attention for a multi-tier system of driver assessment (Figure 4). The logic behind the multi-tier system is that the complexity of testing only increases when there is an indication of unsafe driving, thereby preventing unnecessary stress and financial costs for the participant.

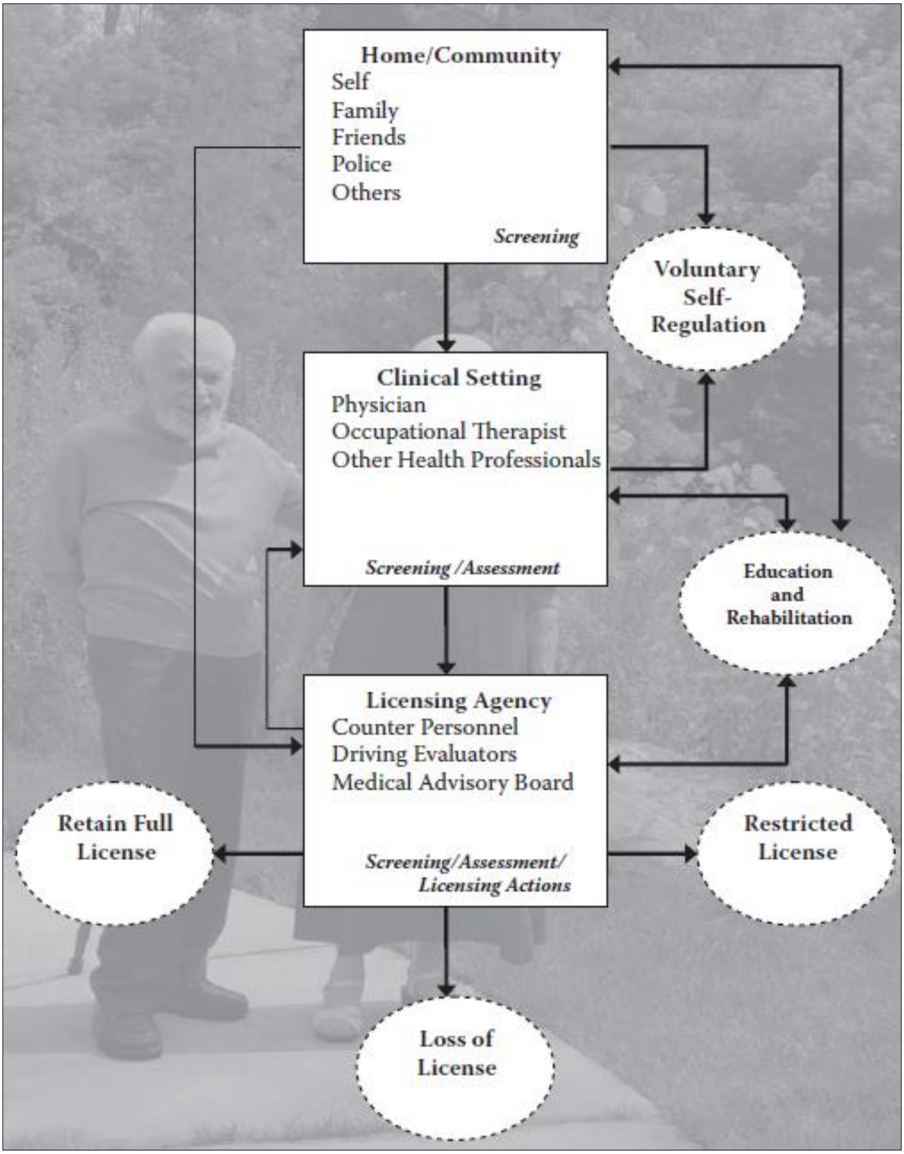

**Figure 4.** Schematic representation of the older adult driver screening and assessment process (Eby et al., 2009).

The purpose is to let (caregivers of the) drivers in the first tier conduct a quick, efficient and cost-effective screening. In case the driver obtains an alarming score on this screening, he or she is referred to the second tier encompassing a more multidimensional in-depth assessment. In case the driver obtains also an alarming score on this assessment, he or she is referred to the third tier consisting of a driving test (De Raedt & Ponjaert-Kristoffersen, 2001; Langford, Bohensky, Koppel, & Newstead, 2008; Lees, Cosman, Lee, Rizzo, & Fricke, 2010). The first tier could consist of a self-evaluation questionnaire like a checklist. Many older drivers are unwilling or unable to recognize deficits in driving-related abilities. Although driver fitness cannot be based on a self-evaluation measurement, checklists are often a useful first step in sensitizing people and to help start the discussion about driver fitness, since they are nonintrusive and therefore less threatening. As a result, people may be more likely to be screened earlier in disease onset, resulting in earlier detection of declines in functional abilities (Eby, Molnar, Shope, Vivoda, & Fordyce, 2003). Checklists could increase awareness regarding traffic skills and problems. A better insight into driving problems, together with advice about how to compensate for certain driving problems supports the self-regulation of driving habits (Lang, Parkes, & Fernandez-Medina, 2013). Checklists are easily accessible since they can be filled in privately at home. One example of a checklist is the "Drivers 65 Plus" checklist of the American Automobile Association - Foundation for Traffic Safety (AAAFTS, 2013). This checklist consists of 15 questions related to four topics: (1) Knowledge of traffic rules, driving behavior and habits, (2) difficulties in certain traffic situations, (3) medical aspects, and (4) traffic offences and accidents. Based on the answers, drivers are divided into one of three categories: (1) Ok, (2) Careful, or (3) Stop.

It is recommended to discuss the results on the checklist with the general practitioner, especially when drivers obtain the categories 'careful' and 'stop'. In this way, people enter the second tier that could consist of a neuropsychological test battery including assessment of functional abilities. This tier would involve general practitioners and occupational therapists. An example of a cognitive test that is related to driving ability is the Useful field of View, which measures attention (Ball, Owsley, Sloane, Roenker, & Bruni, 1993). An example of a motor test that is related to driving ability is the Get-Up-and-Go test, which measures balance (Stav, Justiss, McCarthy, Mann, & Lanford, 2008). An example of a visual test that is related to driving ability is the Snellen chart, measuring visual acuity (Dawson, Uc, Anderson, Johnson, & Rizzo, 2010). In the last decades, several studies have been done in search of reliable predictors of older drivers' driving ability. Research investigating the relation between measures of functional abilities and driving ability has shown that several tests are significantly related to driving ability. For example, studies indicated that older drivers with a reduction of at least 40% of their attention capacity, as measured with the Useful Field of View test, were more likely to incur an accident than older drivers with less attention capacity reduction (Ball et al., 1993; Owsley et al., 1998). Despite of the fairly robust evidence suggesting cognitive screening instruments have value in predicting driving ability, there is still no single instrument that can accurately distinguish between safe and unsafe drivers (Vanlaar et al., 2014). As a consequence, many safe drivers are prohibited from driving, and, vice versa. The value of screening instruments for predicting driving ability differs in function of how driving ability is measured and across screening instruments themselves (Vanlaar et al., 2014).

Since there is still no instrument that can accurately distinguish between safe and unsafe drivers, a driving test remains the golden standard to make decisions about driver fitness. The driving test would be the third tier in a multi-tier system. The test could be performed on a computer (e.g., hazard perception test), on a driving simulator, on a closed circuit, or on the public road. Although driving on the public road has been considered the golden standard to measure driving ability, it also has several disadvantages. It is costly, can be dangerous, and it is difficult to control all variables (e.g., weather conditions and congestions). Hence the traffic situations among drivers can vary. A driving simulator, which is a virtual reality tool, could serve as a good alternative (Figure 5). People drive in a virtual environment that simulates the real environment. Driving simulators offer the opportunity to investigate dangerous situations in a safe environment (Lee, Cameron, & Lee, 2003). It has the benefit of reliable results, since the traffic situations are the same for every driver. Since the environment is controlled, the traffic situations of interest can be investigated (e.g., urban and rural roads). It offers the benefit of detailed results, since it allows to investigate specific driving measures like longitudinal and lateral driving measures. Importantly, there is positive evidence for simulator validity (Aksan et al., 2016; Casutt, Martin, Keller, & Jäncke, 2014; Fisher et al., 2011; Lee et al., 2003).

**Figure 5.** Driving simulator.

During the driving test, performed on road or in a simulator, the examiner can make use of a standardized scoring instrument like the Test Ride for Investigating Practical fitness to drive (Akinwuntan et al., 2005). This instrument takes into account performance on several parameters like speed, lateral control, gaze behavior, and reaction time. Based on the driving test, one of three decisions can be made: (1) pass (almost no driving problems), (2) pass with restrictions (certain driving problems, e.g., pass but not allowed to drive during rush hours), and (3) fail. In case people pass (with or without restrictions) an intervention can be recommended to prevent or attenuate decline in driver fitness. In case people fail, interventions will not help anymore and driving cessation would be more appropriate. Since driving a car is related to autonomy, and important for quality of life and health (Eby et al., 2009), driving cessation can have significant impact (Marottoli et al., 1997; Ragland, Satariano, & MacLeod, 2005). It can lead to social isolation and even depression, bringing along large societal costs. Moreover, if people are not allowed to drive a car anymore, which is a safe mode since people are protected, they end up as pedestrians and thus become more vulnerable road users, leading to more fatalities (EC, 2015b). Therefore, driving cessation is only justified after a thorough assessment and when interventions (e.g., education, vehicle adaptations) do not lead to improvement anymore. In case driving cessation is recommended, it is important that people receive information about alternative ways to stay mobile. Transit training may be effective in increasing the use of public transportation. In this training, participants are given bus schedules and large print detailed pamphlets about how to use the public transit system. In addition, an ambassador demonstrates how to use the schedules and the bus signs for effective route planning, including getting on the correct bus (Stepaniuk, Tuokko, McGee, Garrett, & Benner, 2008). In order to have a smooth transition from the use of private cars to the use of alternative transport modes, it is recommended to start talking about driving cessation in an early phase.

The view that mobility is important for the quality of life of older people seems to exist especially in Anglo-Saxon countries. In these countries, several (research) centers exist that focus on older driver assessment. They also focus on remediation and rehabilitation, or on offering advice about alternative transport modes in case there are problems with driver fitness. For example, in the United States there is the 'National Older Driver Research and Training Center', and in Canada there is the 'Canadian Driving Research Initiative for Vehicular safety in the Elderly'. Although there are centers that assess driver fitness in Europe, these are not focusing on older drivers. For example, in Belgium, drivers of all ages with some deficit (e.g., after stroke), can go to 'the Center of driver fitness and vehicle adaptation'. However, in case of problems with driver fitness, this center does not offer remediation, rehabilitation or advice about alternative transport modes.

## 3. TRAFFIC SAFETY INTERVENTIONS

Traffic safety interventions are necessary to make people safe drivers and to keep them safe drivers for as long as possible. Accordingly, traffic safety interventions help to achieve the goal of the European Commission to reduce the number of fatalities in traffic. Due to the multi-faceted nature of driving, a package of countermeasures is required. These countermeasures can be divided into five E's: (1) education, (2) engineering, (3) enforcement, (4) encouragement and (5) evaluation (Forward & Kazemi, 2009). Education tries to change the (socio-cognitive determinants of) behavior of road users through various programs. Examples are pre- and post-license education programs. Engineering has the goal to improve road infrastructure and vehicles. An example of road infrastructure improvement is replacing an uncontrolled intersection by a traffic light controlled intersection. An example of vehicle improvement is the use of an Advanced Driver Assistance System. These systems can assist the driver in the driving task in order to minimize the number of errors and avoid unsafe behavioral choices as much as possible. For example, by using adaptive cruise control the speed of the vehicle is automatically adjusted to maintain a safe distance from vehicles ahead (Davidse, 2006). Enforcement refers to legal actions from police officers to encourage adherence to the highway code. An example of enforcement is a speed inspection to investigate whether drivers comply with restrictions on speed. Encouragement aims to motivate road users to behave safely and is sometimes intertwined with education and can include some form of incentive program. Last but not least, evaluation aims to assess if interventions were successful. For example, assessing whether an educational program was successful in changing (socio-cognitive determinants of) behavior.

### 3.1. Content of traffic safety education

Education and training are often used interchangeably. While there is some overlap, each represents a distinct concept. Education generally covers a broader range of methods and strategies than training and is carried out over a longer period. Therefore, training which often involves a specific instructional program that relates to car control, can be viewed as a specific component of education (Beanland, Goode, Salmon, & Lenné, 2013; Senserrick & Haworth, 2005).

Education emphasizes: (1) promotion of knowledge and understanding of traffic rules and situations, (2) improvement of skills through training and experience, and (3) strengthening and changing attitudes towards risk awareness, personal safety and the safety of other road users (Dragutinovic & Twisk, 2006).

In most industrialized countries, one must follow driver education, in order to obtain a driver’s license. However, this obliged driver education to obtain a driver’s license (with formal courses offered by professional driver instructors and/or layman instructors) will not be enough to make and keep people safe drivers. Interventions before and after obtaining the driver’s license targeting all groups of drivers (e.g., young novice drivers and older drivers) could have positive effects on driving ability. Interventions offered before obtaining the driver’s license are called pre-license education programs. These programs are often offered at elementary schools and high schools. Although these youngsters are newcomers as car drivers, they are not new to the roads. They already have extensive experience in other traffic roles like pedestrians and (motor)cyclists (Mann & Lansdown, 2009; Waylen & McKenna, 2008). Once one has obtained the driver’s license, the ability to drive safely is often taken for granted. However, having a driver’s license, is no guarantee of safe driving. Therefore, driver education is also needed after one has obtained a driver’s license. Such programs are often referred to as post-license education programs.

The Goals for Driving Education matrix (Figure 6) provides a framework for defining the detailed competencies needed to be a safe driver and determines which aspects should best be included in driver education (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002). The matrix is based on the assumption that the driving task can be decomposed into a hierarchy of competences and skills. The idea of the hierarchical approach is that failure as well as success at higher levels, affect the demands on skills at lower levels. The lowest level, skills for vehicle maneuvering, includes the skills needed to control and operate the vehicle and is comparable to the operational level of Michon’s model (Michon, 1985). The second level, mastering traffic situations, includes speed, knowledge of traffic rules and interaction with other road users and resembles the tactical level of Michon’s model (Michon, 1985). At the third level, goals and context of driving, the focus is on why, where, when, and with whom the driving is carried out, and is comparable to the strategical level of Michon’s model (Michon, 1985). The fourth level entails goals for life and skills for living, and thus refers to the person’s self, including the driver’s perceptions of how to behave in traffic situations. As the lowest levels are more technical in their nature and specifically concern driving, this level connects driving to the individual's personality and general life skills (Keskinen, 2014; Porter, 2011). Although the original matrix entailed these four levels, a couple of years later, a fifth level was added (Keskinen, 2014). This level concerns culture, legislation, enforcement, subculture, social groups, group values, and norms. The driver's social environment constitutes the framework through which he or she seeks to comply with all areas of life.

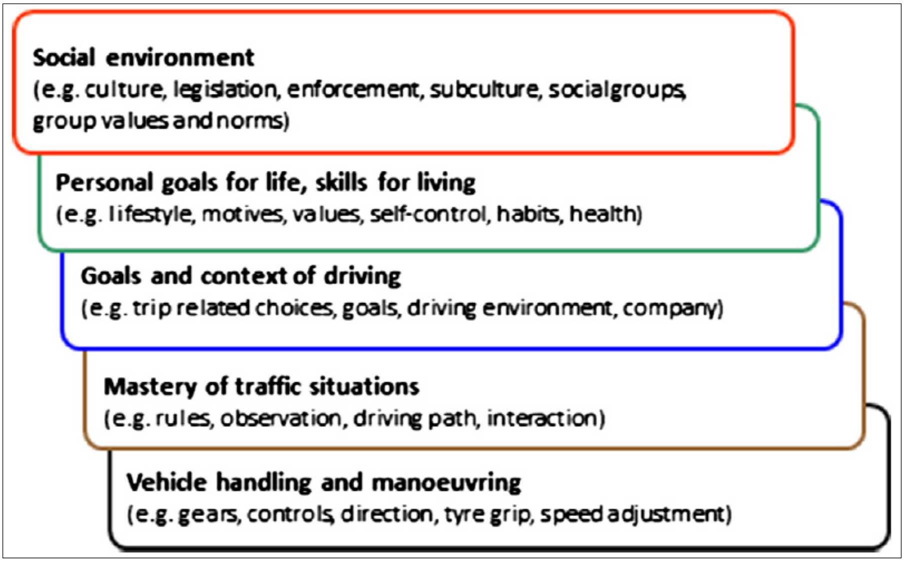

**Figure 6.** The five-level driving hierarchy that has been the basis for the Goals for Driver Education in the Social Perspective (Keskinen, 2014).

Although all levels of the matrix should be addressed in driver education to end up with safe drivers, the obliged driver education to obtain a driver's license often only targets lower-order procedural skills like vehicle handling skills (Keskinen, 2014; Senserrick & Haworth, 2005). As a consequence, instructors adopt a traditional instructive style (Beanland, Goode, et al., 2013). However, the ultimate goal of the obliged driver education should be to create drivers who are safe, and not just technically competent, by the time they are permitted to drive independently. Safe driving goes beyond mere skills. In addition to skills, motives are also important for safe driving (Keskinen, 2014). Therefore, driver education should focus also on the higher levels of the matrix. Especially during post-license education these higher order levels are addressed. Post-license education is usually offered several months after obtaining the driver's license, since novice drivers by that time have encountered new traffic situations, have started to develop their own driving style, and regard car driving as a means to an end rather than as a meaningful activity in itself (de Craen, Vissers, Houtenbos, & Twisk, 2005). Post-license education often makes use of the insight approach which intends to raise awareness and improve insight into factors that contribute to traffic accidents, for example overestimation of skills and underestimation of risk (Senserrick & Haworth, 2005). Rather than focusing on practical skills and what a driver can do, insight programs focus on attitudinal and motivational aspects and what a driver is willing to do. They also focus on personal criticism and (social) responsibility (Senserrick & Swinburne, 2001). These programs typically address the intrinsic motivation of people to prevent danger (instead of coping with it) and to prioritize the safety of oneself as well as that of others above all when participating in traffic. For example, one should be motivated to drive safe, rather than to prioritize belonging to a (risk-supportive) group. Insight programs have flourished enormously over the last few years (Carcary, Power, & Murray, 2001; Kuiken & Twisk, 2001; Molina, Sanmartín, Keskinen, & Sanders, 2007; Nolén et al., 2002; Nyberg & Engström, 1999; Senserrick & Swinburne, 2001). These insight programs often target young drivers, since they were found to be less traffic safety oriented, have the propensity to take and accept more risks and are more influenced by others in traffic compared to older people (Keating, 2007). Younger drivers have their own social environments where peers have more influence than their parents. Their social roles change, for example from grown-up to parent, from student to employee and from single person to a married person.

In these higher order education programs, instructors should adopt a coaching style instead of an instructive style, since the instructor's role at the higher levels is not to offer information and explanations but rather to offer questions that help the learner find his or her own answers in understanding feedback (Beanland, Goode, et al., 2013).

Although driver education is often associated with younger drivers, older drivers can benefit from education as well. It has been shown that, even in old age, the human brain is plastic which implies that cognitive abilities are flexible and can be altered, leading to improvement of those functions (Erickson et al., 2007). Hence, older people can still learn, although less easily than younger people (Kramer & Willis, 2002). The cognitive enrichment hypothesis states that the behaviors of an individual (including cognitive activity, social engagement, exercise, and other behaviors) have a meaningful positive impact on the level of effective cognitive functioning in old age (Hertzog, Kramer, Wilson, & Lindenberger, 2008). A perhaps more popular hypothesis, the ‘use it or lose it’ hypothesis falls under this cognitive enrichment hypothesis and states that keeping cognitively active will maintain one’s level of cognitive functioning, and possibly even prevent cognitive decline and the onset of dementia (Hertzog et al., 2008; Salthouse, 2006). However, research indicates that the benefits of ‘using it’ may be limited to the specific tasks being trained, rather than to overall other, non-trained tasks (Ackerman, Kanfer, & Calderwood, 2010).

Since older people can still learn, the concept of 'lifelong learning' was introduced. Lifelong learning is facilitated by lifelong education. It leads to the systematic acquisition, renewal, upgrading, and completion of knowledge, skills and attitudes that are necessary in response to the constantly changing conditions of modern life. For its successful implementation, it is dependent on people's increasing ability and motivation to engage in self-directed learning activities, and acknowledges the contribution of all available educational influences including formal and informal learning during a person's entire life (Tight, 1998; Weiße, 2015).

The Goals for Driver Education matrix, which was originally conceived with novice drivers in mind, is also suitable for older drivers (Keskinen, 2014; Molnar, Eby, Roberts, St Louis, & Langford, 2009). Older drivers can experience problems on the operational level (slowness) and the tactical level (attention-related problems). On the higher levels, older drivers can experience problems that are connected to health conditions and improper self-assessment (e.g., no awareness of their decrease in driver fitness). Older drivers also have their own social environments where family and peers, as well as the accepted values in society, affect older drivers' views of driving (Keskinen, 2014). Their social roles also change, for example from parent to grandparent, from employee to retiree and from married person to a widower (Hakamies-Blomqvist et al., 2004). The social environment is in many ways important when older drivers make decisions about driving cessation. For example, if there is only one driver in a household, the driving cessation of that driver can have a large impact on mobility. Aspects of lifelong learning in connection with the claims of the five levels of the Goals for Driver Education matrix and an individual maintaining and developing of driving competences plays a very important role for a safe and responsible driving over lifetime (Figure 7).

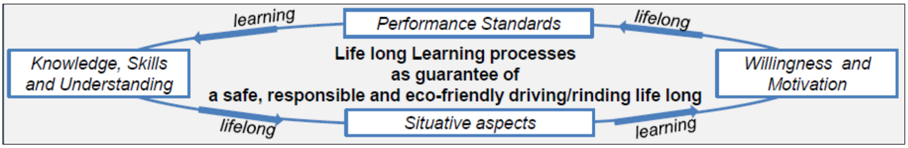

**Figure 7.** Lifelong learning and improving of competencies and driving/riding competences (Weiße, 2015).

## 3.2. Implementation of traffic safety education

Education programs can make use of a passive or more active teaching method. With passive teaching methods learners typically listen to the given information. An example is a driver refresher course that uses classroom instruction to reinforce driving knowledge, and teaches new traffic laws and practices for defensive driving. Another example is the use of testimonials by (relatives of) people who were involved in a traffic accident in order to sensitize people to behave safely in traffic. The underlying idea is that such a testimonial will emotionally affect participants, thereby stimulating them to cognitively reflect upon their own behavior and responsibility as a road user. With active teaching methods, learners typically do something. An example is driving simulator based training where drivers need to practice in a driving simulator.

Training can be applied preventively or curatively. Preventively when there is no decrease in abilities yet with the goal to postpone functional and/or driving impairment. Curatively when there is already functional and/or driving impairment with the goal to attenuate these impairments and restore proper functioning. Examples of curative programs are remediation and rehabilitation programs. These programs are offered when one needs to recover from impairment (e.g., stroke). Training, either preventively or curatively oriented, can target driving ability both directly and indirectly (Figure 8). In an intervention targeting driving ability directly, driving ability itself is being trained. This can be done on the public road, on a closed circuit, on a driving simulator, or on a computer (Casutt, Martin, et al., 2014; Lavallière, Simoneau, Tremblay, Laurendeau, & Teasdale, 2012; Romoser & Fisher, 2009). When targeting driving ability indirectly, the underlying functional abilities important for driving are being trained. This can be done with a (computer-based) training targeting cognitive abilities (Ball, Edwards, Ross, & McGwin Jr, 2010; Cassavaugh & Kramer, 2009), or motor abilities (Marmeleira, Godinho, & Fernandes, 2009; Sayers & Gibson, 2012).

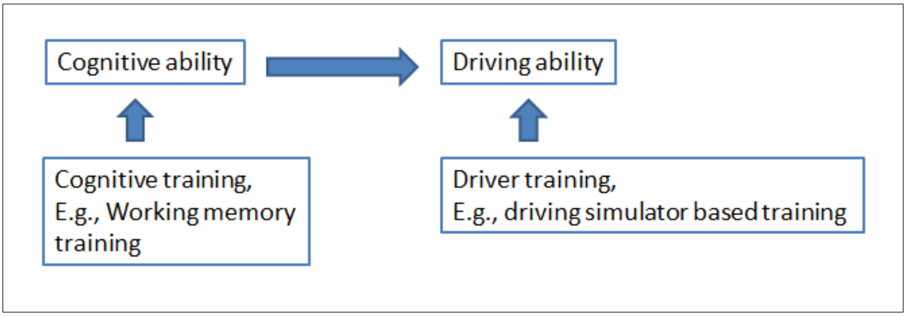

**Figure 8.** Indirect and direct training of driving ability.

Several studies have shown that cognitive training can not only improve the cognitive function being trained (Ball et al., 2002; Ball, Edwards, &

Ross, 2007; Karbach & Kray, 2009; Rebok et al., 2014; Schmiedek, Lövdén, & Lindenberger, 2010), but sometimes also untrained cognitive functions (Karbach & Kray, 2009). This is not surprising since different cognitive functions and their underlying neural circuits are interrelated (McNab et al., 2008). Adaptive training generally leads to larger training gains than non-adaptive training since adaptive training ensures an adequate level of difficulty that does not over- or underchallenge participants (Brehmer, Westerberg, & Bäckman, 2012; Holmes, Gathercole, & Dunning, 2009; Karbach, Strobach, & Schubert, 2015; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002). Interestingly, a limited amount of studies has indicated that cognitive training also improves driving ability (Ball et al., 2002; Ball et al., 2007; Ball et al., 2010; Ball, Ross, Roth, & Edwards, 2013; Cassavaugh & Kramer, 2009; Edwards, Delahunt, & Mahncke, 2009; Edwards, Myers, et al., 2009; Rebok et al., 2014; Roenker, Cissell, Ball, Wadley, & Edwards, 2003). As a result, several commercial packages like DriveSharp, Positscience and Cognifit were developed. However, there is debate about the effects of cognitive training on driving ability (Gaspar, Neider, Simons, McCarley, & Kramer, 2012; Lange & Süß, 2015; Mayhew, Robertson, & Vanlaar, 2014; Melby-Lervåg & Hulme, 2013; Reijnders, van Heugten, & van Boxtel, 2013; Shipstead, Redick, & Engle, 2012). Since near transfer effects are a requirement for far transfer effects (T. L. Harrison et al., 2013), cognitive improvement due to cognitive training is necessary in order to obtain driving improvement by cognitive training. However, a cognitive training targeting driving ability indirectly can only be successful in improving driving ability when the explained variance by cognitive abilities is sufficient. According to the ‘law of identical elements’ and the ‘exercise-specificity approach of learning abilities’ the most appropriate training conditions are those that allow training the same underlying processes that will be used in the task where one wants to have an effect on (Schmidt & Lee, 2005; Thorndike & Woodworth, 1901). Hence, if the goal is to have an effect on driving ability, abilities need to be acquired in a driving-specific context. An intervention targeting driving ability directly instead of indirectly therefore probably will have more effect. Indeed, recent studies have indicated that a driving simulator based training, compared to a cognitive training, is more successful in improving driving ability of older people (Casutt, Theill, Martin, Keller, & Jäncke, 2014; Gaspar et al., 2012; Mayhew, Robertson, et al., 2014) and people who had a stroke (Devos et al., 2009). In addition to the improvement of driving ability of older drivers, driving simulator based training also seems to improve cognitive ability of older drivers (Casutt, Theill, et al., 2014).

## 3.3. Evaluation of education effects

Evaluation is the systematic application of research procedures for assessing the conceptualization, design, implementation and utility of interventions. Evaluation should be integrated in every phase of a program (Dragutinovic & Twisk, 2006). As a result, there are several types of evaluation. A first type is formative evaluation, also called process evaluation. This evaluation takes place in the developmental phase of the program in order to obtain information about changes and improvements that are necessary. Another type of evaluation is summative evaluation, also called outcome evaluation or effect evaluation. This evaluation takes place after a program has been developed and implemented in order to determine whether the program has the intended effect and reached the pre-set objectives. A third type of evaluation is economic evaluation. This evaluation critically reviews the costs and benefits of a program and concludes whether they are justified (Boulanger, Divjak, Orozova-Bekkevold, & Zabukovec, 2007).

Despite the rising popularity of traffic safety education programs, the effects of these programs are not clear. Among 1,500 traffic psychology publications for the years 1998-2008, less than 2% could be classified as evaluation studies (Glendon, 2011). This brings Delhomme et al. (2009) to plead in support of investing more time and effort in decently evaluating education programs (p. 4): "Governments and authorities invest a great deal of money and effort in changing the behavior of road users. Traffic safety communication campaigns are one of the most important means of persuading road users to adopt safe behaviors. However, do we really know if they are successful? Without rigorous evaluation and reporting, it is very difficult to know whether a campaign is successful or not." Therefore, it is recommended to evaluate these programs in order to be able to document their effectiveness and to find out what elements did (not) work, so that directions for future improvements can be formulated (Delhomme et al., 2009; Dragutinovic & Twisk, 2006). Indeed, although interventions aim for beneficial effects, they can also have counterproductive effects. For example, several studies have indicated that skid control training can have counterproductive effects leading to capacity overestimation and increased accident rates (Beanland, Goode, et al., 2013). In addition, studies have indicated that over-fixation on the severity of the immediate physical consequences of a traffic accident by using a fear appeal-like style with bloody and excessively shocking pictures to increase awareness of participants can result in counterproductive effects (Carey, McDermott, & Sarma, 2013;

Peters, Ruiter, & Kok, 2013; Ruiter, Abraham, & Kok, 2001; Ruiter, Kessels, Peters, & Kok, 2014; Ruiter, Verplanken, De Cremer, & Kok, 2004; Witte, 1992).

The evaluation criteria for traffic safety education should be defined in terms of the objectives of the program. Since the ultimate goal of education is to reduce the number of traffic accidents, the effect of an educational program should be investigated on the number of traffic accidents. However, traffic accidents are relatively infrequent events and their data collection is also often incomplete, and is therefore sometimes not valid or reliable enough (Dragutinovic & Twisk, 2006). As a result, the number of traffic accidents that occurs during an evaluation period would be too low in order to be able to detect any serious effects. Although the ultimate goal is to reduce the number of traffic accidents, an educational program often has more specific objectives (i.e., improving (socio-cognitive variables of) behavior of a certain target group).

Instead of using traffic accident data, the evaluation can be done through the use of observational data or self-reports. Observations generate rich and reliable data. This data can be gathered by simply observing participants' behavior or by having participants conduct several tasks. In case data needs to be collected about functional abilities, a neuropsychological test can be administered. In case data needs to be collected about driving ability, a driving test can be set up. However, observational data often includes a relatively small and/or unrepresentative sample because of high financial costs and time restrictions with the additional restriction that the scope of observational data is mostly limited to only one or a few behaviors and/or situations (Twisk, Vlakveld, Commandeur, Shope, & Kok, 2014).

Self-report measures allow investigation of subjective states such as attitudes or emotions which can be inferred only indirectly from observational studies or accident data. Also, they can easily cover a wider range of behaviors and situations which increases the generalizability of such data. Another advantage is the relatively cost-effective way to gather large amounts of information. However, individuals can manipulate outcomes of self-report measures. For example, a participant may deliberately lie to create a better self-image (af Wåhlberg, 2012; Gravetter & Forzano, 2006; Taylor, Peplau, & Sears, 2006). Although the validity of self-report measures is often questioned, there is growing support for the validity of self-report measures as predictors of objective behavior measures (e.g., (Armitage, 2005; Begg, Langley, & Williams, 1999; Boufous et al., 2010; Conner et al., 2007) (Elliott, Armitage, & Baughan, 2007; Elliott, Thomson, Robertson, Stephenson, & Wicks, 2013; Hatakka, Keskinen, Katila, & Laapotti, 1997).

Self-report measures often include questions about socio-cognitive and behavioral variables derived from social cognition models like the Theory of Planned Behavior (Ajzen, 1985).

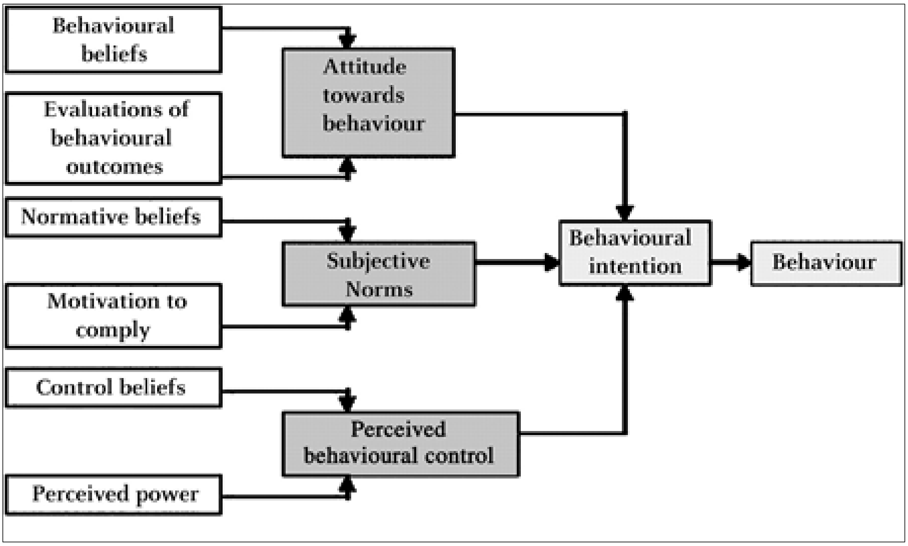

**Figure 9.** Theory of Planned Behavior (Ajzen & Madden, 1986)

The Theory of Planned Behavior (Figure 9), is a social psychological theory and is a successor of the Theory of Reasoned Action. The Theory of Planned Behavior is one of the empirically most supported behavioral theories and has been validated in diverse research domains (Godin & Kok, 1996; Stutton, 1998). The theory helps to understand the specific variables that need to be influenced in order to obtain behavior change. Behavioral intention is a key predictor of behavior (Sheeran & Orbell, 1999). It is determined by three conceptually independent variables: attitude, subjective norms and perceived behavioral control. The attitude toward the behavior is determined by beliefs about outcomes of performing the behavior under study. Subjective norms, also called perceived social expectations, refer to the beliefs that important individuals or groups have about the behavior and one's motivation to comply with these beliefs. Subjective norms can be external (i.e., descriptive and injunctive norms) and internal (i.e., personal norms). Perceived Behavioral Control which is highly similar to Bandura's conceptualization of self-efficacy (Fishbein & Ajzen, 2010), often refers to the subjective probability that a person is capable of executing a certain course of action. This variable influences behavior both directly and indirectly. Some authors have suggested other variables to be added to the model in addition to the three described above, for example past behavior (Sheeran & Orbell, 1999).

# CHAPTER 1

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## The relations between specific measures of simulated driving ability and functional ability: new insights for assessment and training programs of older drivers.

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## Abstract

To gain new insights for driving assessment and training, this study had two objectives: (1) to investigate the relations between specific measures of older drivers' driving ability and demographic/functional ability measures, and (2) to verify the explained variance of these relations to determine the strength of these relations. A sample of 55 older drivers (mean age 76 years) completed a set of functional ability tests as well as a driving simulator test. Results indicate that (1) each specific driving measure is related to a specific set of functional abilities, and (2) only a small proportion of the variability observed in the specific driving measures is explained by demographic variables (3-15%) and by functional abilities (7-36%). For driving assessment programs, it will be necessary to assess several functional abilities to cover the complexity of the driving task. Furthermore, an assessment program focusing solely on demographic and/or functional ability measures, will not be successful in discriminating safe from unsafe older drivers. For driving training programs, it will be necessary to focus on the right set of functional abilities given that specific driving measures are differently related to different functional abilities. Moreover, a training targeting functional abilities might only have marginal effects on driving ability, given the relatively low amount of driving ability variance that is explained by functional abilities.

## Key words

Older drivers; Assessment; Functional ability; Driving simulator; Training

## 1. INTRODUCTION

In most industrialized countries, the number of older drivers is increasing. Driving a car is related to autonomy, and important for quality of life and health (Eby et al., 2009). Therefore, driving cessation can significantly impact people’s health (Marottoli et al., 1997). Although most older drivers have a lot of driving experience (i.e., more than 50 years) and are less involved in risky driving behavior such as speeding and driving under influence, due to increased frailty older drivers are more susceptible to injury from a traffic accident (Eby et al., 2009). These injuries bring along large social and economic costs, and are a serious challenge to public health (Peden et al., 2004). Altogether, there is a need for a driving assessment instrument that adequately distinguishes between safe and unsafe older drivers. In the last decades, several studies have been in search of reliable predictors of older drivers’ driving ability. Although unsafe driving increases with chronological age (Anstey & Wood, 2011), age alone, as the mere passage of time, is not an adequate predictor of driving ability (Anstey et al., 2012; Barrash et al., 2010). Instead, decline of functional abilities (i.e., cognitive, motor and visual abilities) important for driving does not start at the same age and do not occur to the same degree in each individual (Eby et al., 2009; Fildes, 2008; Langford, 2008). Research investigating the relation between measures of functional abilities and driving ability has shown that several tests are significantly related to driving ability, for example the Useful Field of View (UFOV) test (Ball et al., 2006; Jongen et al., 2012; Mullen, Chattha, Weaver, & Bedard, 2008). A recent meta-analysis conducted by Vanlaar et al. (2014) indicates that although there is fairly robust evidence suggesting cognitive screening instruments have value in predicting driving ability, there is still no single instrument that can accurately identify an unsafe driver. As noted by Vanlaar et al. (2014), the predictive value of screening instruments for predicting driving ability differs across different ways of measuring driving ability and across screening instruments themselves. Hence, it is crucial to establish the most appropriate method to predict driving ability.

Driving ability can be assessed in a summarized way (Stav et al., 2008) or in a specific way (Jongen et al., 2012). Possibly, the lack of an instrument that adequately distinguishes between safe and unsafe drivers is the result of the approach that has been used so far to investigate the relation between driving ability and functional abilities, as the majority of studies have used summarized measures of driving ability (Bédard, Weaver, Dārzin, & Porter, 2008; Jones Ross, Scialfa, & Cordazzo, 2015; Stav et al., 2008; Wood, Anstey, Kerr, Lacherez, & Lord, 2008). A summarized measure of driving ability is an evaluator’s overall judgment of driving competence based upon component driving behaviors observed during the execution of a road course (Stav et al., 2008). Hence, specific aspects of driving are incorporated into one overall measure of driving. Often this summarized measure is based on errors and demerit points resulting into a categorical measure, like pass/fail (Bédard et al., 2008). For example, participants 'fail' if they gather too many demerit points or make a serious error. Although the use of summarized measures of driving ability has the advantage of providing a clear view of driving ability status (i.e., pass or fail), it might not be optimal for investigating the relation between driving and functional abilities since driving is a complex, goal-directed task that places high demands on perceptual, cognitive, and motor skills (Groeger, 2000). Therefore, it can be expected that different skills are important for different driving situations. This implies that as part of an assessment, the same test will not necesarrily be a good predictor of all driving situations and problems. For example, it can be expected that the ability to react fast is more important for a driving situation where one needs to react to a sudden event, while the ability to divide attention is more important for a driving situation where one needs to turn left at an intersection and pay attention to other road users.

In the present study, a different approach was used to investigate the relation between driving ability and functional abilities. As opposed to a summarized measure of driving ability, specific measures of driving ability (e.g., mean driving speed and detection time) were investigated. We had two objectives: our first objective was to investigate the relations between specific measures of driving ability and functional abilities of older drivers; our second objective was to verify the explained variance of these relations to determine the strength of these relations. Altogether, the results of this study may have important implications for both driving assessment and training. As for driving assessment, the current investigation of specific measures of driving ability will illustrate whether different driving situations are dependent on different functional abilities. If so, a driving assessment program should always consider a set of functional abilities. However, only if the variance explained by such a set of functional ability tests is sufficiently high, will a screening instrument consisting of these tests be successful in discriminating safe and unsafe drivers. In addition to insights for future driving assessment programs, this approach provides new insights for future driving training programs that may keep older drivers on the road as safe drivers for as long as possible. Effective training programs are tailored to the individual or a group of individuals with common characteristics, targeting those specific abilities that are hampered. This, however, is only possible if that information is available, with driving ability scores at the level of specific driving measures. Summarized measures of driving ability do not provide a detailed enough view of driving ability: whereas those who pass may still experience problems in some driving situations, those who fail might still be able to drive safely in a number of situations. Therefore, while investigating the relation between functional abilities and driving the inclusion of specific driving measures might allow a more accurate view of driving ability than summarized driving score (pass/fail) because the latter will not correspond one-on-one with the score on specific driving measures. It has been shown that, even in old age, the human brain is plastic which implies that functional abilities are flexible and can be altered, leading to improvement of those functions (Erickson et al., 2007). Numerous studies have investigated training programs to keep older drivers safe drivers and to postpone or even counteract functional and driving impairment. Various studies have investigated direct types of training of driving ability through for example simulator training (Casutt, Theill, et al., 2014; Lavallière et al., 2012; Romoser & Fisher, 2009) and indirect types of training of driving ability through training of functional abilities, such as motor abilities (Marmeleira et al., 2009; Sayers & Gibson, 2012) and cognitive abilities (Ball et al., 2010; Cassavaugh & Kramer, 2009). However, only if the variance explained by functional abilities is sufficiently high, will a training of functional abilities be successful in training driving ability.

Although some studies investigating the relations between specific measures of older drivers' driving and functional ability were already conducted (Aksan, Anderson, Dawson, Uc, & Rizzo, 2015; Anstey & Wood, 2011; Backs, Tuttle, Conley, & Cassavaugh, 2011; Jongen et al., 2012; Mullen et al., 2008; Shanmugaratnam, Kass, & Arruda, 2010; Szlyk, Myers, Zhang, Wetzel, & Shapiro, 2002; Tuttle, Cassavaugh, & Backs, 2009), these mainly focused on measures of cognitive ability. Here, in addition to measures of cognitive ability, measures of visual and motor ability were included. Moreover, since unsafe driving increases with age (Anstey & Wood, 2011), and since accident risk increases with decreasing driving experience (i.e., driving less than 3,000 kilometers a year; Langford et al. (2006)), demographic variables of age and driving experience were also included. Functional ability was investigated using validated tests; driving ability was investigated using a driver simulator, allowing the investigation of specific driving measures. This approach will provide us a detailed enough view of driving ability and allow us to determine whether different driving abilities depend on different demographic or functional abilities.

# 2. METHOD

## 2.1. Participants

Participants aged 70 years or older that were still active drivers and had not had a stroke in the last six months were recruited. Recruitment occurred through the Geriatrics department of the Jessa Hospital; in the community via (local) media; via oral presentations for senior associations, and with flyers distributed in senior flats, hospitals and senior associations. Seventy-seven volunteers agreed to participate. Given the possibility of simulator sickness, participants were closely watched for signs of this type of sickness: oculomotor disturbance (e.g., fatigue, headache, eyestrain, difficulty focusing, blurred vision), disorientation (e.g., dizziness, vertigo), and nausea (e.g., increased salivation, sweating, stomach awareness; Mullen, Weaver, Riendeau, Morrison, and Bédard (2010)). If a participant showed any signs of simulator sickness, the simulation was immediately terminated and the participant was excluded from further participation. In total, twenty-two participants suffered from simulator sickness and were therefore excluded in the final sample as there was no data of the simulator drive for these persons. Hence, fifty-five participants remained in the sample. They had a mean age of 76.49 years (SD=5.40) and on average drove 12,335 kilometers a year (SD=8,634). Participants were tested while wearing their normal visual correction. They received a small compensation (Belgian chocolates or waffles and a €5 gift certificate) for participating. The study was approved by the ethical review committees of Hasselt University and the Jessa Hospital.

## 2.2. Functional abilities

Several functional abilities were selected based on a literature study for which a relation with older drivers' driving ability had been shown (see below). These functional abilities were assessed with validated tests. A detailed description of these tests will be given in the next paragraph. The measured functional abilities were 'cognitive ability – mental status, 'cognitive ability – attention', 'cognitive ability – memory', 'visual ability – acuity' and 'motor ability – balance'.

### *2.2.1. Cognitive ability – mental status*

Mental status was assessed with the Mini Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA). The MMSE is a brief global cognition test that is used to screen for Mild Cognitive

Impairment (MCI). It comprises items assessing orientation to time and place, registration and recall, attention, language and constructional ability (Folstein, Folstein, & McHugh, 1975). Possible scores range from 0 to 30, with higher scores reflecting higher cognitive ability. A score of 24 or above indicates no impairment (Stav et al., 2008). Previous studies with older drivers found a significant correlation between the MMSE and driving errors during an on-road test and naturalistic driving (Davis et al., 2012) and between the MMSE and specific measures of simulated driving ability (i.e., giving right of way, collisions and lane keeping during a secondary task; Jongen et al. (2012)).

Although to our knowledge, the relation between MoCA and older drivers' driving ability has not been investigated yet, this test was included in the present study since the MoCA was developed to screen patients with mild cognitive complaints that usually perform in the normal range on the MMSE (Nasreddine et al., 2005). In comparison with the MMSE, the MoCA focusses more on frontal executive functioning and attention (Smith, Gildeh, & Holmes, 2007). In addition, the MoCA is less prone to ceiling effects than the MMSE (Zadikoff et al., 2008). Like the MMSE, possible scores on the MoCA range from 0 to 30, with higher scores reflecting higher cognitive ability. A score of 26 or above indicates no impairment (Nasreddine et al., 2005).

### *2.2.2. Cognitive ability – attention*

Attention was assessed with the Useful Field of View (UFOV) and the Attention Network Test (ANT). The UFOV, consisting of three subtests, was used to assess participants' visual processing speed (UFOV1), divided attention (UFOV2) and selective attention (UFOV3; Ball et al. (1993)). This test was PC-based, with stimuli presented on a 19-inch monitor and responses made using a computer mouse. Given that participants had difficulty with handling the mouse, the test administrator always did this for them. This version of the UFOV has been shown to be both reliable and valid (Edwards et al., 2005). Scores are expressed in milliseconds, representing the exposure duration required for an observer to perform at an accuracy level of 75%. For each subtest, possible scores range from 16.7ms to 500ms. Lower scores, correspond with improved visual attention. As stated in the UFOV user's guide (2002), the criterion for normal UFOV are 30ms for UFOV1, 100ms for UFOV2 and 350ms for UFOV3. Several studies with older drivers have shown that the UFOV test is an important predictor of driving ability (Ball et al., 1993; Clay et al., 2005) and that UFOV performance was related to specific measures of simulated driving ability (i.e., left turning and giving right of way; Jongen et al. (2012)).

The ANT was designed to evaluate three attentional networks: the alerting network, the orienting network and the conflict network. The alerting network is related to maintaining readiness, the orienting network is responsible for selecting the region of space or the channel to be attended and the conflict network is involved in resolving conflict among possible actions (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Redick & Engle, 2006). The standard version of the ANT was employed, presented on a 19-inch color monitor, and responses were entered on a keyboard. The ANT was used to assess the efficiency of visual attention, as reflected by the efficiency scores for each of three attention networks. Overall mean accuracy and response time were also calculated. Higher accuracy scores and lower response times, correspond with improved attentional capacity. To the best of our knowledge, there are no clear criteria available for this test. Jongen et al. (2012) demonstrated that the ANT was related to specific measures of simulated driving ability of older drivers (i.e., left turning, reaction to road hazards and lane keeping), while Mullen et al. (2008) demonstrated that the ANT predicted simulated driving ability of older drivers on the rural highway (i.e., speed maintenance and errors) and parking lot courses (i.e., collisions and errors).

### *2.2.3. Cognitive ability – memory*

Memory was assessed with the Digit Span test and the Road Sign Recognition test. The Digit Span forward is originally part of the Digit Span Subtest of the Wechsler Adult Intelligence Scale (WAIS; Wechsler (1955)). In the task, participants repeat a random sequence of numbers in forward direction (Clark et al., 2011). The more numbers a person can repeat, the better the cognitive ability. Scores on this task were divided into four categories (0 = impaired, 1 = beneath average, 2 = average, 3 = above average). Szlyk et al. (2002) found that the Digit Span Test correlated significantly with brake pedal pressure and horizontal eye movements of older drivers measured in a driving simulator.

The Road Sign Recognition test is derived from the Stroke Driver Screening Assessment (SDSA) test. The test consists of twelve cards with simple drawings depicting different traffic situations, such as a railway crossing, a low bridge or children crossing. The cards are placed in front of the participant, who receives a larger set (i.e., 19) cards with road signs. The participant is instructed to place the appropriate road sign on top of each traffic situation card. The time limit for the task is three minutes. One point is given for each correct answer, resulting into a maximum score of twelve. A higher score thus corresponds with more knowledge of road signs (Lundberg, Caneman, Samuelsson, Hakamies-Blomqvist, & Almkvist, 2003). To the best of our knowledge, there are no clear criteria available for this test. MacGregor, Freeman, and Zhang (2001) found that the road sign recognition test could successfully identify older drivers with a recent motor vehicle crash. In addition, Devos et al. (2011) found significant correlations between the road sign recognition test and a summarized measure of on-road driving performance of older people who had a stroke.

### *2.2.4. Visual ability – acuity*

Visual acuity was assessed with the Snellen chart since it is one of the most common measurements of visual ability (Rosser, Laidlaw, & Murdoch, 2001). The chart consists of twelve lines. Participants have to stand six meters from the chart and read the lines. The more lines a person can read, the better the visual acuity. Possible scores range from 0 to 1.2. A minimum of 6/12, corresponds with a normal score (Carter, 2006). The test was administered using both eyes. Dawson et al. (2010) found that the Snellen chart was a significant predictor of driving safety errors (e.g., incomplete stop and straddles lane line) in older drivers.

### *2.2.5. Motor ability – balance*

Balance was assessed with the Get-Up-and-Go test, the Functional reach test and the Four-test Balance Scale. The Get-Up-and-Go test, also known as Timed Up-and-Go or Rapid Pace Walk, measures, in seconds, the time taken by an individual to stand up from a standard arm chair, walk a distance of three meter, turn, walk back to the chair and sit down again (Clark et al., 2011). The criterion used was eleven seconds. Scores on this task were divided into three categories (0 = more than 20 seconds, 1 = between 20 and 11 seconds, 2 = less than 11 seconds). Faster performance corresponds with higher motor ability. In a study by Stav et al. (2008) this test, in comparison with other motor tests of neck rotation and muscles, showed the strongest relation with a summarized measure of older drivers' driving ability.

The Functional Reach test measures the distance between arm length and maximal forward reach using a fixed base of support (Duncan, Weiner, Chandler, & Studenski, 1990). Longer functional reach scores correspond with higher motor ability. Older people who are unable to reach more than fifteen centimeter have an increased risk of fall and frailty (Jonsson, Henriksson, & Hirschfeld, 2003). This test was a significant predictor of driving safety errors among older drivers with Alzheimer Disease

(Dawson, Anderson, Uc, Dastrup, & Rizzo, 2009). Moreover, steering variability during driving with distraction was related to this measure of postural control in older drivers with Parkinson Disease (Uc et al., 2006). Although to our knowledge, the relation between the Four-test Balance Scale and driving ability of older drivers has not been investigated yet, this test was included in the present study. This test includes four timed static balance positions of increasing difficulty that are completed without assistive devices. The four positions consist of standing feet together, standing semi-tandem, standing tandem and one leg standing. If a person cannot maintain the position for at least ten seconds, the test is failed at that stage (Gardner, Buchner, Robertson, & Campbell, 2001). Motor ability increases with an increased number of positions a person can maintain for at least ten seconds. Scores on these tasks were dichotomized (0 = less than 10 seconds, 1 = at least 10 seconds). Scores on the four positions were summed up and divided by four, resulting into one score.

### 2.3. Driving simulator

The experiment 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. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. The projection screen offered a resolution of 1024×768 pixels on each screen and a 60 Hz refresh rate. Data (e.g., speed, lateral position, throttle and brake values) were collected at frame rate.

### 2.4. Scenario

Practice rides preceded the main ride to get acquainted with the driving simulator. The main ride, performed in daylight, consisted of inner-city (50 km/h) sections, outer-city (70, 90 km/h) sections and highway (120 km/h) sections. Four traffic situations were included that are known to be difficult for the older driver. These situations were derived from crash data that were gathered by the police through a crash form. These situations correspond with situations mentioned most often in the literature to be difficult for the older driver and include responses to signs, signals and road hazards (Bao & Boyle, 2008; Horswill et al., 2009) and gap acceptance while turning left at an intersection (Yan et al., 2007). A detailed description of the driving situations in the main ride is presented in Table 1. These situations occurred each two times and were randomized between-subjects, into two different orders. Apart from the roadworks and road hazards, there never was any traffic driving directly in front of or following the driver. Other vehicles were presented on the roadway at random intervals but required no passing or braking on the part of the driver. The scenario did not contain any curves in order to decrease the risk of simulator sickness (Romoser, 2008). The speed limit was indicated by the appropriate sign at the start of each outer-city and inner-city segment and repeated 30 meters after every intersection.

**Table 1.** Scenario description.

| **Driving situation** | **Driving environment** | **Purpose** |
|---|---|---|
| Stop sign | Four-way intersection consisting of a straight piece of road and a minor road to the left and to the right within the inner-city sections | Subjects were required to make a complete stop. Cross traffic from left or right occurred when the driver approached the intersection |
| Left turn | Four-way intersection consisting of a straight piece of road and a minor road to the left and to the right. One in an inner-city (50 km/h) and one in an outer-city (70 km/h) section | When the driver approached the intersection, the instruction to turn left was played. On the major road in the opposite lane, a stream of oncoming cars was driving with a speed equaling the speed limit, forcing the driver to make a stop. The first part of the stream consisted of very small gaps (less than 3s) and was followed by the second part of the stream that, similar to Yan et al. (2007), consisted of gaps uniformly increasing in duration from 3s to 16s. Participants were asked to indicate their decision to turn left when they judged it was safe to do so by pressing a button. This procedure was followed to minimize the chance of simulator sickness that was very high in a previous study where participants actually made the left turn maneuver (Jongen et al., 2012) |
| Roadworks | Outer-city section | A car was driving in front of the driver with a speed at least 10km/h beneath the speed limit. Due to roadblocks, there was no opportunity to overtake |
| Road hazards | Inner-city section | A pedestrian was suddenly crossing the road. Road hazards were calibrated in such a way that, when driving at speed limit, crashes could be avoided by braking |

## 2.5. Driving measures

A total of eight specific driving measures were recorded. The first three driving measures (i.e., mean driving speed, mean following distance and standard deviation of lateral position (SDLP)) were chosen since they represent longitudinal and lateral control measures. Measures of longitudinal control (i.e., mean driving speed and mean following distance) were selected since older drivers compensate for age-related increases in response time, for example by adopting slower speeds (Fisher et al., 2011). A measure of lateral control (i.e., SDLP) was selected since this measure is an index of road-tracking precision (Ramaekers, 2003), which is considered a reliable characteristic of individual driving performance (O'hanlon & Ramaekers, 1995) (Vuurman, Theunissen, Van Oers, Van Leeuwen, & Jolles, 2007; Wester, Böcker, Volkerts, Verster, & Kenemans, 2008) and provides a sensitive measure of driver impairment (De Waard, 1996; Ramaekers, 2003). Mean driving speed was averaged across the different speed limits and, like SDLP, was measured across separate road segments (i.e., 4.8 km) without any events (Trick, Toxopeus, & Wilson, 2010). Mean following distance (m) was assessed as the average distance between the driver and a lead vehicle with a speed at least 10km/h beneath the speed limit. The other four driving measures were selected since they represent situations that are mentioned most often in the literature to be difficult for the older driver (Bao & Boyle, 2008; Horswill et al., 2009; Yan et al., 2007). Complete stop at a stop sign (yes or no) was used to assess whether drivers would comply with Belgian traffic regulations that drivers must make a full stop (i.e., mean driving speed = 0 km/h) at a stop sign (Bao & Boyle, 2008; Jongen et al., 2012). Left turn gap acceptance decision[1] (s) is the time headway between two vehicles on the major road into which a left-turn driver chooses to turn (Jongen et al., 2012; Yan et al., 2007). Responses to road hazards were measured with detection time (s) defined as the onset time of throttle release time relative to the onset time of the road hazard and reaction time (s) defined as the onset time of braking relative to the onset time of throttle release (Regan, Lee, & Young, 2008). Finally, the number of crashes throughout the whole ride was measured.

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[1] The driving situation ‘turning left at an intersection’ was implemented later, hence the sample size of the driving measure ‘gap acceptance’ is lower (N=38) compared to the sample size of the seven other driving measures (N=55).

## 2.6. Procedure

After a general intake in the Jessa hospital by a medical doctor, all participants gave informed consent and filled in a questionnaire providing information on demographics (i.e., age, driving experience). The functional ability tests were carried out at the Jessa Hospital, the simulator rides were carried out at the Transportation Research Institute (IMOB). The functional ability tests systematically preceded simulator driving and both were always scheduled on different days, though in the same week.

## 2.7. Data analysis

Before analyses, outliers were treated for each variable. Outliers larger than three standard deviations were replaced with the maximum score within the three standard deviation range (Wood et al., 2008).

To verify whether the group of participants excluded from the final sample due to simulator sickness differed significantly from the group of participants included in the final sample with respect to demographic and functional ability measures, Mann-Whitney tests were conducted. This check illustrates whether the excluded participants are the very ones that most need to be studied (e.g., lower scores on all or the majority of functional ability measures), and whether simulator sickness is related to certain measures of demographic/functional ability (Fisher et al., 2011). Subsequently, the following analyses were conducted on the group of participants included in the final sample:

First, descriptive statistics were derived from the scores of the functional ability tests to determine if the sample was cognitively and physically healthy.

Second, Pearson's Product Moment Correlations were computed across driving measures, across demographic/functional ability measures and between demographic/functional ability measures and driving measures. The first two of these three correlational analyses were conducted to check for collinearity. Collinearity was checked by computing the Variance Inflation Factor (VIF). Collinearity was defined as a VIF of 10 or more (Myers, 1990). The third correlational analysis, between demographic/functional ability measures and driving measures, was conducted to investigate the size of the relation between a demographic/functional ability measure and a driving measure. This last process allowed for identification of functional ability measures to be included as predictors in a regression analysis. Effect size correlations of ±.1 are considered as "small", those of ±.3 as "medium" and those of ±.5 as "large" (Field, 2013).

Third, to answer our two objectives: hierarchical linear regression analyses were conducted for each of the eight specific driving measures. Specifically, age and driving experience were entered as predictors in Step 1 in each model to control for these two variables. In Step 2, only those measures of functional abilities that had a significant correlation ($p<.05$) with the specific driving measure under investigation were entered as predictors. This way only the predictive value was investigated of functional abilities related to a specific driving measure. This approach was necessary given our sample size ($N=55$) that only allowed the inclusion of maximum 4 to 5 predictors in the regression model, using the rule of thumb that 10 or 15 cases of data for each predictor in the model are needed (Field, 2013; Stevens, 2002). The enter method with an entry level of $p=.05$ was used to determine the significant predictors for each specific driving measure. In addition, it was checked whether the assumption of linearity was met. However, there were no signs of non-linearity.

## 3. RESULTS

### 3.1. Difference between participants included and excluded in the final sample

The comparison of both groups is shown in Table 2. In general, the group of participants excluded from the final sample due to simulator sickness did not significantly differ from the group included in the final sample ($p>.05$) on demographic variables, mental status and memory. There were group differences for a measure of attention (i.e., UFOV1), visual ability-acuity (i.e., Snellen chart) and motor ability-balance (i.e., Functional Reach Test). More in detail, the group that was excluded due to simulator sickness had a better score on UFOV1, implicating a faster processing speed, a better score on the Snellen chart, implicating better visual acuity, but a poorer score on the Functional Reach Test, implicating less balance.

**Table 2.** Descriptive statistics and group comparison (Mann Whitney test) of participants included and excluded in the final sample.

| **Dependent measure** | **Mean (SD) Excluded N=22** | **Mean (SD) Included N=55** | **Mann-Whitney Z** | **Mann-Whitney p** |
|---|---|---|---|---|
| *Demographic variable* | | | | |
| Age (year) | 74.18 (3.10) | 76.49 (5.40) | -1.43 | .15 |
| Driving experience (km/year) | 9,743 (5,570) | 12,335 (8,634) | -0.79 | .43 |
| *Cognitive ability – mental status* | | | | |
| MMSE (range 0 – 30) | 28.14 (1.36) | 28.22 (1.55) | -0.45 | .66 |
| MoCA (range 0 – 30) | 25.64 (1.89) | 25.62 (2.61) | -0.44 | .66 |
| *Cognitive ability – attention* | | | | |
| UFOV1 (ms) | 21.27 (12.30) | 33.82 (28.53) | -2.43 | .02* |
| UFOV2 (ms) | 90.91 (79.98) | 152.57 (122.95) | -1.91 | .06 |
| UFOV3 (ms) | 245.31 (106.87) | 277.92 (120.29) | -1.12 | .26 |
| ANT alerting (ms) | 30.91 (31.77) | 28.19 (34.26) | -0.96 | .34 |
| ANT orienting (ms) | 58.86 (24.79) | 63.39 (43.25) | -0.19 | .85 |
| ANT conflict (ms) | 177.14 (36.92) | 162.74 (65.39) | -1.55 | .12 |
| ANT mean accuracy (%) | 98.37 (1.02) | 96.91 (4.17) | -1.22 | .22 |
| ANT mean reaction time (ms) | 776.41 (85.88) | 795.63 (79.49) | -0.98 | .33 |
| *Cognitive ability - memory* | | | | |
| Digit Span Forward (range 0 – 3) | 2.23 (0.53) | 2.47 (0.69) | -1.89 | .06 |
| Road Sign Recognition test (range 0 – 12) | 6.86 (2.51) | 6.49 (3.34) | -0.40 | .69 |

| **Dependent measure (continued)** | **Mean (SD) Excluded N=22** | **Mean (SD) Included N=55** | **Mann-Whitney Z** | **Mann-Whitney p** |
|---|---|---|---|---|
| *Visual ability – acuity* | | | | |
| Snellen chart (range 0.00 – 1.20) | 0.82 (0.23) | 0.69 (0.23) | -2.18 | .03* |
| *Motor ability - balance* | | | | |
| Get-Up-And-Go Test (range 0 – 2) | 1.55 (0.51) | 1.56 (0.50) | -0.14 | .89 |
| Functional reach test (cm) | 35.43 (3.39) | 37.11 (5.55) | -1.96 | .05* |
| Four Test Balance Scale (range 0 – 1) | 0.86 (0.19) | 0.86 (0.19) | -0.09 | .93 |

*p<.05, two-tailed; **p<.01, two-tailed

## 3.2. Performance on the functional ability tests

Descriptive statistics for each of the tests are shown in Table 2. Based on criteria mentioned in 2.2, results indicate that, in general, participants were cognitively and physically healthy, since on the majority of tests (i.e., MMSE, MOCA, UFOV1, UFOV2, UFOV3, digit span forward, Snellen chart, Functional reach test) their average scores where within the normal range, or in line with previous research with healthy older drivers (i.e., ANT, see Jongen et al. (2012) and Mullen et al. (2008). However, on some tests, their average scores were not within the normal range (i.e., four test balance scale, Get-Up-And-Go test) or not in line with previous research with healthy older drivers (i.e., road sign recognition test, see Lincoln, Radford, and Nouri (2012)).

## 3.3. Bivariate correlations

Pearson's Product Moment Correlations across driving measures, across demographic/functional ability measures, and between demographic/functional ability measures and driving measures are shown in Table 3, 4, and 5, respectively.

With regard to the correlations across driving measures, some of the measures correlate strongly with each other, notably, mean following distance with mean driving speed, reaction time with detection time, and crashes with SDLP. However, all VIF values were between 1.22 and 4.76, indicating absence of collinearity.

With regard to the correlations across demographic/functional ability measures, especially UFOV2 correlates strongly with several other predictors, notably with UFOV1 and UFOV3. However, all predictors had a VIF value between 1.49 and 5.79, indicating absence of collinearity.

With regard to the correlations between the demographic/functional ability measures and the driving measures, one driving measure (i.e., gap acceptance) did not correlate significantly with any of the demographic or functional ability measures, and six functional ability measures (MMSE, MoCA, UFOV1, ANT conflict, road sign recognition test and Get-Up-And-Go test) did not correlate with any driving measure. Most driving measures correlated significantly with more than one demographic or functional ability measure: Mean driving speed correlated with age, UFOV2, UFOV3, Functional reach test and Four Test Balance scale. Mean following distance correlated with Functional reach test and Four Test Balance scale. SDLP correlated with driving experience, UFOV3, ANT mean accuracy, ANT mean reaction time and Digit Span Forward. Complete stop correlated with ANT orienting, Snellen Chart and Four Test Balance scale. Detection time correlated with ANT alerting and Functional Reach test. Crashes correlated with UFOV3, ANT mean accuracy, ANT mean reaction time and Digit Span Forward. One driving measures (i.e., reaction time) correlated with solely one functional ability measure: ANT alerting. All these correlations were of small to medium size.

**Table 3.** Bivariate correlations across driving measures.

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| 1 Mean driving speed | - | | | | | | | |
| 2 Mean following distance | -.82** | - | | | | | | |
| 3 SDLP | .05 | -.19 | - | | | | | |
| 4 Complete stop | .14 | -.10 | -.08 | - | | | | |
| 5 Gap acceptance | -.13 | .21 | -.19 | -.29 | - | | | |
| 6 Detection time | -.17 | .19 | -.07 | .08 | -.20 | - | | |
| 7 Reaction time | .08 | -.14 | .15 | .16 | .13 | -.57** | - | |
| 8 Crashes | .05 | -.05 | .30* | .18 | -.03 | .05 | .02 | - |

*p<.05, two-tailed; **p<.01, two-tailed

**Table 4.** Bivariate correlations across demographic/functional ability measures.

| **Measures** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| 1 Age | - | | | | | | | | |
| 2 Driving experience | -.21 | - | | | | | | | |
| 3 MMSE | -.09 | .05 | - | | | | | | |
| 4 MOCA | -.29* | .08 | .44** | - | | | | | |
| 5 UFOV1 | .34* | .07 | -.09 | -.29* | - | | | | |
| 6 UFOV2 | .48** | -.10 | -.40** | -.61** | .60** | - | | | |
| 7 UFOV3 | .50** | -.08 | -.22 | -.41** | .37** | .71** | - | | |
| 8 ANT alerting | .05 | .12 | .22 | .11 | -.00 | .00 | .01 | - | |
| 9 ANT orienting | .29* | .12 | -.15 | .04 | -.01 | .06 | .14 | .19 | - |
| 10 ANT conflict | -.02 | -.04 | -.18 | -.16 | .16 | .09 | .09 | -.14 | -.23 |
| 11 ANT mean accuracy | -.28* | .28* | .05 | .29* | -.10 | -.38** | -.36** | -.15 | .02 |
| 12 ANT mean reaction time | .34* | -.32* | -.06 | -.17 | .40** | .47** | .50** | .09 | .05 |
| 13 Digit span forward | -.17 | .20 | .30* | .36** | -.12 | -.35** | -.33* | -.04 | -.16 |
| 14 Road Sign Recognition test | -.22 | .17 | .16 | .26 | -.23 | -.46** | -.36** | .02 | .06 |
| 15 Snellen Chart | -.41** | .12 | .22 | .25 | -.19 | -.38** | -.21 | .11 | -.17 |
| 16 Get-Up-And-Go test | -.35** | .14 | .17 | .22 | -.09 | -.31* | -.34* | .05 | -.20 |
| 17 Functional Reach Test | -.13 | .08 | .15 | .34* | -.01 | -.25 | -.11 | -.20 | .15 |
| 18 Four Test Balance Scale | -.37** | .10 | -.25 | -.02 | -.16 | -.21 | -.41** | -.13 | .10 |

| **Measures (continued)** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
|---|---|---|---|---|---|---|---|---|---|
| 1 Age | | | | | | | | | |
| 2 Driving experience | | | | | | | | | |
| 3 MMSE | | | | | | | | | |
| 4 MOCA | | | | | | | | | |
| 5 UFOV1 | | | | | | | | | |
| 6 UFOV2 | | | | | | | | | |
| 7 UFOV3 | | | | | | | | | |
| 8 ANT alerting | | | | | | | | | |
| 9 ANT orienting | | | | | | | | | |
| 10 ANT conflict | - | | | | | | | | |
| 11 ANT mean accuracy | -.18 | - | | | | | | | |
| 12 ANT mean reaction time | .22 | -.27 | - | | | | | | |
| 13 Digit span forward | -.03 | .42** | -.38** | - | | | | | |
| 14 Road Sign Recognition test | -.09 | .27 | -.32* | .36** | - | | | | |
| 15 Snellen Chart | -.03 | .16 | .01 | .06 | .16 | - | | | |
| 16 Get-Up-And-Go test | -.20 | .06 | -.40** | .18 | .26 | .02 | - | | |
| 17 Functional Reach Test | -.01 | .19 | -.07 | .05 | .28* | .09 | .11 | - | |
| 18 Four Test Balance Scale | -.17 | .25 | -.50** | .06 | .29* | -.08 | .27* | .03 | - |

*p<.05, two-tailed; **p<.01, two-tailed

**Table 5.** Bivariate correlations between demographic/functional ability measures and driving measures.

| Demographic/ clinical measure | Mean driving speed | Mean following distance | SDLP | Complete stop | Gap acceptance | Detection time | Reaction time | Crashes |
|---|---|---|---|---|---|---|---|---|
| Age | -.29* | .16 | .06 | .12 | .01 | .15 | -.13 | .19 |
| Driving experience | -.04 | .20 | -.39** | .11 | .30 | .03 | .09 | -.25 |
| MMSE | .16 | -.04 | .00 | -.15 | -.02 | -.28 | .03 | .03 |
| MOCA | .24 | -.13 | .08 | -.13 | .23 | -.10 | -.16 | -.06 |
| UFOV1 | -.06 | -.05 | -.05 | .04 | -.17 | .03 | .03 | .03 |
| UFOV2 | -.32* | .23 | .14 | .19 | -.19 | .13 | .05 | .20 |
| UFOV3 | -.32* | .12 | .27* | .09 | .19 | .05 | -.03 | .29* |
| ANT alerting | -.06 | .23 | .10 | .12 | -.24 | .36* | -.34* | .08 |
| ANT orienting | -.09 | .11 | -.02 | .38** | -.19 | .11 | -.09 | .08 |
| ANT conflict | -.05 | .03 | .02 | -.06 | .18 | -.09 | .17 | -.18 |
| ANT mean accuracy | .19 | -.12 | -.35** | -.16 | -.04 | .12 | -.11 | -.31* |
| ANT mean reaction time | -.25 | .12 | .28* | -.05 | -.11 | -.13 | .06 | .35** |
| Digit span forward | .08 | .00 | -.29* | -.22 | .02 | -.13 | .07 | -.28* |
| Road sign recognition test | .18 | -.12 | -.20 | .05 | .00 | .03 | -.05 | -.18 |
| Snellen Chart | .02 | -.06 | -.02 | -.45** | -.08 | .00 | -.21 | -.02 |
| Get-Up-And-Go test | .26 | -.24 | -.03 | .06 | .01 | .10 | -.00 | -.11 |
| Functional reach test | .32* | -.32* | .13 | -.09 | .09 | -.29* | .00 | -.12 |
| Four Test Balance Scale | .37** | -.36** | -.15 | .30* | -.27 | .01 | -.02 | -.12 |

*p<.05, two-tailed; **p<.01, two-tailed

## 3.4. Hierarchical linear regression analyses

Results of the hierarchical regression analyses are shown in Table 6 and Table 7. Since gap acceptance did not correlate with any of the demographic/functional ability measures, solely a regression with block 1 was conducted for this measure. After adjustment for age and driving experience:

- Mean driving speed was significantly predicted solely by motor ability-balance
- Mean following distance was significantly predicted both by driving experience and by motor ability-balance
- SDLP was significantly predicted solely by driving experience
- Complete stop was significantly predicted both by cognitive ability-attention and visual ability-acuity
- Detection time and reaction time were significantly predicted solely by cognitive ability-attention
- There were no significant predictors for gap acceptance and crashes.

As for the range of explained variance across driving measures, demographic variables age and driving experience explained 3-15% of the variability observed in the specific driving measures, functional abilities explained an additional 7%-36%. More in detail, measures of functional ability explained, in addition to age and driving experience:

- About 17% of the variance in mean driving speed
- About 21% of the variance in mean following distance
- About 7% of the variance in SDLP
- About 36% of the variance in complete stop
- About 11% of the variance in detection time and reaction time
- About 7% of the variance in crashes

**Table 6.** Regression weights (β) and significance value (p) per predictor of the regression model per driving measure.

| **Driving measure** | **Regression block** | **Predictors** | **β** | **p** |
|---|---|---|---|---|
| Mean driving speed | Block 1 | Age | -.10 | .55 |
| | | Driving experience | -.12 | .36 |
| | Block 2 | UFOV2 | -.12 | .52 |
| | | UFOV3 | -.04 | .83 |
| | | Functional Reach test | .27 | .04* |
| | | Four Test Balance scale | .29 | .05* |

| **Driving measure (continued)** | **Regression block** | **Predictors** | **β** | **p** |
|---|---|---|---|---|
| Mean following distance | Block 1 | Age | .05 | .74 |
| | | Driving experience | .27 | .03* |
| | Block 2 | Functional Reach test | -.32 | .01** |
| | | Four Test Balance scale | -.36 | .01** |
| SDLP | Block 1 | Age | -.15 | .37 |
| | | Driving experience | -.42 | .01** |
| | Block 2 | UFOV3 | .30 | .12 |
| | | ANT mean accuracy | .17 | .32 |
| | | ANT mean reaction time | .01 | .98 |
| | | Digit span forward | -.08 | .61 |
| Complete stop | Block 1 | Age | -.06 | .72 |
| | | Driving experience | .09 | .48 |
| | Block 2 | ANT orienting | .34 | .01** |
| | | Snellen chart | -.40 | .00** |
| | | Four Test Balance scale | .21 | .12 |
| Gap acceptance | Block 1 | Age | -.03 | .86 |
| | | Driving experience | .30 | .11 |
| Detection time | Block 1 | Age | .19 | .21 |
| | | Driving experience | -.08 | .56 |
| | Block 2 | ANT alerting | .33 | .04* |
| | | Functional Reach test | -.01 | .95 |
| Reaction time | Block 1 | Age | -.10 | .50 |
| | | Driving experience | .14 | .37 |
| | Block 2 | ANT alerting | -.34 | .03* |
| Crashes | Block 1 | Age | .05 | .79 |
| | | Driving experience | -.20 | .21 |
| | Block 2 | UFOV3 | .17 | .39 |
| | | ANT mean accuracy | .16 | .37 |
| | | ANT mean reaction time | .15 | .38 |
| | | Digit span forward | -.10 | .54 |

*p<.05; **p<.01

**Table 7.** Model summary for regression analysis per driving measure.

| Driving measure | Block | R | R² | Adj. R² | SE of the estimate[a] | R² change | p F change |
|---|---|---|---|---|---|---|---|
| Mean driving speed | 1 | .32 | .10 | .06 | 2.62 | .10 | .07 |
|  | 2 | .52 | .27 | .17 | 2.47 | .17 | .05* |
| Mean following distance | 1 | .30 | .09 | .05 | 66.39 | .09 | .10 |
|  | 2 | .54 | .30 | .24 | 59.49 | .21 | .00** |
| SDLP | 1 | .39 | .15 | .11 | 0.03 | .15 | .02* |
|  | 2 | .46 | .22 | .11 | 0.03 | .07 | .45 |
| Complete stop | 1 | .18 | .03 | -.01 | 0.38 | .03 | .46 |
|  | 2 | .62 | .39 | .32 | 0.31 | .36 | .00** |
| Gap acceptance | 1 | .30 | .09 | .03 | 1.19 | .09 | .27 |
| Detection time | 1 | .24 | .06 | .01 | 0.36 | .06 | .32 |
|  | 2 | .40 | .16 | .08 | 0.34 | .11 | .10 |
| Reaction time | 1 | .17 | .03 | -.02 | 0.25 | .03 | .56 |
|  | 2 | .37 | .14 | .07 | 0.24 | .11 | .03* |
| Crashes | 1 | .28 | .08 | .04 | 0.81 | .08 | .14 |
|  | 2 | .38 | .14 | .03 | 0.81 | .07 | .48 |

[a] Square root of the mean square residual
*p<.05; **p<.01

## 4. DISCUSSION

### 4.1. Investigating specific measures of older drivers' driving ability

The first objective was to investigate the relations between specific measures of older drivers' driving ability and demographic/functional ability measures. Results indicate that each specific driving measure is related to a specific set of functional abilities. More in detail, balance mainly predicted longitudinal driving measures of mean driving speed and mean following distance. This latter longitudinal driving measure, together with a lateral driving measure (i.e., SDLP) was also predicted by driving experience. Attention mainly predicted detection of and reaction to an event (i.e., detection time, reaction time, complete stop at a stop sign).

More specifically, alerting attention was especially important for the detection of and reaction to a sudden event, while orienting attention was especially important for making a complete stop at a stop sign. This latter driving measure was also predicted by visual acuity. This finding, that the importance of functional abilities depends on the specific driving measure under investigation, is in line with previous studies with older drivers specifically addressing this issue (Aksan et al., 2015; Anstey & Wood, 2011; Mullen et al., 2008). For example, the UFOV predicted performance on a rural highway course, while the ANT also predicted performance on parking lot courses (Mullen et al., 2008). In addition, this finding is in line with previous research investigating driving ability of older drivers using several specific measures of driving and cognitive ability, but not specifically addressing this issue (Backs et al., 2011; Jongen et al., 2012; Shanmugaratnam et al., 2010; Szlyk et al., 2002; Tuttle et al., 2009).

Related to the second objective, we examined the explained variance of the relations between specific measures of driving ability and demographic/functional ability to determine the strength of these relations. Results indicate that age and driving experience explain only a small proportion of the variance in the specific driving measures (i.e., between 3% and 15%). In addition to these demographic variables, specific measures of functional ability also explain only a small proportion of the variance in the specific driving measures (i.e., between 7% and 36%). So although measures of functional ability explain a larger proportion of the variance compared to demographic variables, an even larger proportion of the total variance currently remains unexplained. Previous research investigating specific measures of older drivers' driving ability while using a set of cognitive predictors reported similar percentages. For example Backs et al. (2011) found percentages between 4% and 36%, Mullen et al. (2008) found percentages between 16% and 40%, and Shanmugaratnam et al. (2010) found percentages between 26% and 28%. Altogether, these results provide necessary insights for the development of assessment and training programs.

### 4.2. Implications for driving assessment and driving training programs

With regard to the development of driving assessment programs, there are two important conclusions that follow from our findings.

First, it will be necessary to assess several functional abilities, in contrast to one single functional ability. This conclusion is contradictory to policies that want to use a multi-tier system given the logistics and costs of comprehensive driving assessments consisting of neuropsychological tests (i.e., vision, motor and cognition) and an on road driving test. The logic behind the multi-tier system is that the complexity of testing only increases when there is an indication of unsafe driving, thereby preventing unnecessary stress for the participant and financial costs for both the participants and the society. The purpose is to first let general practitioners conduct a quick, efficient and cost-effective screening (first tier). In case the driver fails this screening, he is referred to a more multidimensional in-depth assessment (second tier). In case the driver also fails this assessment, he is referred to a driving test (third tier, (De Raedt & Ponjaert-Kristoffersen, 2001; Langford et al., 2008; Lees et al., 2010). The ideal screening instrument in the first tier should classify with certainty a large proportion of drivers as safe or not, to minimize the proportion requiring further testing. However, predicting driving ability on the basis of a single variable may not be possible due to the multifactorial nature of driving ability (Bédard et al., 2008). For example, based on the present results, for a driver with hazard detection problems, only a screening instrument that includes a test of (alerting) attention might indicate these problems, while for a driver with longitudinal driving problems, only a screening instrument that includes a test of balance might indicate these problems.

Second, a driving assessment program that only includes measures of functional abilities will not be successful in discriminating safe from unsafe older drivers. Although measures of functional ability are still useful in predicting driving ability of older drivers, incorporating a more context-relevant assessment (i.e., driving based) seems necessary to obtain reliable screening results. This could be done with a direct test of driving ability, on the road or in a driving simulator. This conclusion is also contradictory to a multi-tier system, since it is in support of only the third tier. Although on road testing has been considered the golden standard to evaluate driving ability, it is costly and can be dangerous. Driving simulators could serve as a good alternative, since it allows assessment under safe conditions and offers the benefit of detailed and reliable results. However, on road testing would still be valuable since simulators lack some of the complexity of real-world driving (e.g., interacting with other road users) and actions in a simulator have no real consequences. Moreover, many older drivers are unfamiliar with computer technology and the use of driving simulations may be intimidating and impede their performance. Lastly, due to simulator sickness, not all drivers can be tested in a driving simulator (Fisher et al., 2011).

With regard to the development of driving training programs, there are again two important conclusions that follow from our findings.

First, driving training programs will need to focus on the right set of functional abilities given that specific driving measures are differently related to different functional abilities. A training of functional abilities might thus transfer to some driving situations, but not to all driving situations. For example, based on the present results, a training of alerting attention might improve hazard detection, but not affect longitudinal driving measures. Recently, there is an increasing number of commercial cognitive training packages for older drivers. However, there is debate about the transfer effects of these training packages to activities of daily life, for example driving (Gaspar et al., 2012; Mayhew, Robertson, et al., 2014). It was found that although these programs often improve the specific cognitive function being trained, this improvement generally fails to transfer to driving. The current findings might help to explain this since possibly transfer effects on driving in these previous studies were not measured on the correct driving measures.

Importantly, however, the second conclusion regarding training that follows from our findings is that a driving training targeting functional abilities might only have marginal effects on driving ability, given the relatively low amount of driving ability variance that is explained by these abilities. Recent studies indicate that a context-relevant training (i.e., driving based) might be more successful in improving driving ability (Casutt, Theill, et al., 2014; Gaspar et al., 2012; Mayhew, Robertson, et al., 2014). This is in line with the practice-specificity approach of learning which states that if the final purpose is to transfer to the road, they must be acquired in a driving-specific context, since the best training conditions are those allowing the learning of the same underlying processes that will be used in the transfer task (Schmidt & Lee, 2005; Thorndike & Woodworth, 1901). Driving simulator training has received a lot of attention in the past years, since it can specifically target those driving functions that are impaired. Evidence for this type of training for older drivers is promising immediately after training (Casutt, Theill, et al., 2014; Lavallière et al., 2012; Romoser & Fisher, 2009), as well as several years later (Romoser, 2012).

## 4.3. Limitations and future research

Some limitations have to be noted. First, the sample size of this study is relatively small. Although the original sample consisted of seventy-seven older drivers, due to simulator sickness the final sample consisted of fifty-five older drivers. This relatively high drop-out rate due to simulator sickness is not unusual (Casutt, Martin, et al., 2014; Romoser & Fisher, 2009). Further investigation of simulator sickness and ways to prevent it are important, especially since driving simulators may be part of assessment and training programs. Earlier research has related simulator sickness to several factors, for example, age: the older one is, the higher the risk of sickness (Mullen et al., 2010; Teasdale, Lavallière, Tremblay, Laurendeau, & Simoneau, 2009). In at least one study, cognitive differences were not associated with simulator sickness, indicating that simulator sickness does not prevent examination in a driving simulator of drivers with cognitive impairment (Mullen et al., 2010). However, in the present study, simulator sickness was related to some measures of cognitive, visual and motor ability: those who got sick had better a better score on the UFOV1 and Snellen chart, but poorer scores on the Functional reach test, compared to those that did not got sick. Since the group included in the analyses differed on these aspects from the group excluded in the analyses, this limits the generalizability of results. Another aspect that can limit the generalizability of results is the possibility of a self-selection bias. Especially those drivers that think of themselves as good drivers could be more willing to volunteer to participate in a study investigating driving ability. Related to this issue, participants in the present study drove between 4,000 and 12,000 kilometers a year. Hence, they do not belong to the risk group of older drivers driving less than 3000 kilometers a year (Langford et al., 2006). A last aspect that limits the generalizability of results is that the present study investigated mainly healthy older drivers, therefore, the present sample is not representative for the population of older drivers.

Second, when using a driving simulator apart from all the benefits, a key-issue is the degree to which simulated driving corresponds to real world driving and the extent to which findings in the simulator will thus correspond with on road findings. Recent research has provided positive evidence for simulator validity (Casutt, Martin, et al., 2014; Fisher et al., 2011; Shechtman, Classen, Awadzi, & Mann, 2009), nevertheless a validation on road is necessary to validate our conclusions that each specific driving measure is related to a specific set of functional abilities and that only a small proportion of the variability observed in specific driving measures is explained by functional abilities. Results of recent studies investigating the relation between cognitive abilities and driving errors in different situations on road seems to be in line with our results (Aksan et al., 2015; Anstey & Wood, 2011). However, future research should investigate the relation between several measures of driving ability on road (not only driving errors) with several functional abilities (not only cognitive abilities) since the results of the present study indicate that each specific driving measure is related to a specific set of functional abilities.

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# CHAPTER 2

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## Does attention capacity moderate the effect of driver distraction in older drivers?

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## Abstract

With age, a decline in attention capacity may occur and this may impact driving performance especially while distracted. Although the effect of distraction on driving performance of older drivers was investigated, the moderating effect of attention capacity on driving performance during distraction has not been investigated yet. Therefore, the aim was to investigate whether attention capacity has a moderating effect on older drivers' driving performance during visual distraction (experiment 1) and cognitive distraction (experiment 2). In a fixed-based driving simulator, older drivers completed a driving task without and with visual distraction (experiment 1, N = 17, mean age 78 years) or cognitive distraction (experiment 2, N = 35, mean age 76 years). Several specific driving measures of varying complexity (i.e., speed, lane keeping, following distance, braking behavior, and crashes) were investigated. In addition to these objective driving measures, subjective measures of workload and driving performance were also included. In experiment 1, crash occurrence increased with visual distraction and was negatively related to attention capacity. In experiment 2, complete stops at stop signs decreased, initiation of braking at pedestrian crossings was later, and crash occurrence increased with cognitive distraction. Interestingly, for a measure of lane keeping (i.e., Standard Deviation of Lateral Position (SDLP)), effects of both types of distraction were moderated by attention capacity. Despite the decrease of driving performance with distraction, participants estimated their driving performance during distraction as good. These results imply that attention capacity is important for driving. Driver assessment and training programs might therefore focus on attention capacity. Nonetheless, it is crucial to eliminate driver distraction as much as possible given the deterioration of performance on several driving measures in those with low and high attention capacity.

## Key words

Older drivers; Distraction; Attention; Driving simulator

# 1. INTRODUCTION

Carrying out additional tasks during driving may cause driver distraction, which can be defined as: the diversion of attention away from activities critical for safe driving toward a competing (driving- or non-driving related) activity (Regan et al., 2011). Several statistics indicate that driver distraction is a serious threat to traffic safety. Based on in-depth crash data from the Australian National Crash In-depth Study (ANCIS), it was concluded that distraction is the second largest cause (25%) of crashes that were due to inattention (Beanland, Fitzharris, Young, & Lenné, 2013). In addition, naturalistic data from the 100-car study showed that 78% of crashes and 65% of near crashes were due to some form of inattention, with the majority due to secondary task distraction (Dingus et al., 2006; Neale et al., 2005). The studies mentioned above did not investigate whether these effects were different among older drivers (65+). Data from the Crashworthiness Data System (CDS) however showed that between 1995 and 1999, 52.2% of the older drivers (65+) were not attentive at the time of their crash, with 7.9% of the older drivers being distracted (Stutts et al., 2001). This latter percentage seems to have increased between 2000 and 2003, since 14% of the older drivers (70+) were distracted at the time of their crash (Stutts et al., 2005). Although several studies argue that driver distraction is mainly a problem of young novice drivers (Hakamies-Blomqvist, 1994; McEvoy et al., 2007; Young & Lenné, 2010), these data showed no significant differences between young and older drivers (Stutts et al., 2005; Stutts et al., 2001). Therefore, it can be concluded that driver inattention and more specifically distraction plays an important role in crashes of older drivers. Since older drivers are the fastest growing segment of the driving population, research about the effect of distraction on the driving performance of older drivers is important (Regan et al., 2008).

Two important types of distraction are visual distraction and cognitive distraction. While visual distraction means that the driver has his eyes off the road (e.g., by operating a vehicle entertainment system), cognitive distraction means that the driver has his mind off the road (e.g., conducting a hands-free mobile phone conversation; J. Engström and Markkula (2007). The effects of these types of distraction on older drivers' driving performance have been investigated with a driving simulator (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Ni, Kang, & Andersen, 2007; Strayer & Drew, 2004). Ni et al. (2007) investigated the effect of visual distraction and found that it impaired following distance, especially when visibility is reduced. Strayer and Drew (2004) investigated the effect of cognitive distraction and found that it impaired following distance and reaction time. Horberry et al. (2006) investigated both types of distraction and found that both impaired speed-related aspects of driving performance, with visual distraction having the largest negative impact. In sum, these studies showed adverse effects of both types of distraction on the driving performance of older drivers. Interestingly, previous research with older drivers has indicated that distraction mainly affects driving subtasks that require deliberation or active exploration, whereas it leaves reflexive and habitual subtasks largely unaffected. Attentional demand thus increases with driving complexity (Cantin et al., 2009; Stinchcombe & Gagnon, 2013; Stinchcombe et al., 2011). This is in line with the complexity hypothesis, indicating that performance of older people is especially impaired when the complexity of the task is raised (Mayr & Kliegl, 1993). Previous research has classified driving complexity according to the Fastenmeier (1995) taxonomy of driving complexity (Patten et al., 2004; Patten et al., 2006; Stinchcombe & Gagnon, 2013; Stinchcombe et al., 2011; Törnros & Bolling, 2006). This taxonomy consists of two dimensions: information processing and vehicle handling. Consequently, four combinations of demands are possible: low demands on both information processing and vehicle handling, low demands on information processing and high demands on vehicle handing, high demands on information processing and low demands on vehicle handing, and high demands on both information processing and vehicle handling.

Adverse effects of distraction on driving performance reflect a mismatch between resources demanded by the driving task and resources devoted to it. Resource demands may simply exceed resource availability, as our cognitive capacity is limited (Proctor & Van Zandt, 2008). Therefore, especially those with a low cognitive capacity are susceptible to distractor interference (Lavie et al., 2004). Both young and older people have low cognitive capacity. The capacity of young people is limited since it depends on the maturation of the prefrontal cortex and parietal lobes, which can last until the age of 25 years (De Luca & Leventer, 2008; Glendon & Bryan, 2011). The capacity of older people is limited since with age, cognitive capacity declines (Salthouse, 2004; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Although effects of distraction on the driving performance of older drivers have been investigated (Horberry et al., 2006; Ni et al., 2007; Strayer & Drew, 2004), the moderating effect of cognitive capacity on older drivers’ driving performance during distraction has not been investigated yet. For young drivers, however, it has been shown that a lower cognitive capacity is related to a lower percentage of correct lane changes during a Lane Change Task (LCT) with cognitive distraction (Ross et al., 2014).

Taken together, the aim of this study was to investigate whether cognitive capacity has a moderating effect on older drivers’ driving performance during visual distraction (experiment 1) and cognitive distraction (experiment 2). In addition to investigating objective driving measures, also subjective measures of workload and driving performance were investigated. A driving simulator was used, as simulators provide the opportunity to present drivers with a variety of stimuli (e.g., distraction) in a standardized, safe and controlled environment (Freund, Gravenstein, Ferris, & Shaheen, 2002; Lee et al., 2003) and furthermore allow to investigate specific driving measures with varying complexity. Recent research has provided positive evidence for simulator validity (Fisher et al., 2011; Shechtman et al., 2009; Underwood, Crundall, & Chapman, 2011). Attention was used as a measure of cognitive capacity, since it is important for driving and according to a recent meta-analysis measures of attention were the best predictors of driving performance in older drivers (Mathias & Lucas, 2009). Previous studies investigated the relation between attention and older drivers' driving performance (Ball et al., 1993; Jongen et al., 2012; Marmeleira, Ferreira, Godinho, & Fernandes, 2007; Owsley et al., 1998; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Selander, Lee, Johansson, & Falkmer, 2011). Here, the moderating effects of attention capacity on older drivers' driving performance during distraction will be investigated. In case attention capacity has a moderating effect on driving performance during distraction, this has implications for future interventions. Previous research has indicated that attention capacity in older adults can be trained and that these effects are long lasting and translate to improvements in everyday skills like driving (Ball et al., 2002; Ball et al., 2007; Ball et al., 2010; Ball et al., 2013; Rebok et al., 2014; Roenker et al., 2003). Improving attention capacity might thus affect the ability of older drivers to deal with driver distraction.

## 2. METHOD

The methodology of experiments 1 and 2 is similar. However, in experiment 1, visual distraction was investigated, in experiment 2 cognitive distraction was investigated, in different samples of older drivers.

### 2.1. Participants

Community-dwelling participants aged 70 years or older who were still active drivers, had not had a stroke or sequel in the last six months and had a Mini-Mental State Examination (MMSE) score of 25 or above were recruited. Recruitment occurred through the Geriatrics department of the Jessa Hospital; in the community via (local) media; via oral presentations for senior associations, and with flyers distributed in senior flats, hospitals and senior associations. Given the possibility of simulator sickness, participants were closely watched for signs of this type of sickness. If a participant showed any signs of simulator sickness, the simulation was immediately terminated and the participant was excluded from further participation. In experiment 1, twenty drivers volunteered. However, three participants suffered from simulator sickness. Hence, seventeen participants remained in the sample and received the visual distracting task. They had a mean age of 78.12 years (SD=5.86), on average had an MMSE score of 28.24 (SD=1.60) and on average drove 14,608.00 km/year (SD=11,277.62). In experiment 2, fifty-seven participants volunteered. However, nineteen participants suffered from simulator sickness and three participants were unable to accomplish the cognitive distracting task during the practice session. Hence, thirty-five participants remained in the sample and received the cognitive distracting task. They had a mean age of 75.69 years (SD=4.81), on average had an MMSE score of 28.4 (SD=1.53) and on average drove 11,198.53 km/year (SD=7,143.49). Participants were tested while wearing their normal visual correction. They received a small compensation (Belgian chocolates or waffles and a €5 gift certificate) for participating. Both experiments were approved by the ethical review committees of Hasselt University and the Jessa Hospital.

### 2.2. Subjective measure of workload and driving performance

In both experiments, after the ride with distraction, a standard subjective measure of workload, NASA Task Load Index (TLX), was administered (Hart, 2006; Hart & Staveland, 1988). In addition to the six standard questions (How mentally demanding was the driving task, How physically demanding was the driving task, How hurried or rushed was the pace of the driving task?, How hard did you have to work to accomplish your level of driving performance?, How insecure, discouraged, irritated, stressed and annoyed were you during the driving task? and How successful were you in accomplishing the driving task?), one question was added: “How successful were you in accomplishing the distracting task during driving?”. All questions could be answered on a 10-point Likert scale ranging from ‘very bad’ (1) to ‘very good’ (10).

### 2.3. Cognitive measures

In both experiments, the Mini-Mental State Examination (MMSE) was administered to check whether the inclusion criterion was met. The MMSE is a brief global cognition test that is used to screen for Mild Cognitive Impairment (MCI). It comprises items assessing orientation to time and place, registration and recall, attention, language and constructional ability (Folstein et al., 1975). Possible scores range from 0 to 30, with higher scores reflecting a better cognitive ability.

Attention was used as a measure of cognitive capacity. In order to measure attention capacity, the Useful Field of View (UFOV; Ball et al. (1993)) was administered in both experiments. The UFOV consists of three subtests. The first subtest, UFOV-1, assesses participants' visual information processing speed. This subtest involves the identification of a central target (i.e., car or truck). The second subtest, UFOV-2, assesses participants' divided attention ability. This subtest is comparable with the first subtest, however, in addition it involves the localization of a simultaneous peripheral target (i.e., car). The third subtest, UFOV-3, assesses participants' selective attention ability. This subtest is comparable with the second subtest, however, in addition it involves distractors (i.e., triangles). This test was PC-based, with stimuli presented on a 19-inch monitor and responses made using a computer mouse. Since it was not clear if all participants would be able to handle the mouse, participants were asked to verbalize the answer and the test administrator used the mouse to record their responses. Scores are expressed in milliseconds, representing the exposure duration required for an observer to perform at an accuracy level of 75%. For each subtest, possible scores range from 16.7ms to 500ms, and lower scores correspond with improved visual attention. This version of the UFOV has been shown to be both reliable and valid (Edwards et al., 2005). Several studies have shown that the UFOV test is an important predictor of driving performance: a decreased performance on the UFOV is related to a decrease of driving performance (Ball et al., 2005; Ball et al., 1993; Ball et al., 2006; Owsley et al., 1991).

## 2.4. Driving simulator

Both experiments were conducted on a fixed-based medium-fidelity driving simulator (STISIM M400; Systems Technology Incorporated) with a force-feedback steering wheel, brake pedal and accelerator. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. The projection screen offered a resolution of 1024×768 pixels on each screen and a 60 Hz refresh rate. Data were collected at frame rate.

## 2.5. Distraction

In both experiments, participants completed a simulated driving task without distraction and a simulated driving task with either visual distraction (experiment 1) or cognitive distraction (experiment 2). For both distracting tasks, participants first received two practice sessions. First, they practiced the distraction task without an additional driving task. Secondly, they practiced the distraction task with an additional driving task. Participants who were not able to perform the distracting tasks in the practice session were excluded from the experiment. Participants were instructed to drive as they would normally do and to perform the distracting task. For the distracting task the instruction was to respond as fast as possible. Neither of the two tasks (i.e., driving and distracting tasks) was explicitly prioritized in the instruction (Victor, Engström, & Harbluk, 2009).

### *2.5.1. Experiment 1: visual distraction*

The visual distraction consisted of a modified version of the detection reaction time task used by Lee et al. (2003). During this task, two yellow-colored diamond shapes were continuously presented, one to the left side and one to the right side of the rear view mirror. Every 10-12 s a color change occurred until participants responded by pressing the horn, with a maximum of 6s. Six seconds after the onset of the color change, stimuli turned yellow again, and if no response was made these were coded as missed trials. Responses were coded as correct or missed and response times were recorded.

### *2.5.2. Experiment 2: cognitive distraction*

The cognitive distraction consisted of the Paced Auditory Serial Addition (PASAT) task (Gronwall, 1977). The task required participants to add serial pairs of randomized digits so that each digit was added to the digit immediately preceding. A recorded version was administered, where numbers were presented with an inter-number-interval of 4s. Participants were asked to respond verbally, and these responses were recorded for later analyses. Responses were coded as correct, false or missed, but response times were not recorded.

## 2.6. Scenario

In both experiments, practice rides preceded two main rides, to get acquainted with the driving simulator. The practice rides consisted of two phases. In the first phase, a scenario (2.1 km) was presented that had almost no signs and no other road users to acquaint drivers with the experience of driving in a simulator. In the second phase, the distracting task was combined with a driving task (5.5 km) in a scenario that was similar to that in the main ride. The main rides consisted of a ride without distraction and a ride with visual distraction (experiment 1) or cognitive distraction (experiment 2). Both rides were 17 km long and comparable in terms of scenario and traffic situations. Order of the main rides was counterbalanced across subjects. The rides, performed in daylight and good weather conditions, consisted of inner-city (50 km/h) sections, outer-city (70, 90 km/h) sections and highway (120 km/h) sections. In these rides, three traffic situations that are known to be difficult for the older driver were presented in a randomized fashion.

First, two four-way intersections with a stop sign where subjects were required to make a complete stop all occurred within the inner-city segments. Cross traffic occurred when the driver approached the intersection.

Second, four pedestrian crossings where subjects were required to give way all occurred within inner-city segments. Pedestrians crossed from left and right when the driver approached the pedestrian crossing.

Third, in two outer-city sections a car was driving in front of the driver with a speed at least 10km/h beneath the speed limit. Due to roadblocks of the other lane, there was no opportunity to overtake. Cars were calibrated in such a way that crashes could be avoided by braking, when driving at speed limit.

Apart from the roadworks, there never was any traffic driving directly in front of or following the driver. Other vehicles were presented on the roadway at random intervals but required no passing or braking on the part of the driver. The scenario did not contain any curves in order to decrease the risk of simulator sickness (Romoser, 2008). The speed limit was indicated by the appropriate sign at the start of each outer-city and inner-city segment and repeated 30 meters after every intersection.

## 2.7. Driving measures

In both experiments, a total of seven specific driving measures were considered for analyses: mean driving speed, standard deviation of lateral lane position (SDLP), following distance, complete stops at stop signs, brake initiation at pedestrian crossings and stop signs, and crashes. These driving measures, with the exception of crashes, were classified as either low or high demanding based on the taxonomy by Fastenmeier (1995). The driving measures mean driving speed (km/h) and SDLP (m) were classified as driving measures with a low demand on both information processing and vehicle handling, since these measures occurred on areas where there were no interactions with other road users. Mean driving speed and SDLP, were measured across separate road segments (i.e., 4.8 km) without any events (Trick et al., 2010). The driving measure following distance (m) was classified as a driving measure with low demand on vehicle handling, but a high demand on information processing, since this measure occurred on areas with road works where they had to interact with a leading vehicle. Following distance was measured as the average distance between the driver and a lead vehicle. The driving measures complete stops at stops signs and brake initiation at stops signs and pedestrian crossings were classified as driving measures with a high demand on both information processing and vehicle handing, since these measures occurred within city centers with intersections where drivers had to give right of way. Complete stop (yes or no) was computed from 200 m before reaching the stop sign until the location of the stop sign. It was determined whether drivers complied with Belgian traffic regulations that drivers must make a full stop (i.e., speed = 0 km/h) at a stop sign (Bao & Boyle, 2008; Jongen et al., 2012). Brake initiation (m) was computed as the distance at which the driver initially responds (by braking) to the pedestrian crossing/stop sign before entering the pedestrian crossing or intersection with a stop sign (Bao & Boyle, 2008; Jongen et al., 2012). Finally, the number of crashes throughout the whole ride was measured.

### 2.8. Procedure

Procedures were the same in experiment 1 and 2. First, all participants gave informed consent. The MMSE and UFOV were carried out at the Jessa Hospital, the simulator rides were carried out at the Transportation Research Institute (IMOB). The MMSE and UFOV systematically preceded simulator driving and both were always scheduled on different days, though in the same week. The NASA TLX always was administered after the ride with distraction.

### 2.9. Data analysis

The data was processed using SPSS (IBM Statistics 20). Statistical analyses were the same for each experiment.

Before analyses, outliers were treated for each variable. Outliers larger than three standard deviations were replaced with the maximum score within the three standard deviation range (Wood et al., 2008). In experiment 1, this procedure affected no more than 3.90% of the observations for the UFOV and 0% of the observations for all driving measures. In experiment 2, this procedure affected 0% of the observations for the UFOV and no more than 0.82% and 1.22% of the observations for all driving measures during the ride without distraction and with distraction, respectively.

Descriptive statistics were conducted to examine performance on the UFOV, the subjective assessment on the NASA TLX and the performance on the distracting tasks and driving tasks.

Repeated measures analyses of covariance (ANCOVA) were conducted for each of the 7 dependent driving measures. In each ANCOVA, distraction (i.e., with distraction and without distraction) served as within-subjects variable and attention capacity (i.e., the sum of scores on the three subtests of the UFOV: UFOV-total) served as covariate. In the ANCOVA of one driving measure (i.e., mean driving speed) speed limit (i.e., 50 km/h, 70 km/h, 90 km/h and 120 km/h) served as an additional within-subjects variable. The Greenhouse–Geisser epsilon correction factor was applied to compensate for possible effects of non-sphericity in the measurements compared. Only the corrected F and probability values are reported. An alpha level of .05 was maintained for all statistical tests. Significant interactions between the within-subjects variable distraction and the covariate attention capacity were further investigated, using a median split to divide participants into those scoring lower and higher on the covariate. First, a repeated measures analysis of variance (ANOVA) with distraction (i.e., with distraction and without distraction) as within-subjects variable was conducted for each group (i.e., lower/higher attention capacity) to assess the main effect of distraction. Second, separate univariate analyses of variance (ANOVA) for each level of distraction (i.e., with distraction and without distraction) were conducted with group (i.e., lower/higher attention capacity) as between-subjects factor to assess the main effect of group.

## 3. RESULTS

### 3.1. Performance on the UFOV

The results of the UFOV are reported in Table 1, separately for experiment 1 and 2. Based on UFOV norm scores, results from both experiments indicate normal central vision but somewhat slowed processing speed

(UFOV-1), some difficulty with divided attention (UFOV-2), and normal selective attention (UFOV-3).

**Table 1.** Means and standard deviations for the UFOV per experiment.

| **UFOV** | **Experiment 1** | **Experiment 2** |
|---|---|---|
| UFOV-1 | 38.79 (33.33) | 31.45 (25.82) |
| UFOV-2 | 187.67 (141.30) | 140.41 (111.62) |
| UFOV-3 | 322.55 (131.61) | 258.53 (111.18) |
| UFOV-total | 549.01 (266.47) | 430.39 (219.76) |

### 3.2. Performance on the subjective measure of workload and driving performance

The scores on the NASA TLX are reported in Table 2, separately for experiment 1 and 2. In sum, in experiment 1, participants assessed the (mental, physical and temporal) demand, effort and frustration of the driving task during distraction relatively low, while they rated their performance on the visual distracting task during driving and their driving performance during distraction quite high. In experiment 2, participants assessed the (physical and temporal) demand and frustration of the driving task during distraction relatively low, while they rated the mental demand and effort of the driving task during distraction quite high. In addition, they rated their performance on the cognitive distracting task during driving quite low, while they rated their driving performance during distraction quite high.

**Table 2.** Means and standard deviations for the scores on the NASA TLX per experiment.

| **Question** | **Experiment 1** | **Experiment 2** |
|---|---|---|
| Mental demand driving task | 4.50 (2.07) | 7.09 (1.72) |
| Physical demand driving task | 3.83 (2.04) | 4.29 (2.01) |
| Temporal demand driving task | 3.58 (1.44) | 4.23 (2.17) |
| Effort driving task | 4.50 (2.07) | 6.66 (2.31) |
| Frustration driving task | 3.50 (2.28) | 4.20 (2.45) |
| Performance driving task | 7.67 (1.30) | 6.89 (1.81) |
| Performance distracting task | 7.00 (1.71) | 4.69 (1.98) |

### 3.3. Performance on the distracting tasks

In experiment 1, the average percentage correct on the visual task without driving was 89.80%, while the average percentage missed was 10.20%. On the visual task with driving, the average percentage correct was 91.76%, while the average percentage missed was 8.24% and mean response time was 1.19 s.

In experiment 2, the average percentage correct on the cognitive task without driving was 70.77%, while the average percentage false was 13.52% and the average percentage missed was 15.71%. On the cognitive task with driving, the average percentage correct was 62.49%, while the average percentage false was 14.14% and the average percentage missed was 23.37%.

### 3.4. Performance on the driving tasks

The results of the descriptive statistics and repeated measures ANCOVA are presented in Table 3 and Table 4, separately for experiment 1 and 2. Table 5 illustrates the additional ANOVA analyses on the interactions between distraction and attention capacity, separately for experiment 1 and 2. Figure 1 provides a visualization of these significant interactions, separately for experiment 1 and 2. Results will be described separately for experiment 1 and 2. Crashes consisted of both single vehicle crashes (e.g., with a pedestrian walking on the pedestrian crossing), and multi-vehicle crashes (e.g., with a car coming from left when they did not stopped at an intersection with a stop sign). Since the number of crashes per type of crash (i.e., single vehicle and multi-vehicle crashes) was too small, no analyses were done separately for the different types of crashes.

**Table 3.** Means and standard errors for the dependent driving measures per experiment.

| | **Experiment 1** | | **Experiment 2** | |
|---|---|---|---|---|
| | *No visual distraction* | *Visual distraction* | *No cognitive distraction* | *Cognitive distraction* |
| Driving measure | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) |
| Mean driving speed (km/h ) | | | | |
| Speed limit 50 km/h | 42.31 (0.78) | 41.47 (0.75) | 41.13 (1.05) | 39.66 (1.15) |
| Speed limit 70 km/h | 56.44 (1.07) | 55.09 (2.11) | 52.44 (1.36) | 51.04 (1.56) |
| Speed limit 90 km/h | 76.61 (2.43) | 77.12 (4.93) | 75.37 (2.87) | 73.84 (3.70) |
| Speed limit 120 km/h | 83.76 (3.04) | 83.80 (3.17) | 80.20 (2.40) | 73.19 (3.41) |
| SDLP (m) | 0.18 (0.01) | 0.18 (0.01) | 0.17 (0.01) | 0.17 (0.01) |
| Following distance (m) | 91.13 (8.93) | 100.37 (12.99) | 110.38 (10.60) | 117.90 (13.10) |
| Complete stops at stop signs (0 = no/1 = yes) | 0.53 (0.08) | 0.41 (0.10) | 0.56 (0.07) | 0.37 (0.07) |
| Brake initiation at stop signs (m) | 63.38 (5.68) | 67.65 (7.04) | 60.81 (3.76) | 58.55 (4.07) |
| Brake initiation at pedestrian crossings (m) | 61.26 (2.93) | 67.93 (3.95) | 63.94 (2.85) | 58.57 (2.59) |
| Crashes (number) | 0.46 (0.14) | 0.88 (0.25) | 0.67 (0.15) | 1.26 (0.30) |

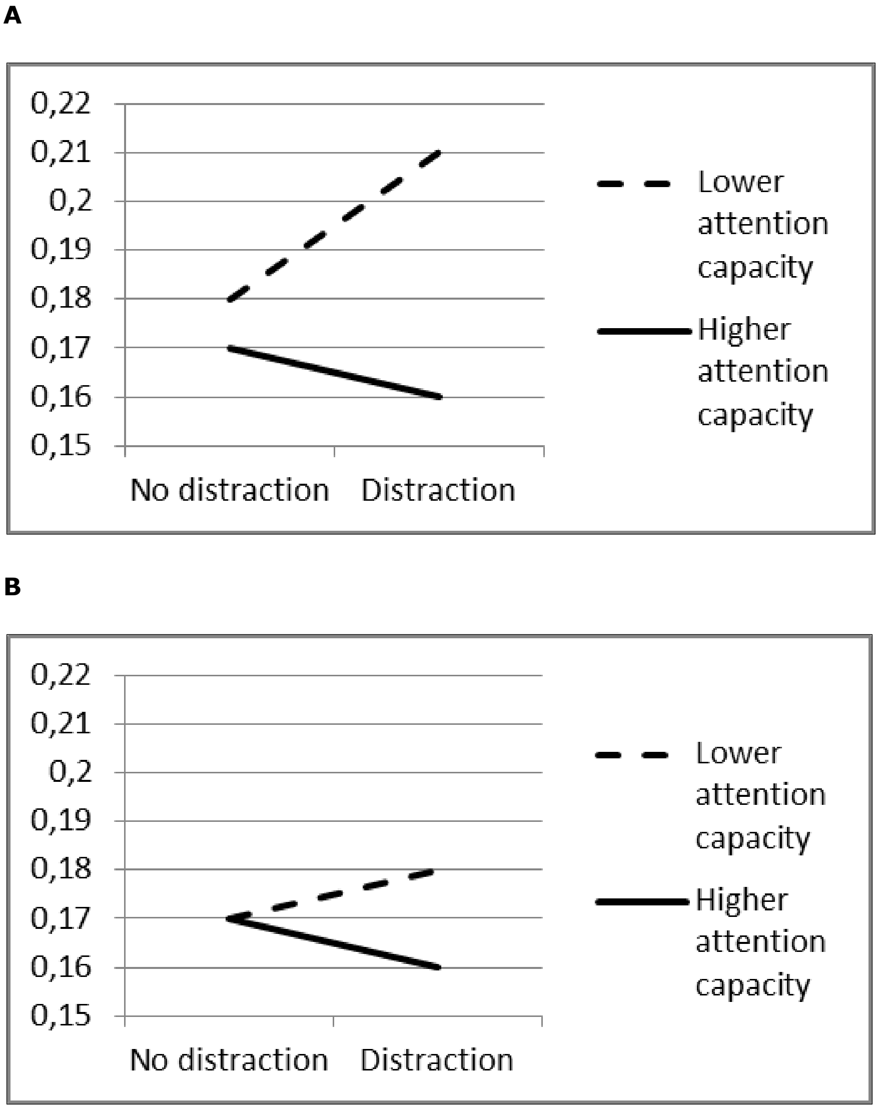

**Figure 1**. Interaction effects between distraction and attention capacity for SDLP in experiment 1 (A) and experiment 2 (B).

**Table 4.** Corrected F and probability values per dependent driving measure and per experiment.

| | **Experiment 1** | | **Experiment 2** | |
|---|---|---|---|---|
| Driving measure | F | p | F | p |
| Mean driving speed | | | | |
| Distraction | 0.05 | .83 | 2.24 | .14 |
| Distraction x attention capacity | 0.15 | .71 | 0.12 | .73 |
| Distraction x speed limit | 0.10 | .91 | 3.00 | .06 |
| Distraction x attention capacity x speed limit | 0.41 | .68 | 1.41 | .25 |
| Speed limit | 107.67 | .00** | 167.79 | .00** |
| Speed limit x attention capacity | 1.22 | .31 | 0.90 | .40 |
| Attention capacity | 1.45 | .25 | 0.58 | .45 |
| SDLP | | | | |
| Distraction | 1.01 | .33 | 0.21 | .65 |
| Distraction x attention capacity | 4.06 | .06 | 3.48 | .07 |
| Attention capacity | 2.49 | .14 | 0.92 | .35 |
| Following distance | | | | |
| Distraction | 0.44 | .52 | 0.34 | .56 |
| Distraction x attention capacity | 0.01 | .93 | 0.93 | .34 |
| Attention capacity | 0.04 | .85 | 0.05 | .82 |

| | **Experiment 1** | | **Experiment 2** | |
|---|---|---|---|---|
| Driving measure (continued) | F | p | F | p |
| Complete stops at stop signs | | | | |
| Distraction | 1.28 | .28 | 7.21 | .01** |
| Distraction x attention capacity | 0.04 | .85 | 0.11 | .75 |
| Attention capacity | 0.10 | .76 | 0.64 | .43 |
| Brake initiation at stop signs | | | | |
| Distraction | 0.29 | .60 | 0.35 | .56 |
| Distraction x attention capacity | 0.08 | .79 | 0.29 | .60 |
| Attention capacity | 0.05 | .83 | 0.15 | .70 |
| Brake initiation at pedestrian crossings | | | | |
| Distraction | 2.75 | .12 | 4.57 | .04* |
| Distraction x attention capacity | 1.30 | .27 | 0.40 | .53 |
| Attention capacity | 0.58 | .46 | 0.56 | .46 |
| Crashes | | | | |
| Distraction | 3.37 | .09 | 4.04 | .05* |
| Distraction x attention capacity | 0.79 | .39 | 1.01 | .32 |
| Attention capacity | 6.22 | .03* | 1.06 | .31 |

*<.05, **<.01

**Table 5.** Additional ANOVA analyses on the interaction between distraction and attention capacity for SDLP separately for experiment 1 (A) and experiment 2 (B).

**A**

| **Attention capacity** | **Scenario** | **p** |
|---|---|---|
| Lower capacity | Ride without visual distraction (M=0.18) vs.<br>Ride with visual distraction (M=0.21) | .03* |
| Higher capacity | Ride without visual distraction (M=0.17) vs.<br>Ride with visual distraction (M=0.16) | .21 |
| **Scenario** | **Attention capacity** | **p** |
| Ride without visual distraction | Lower capacity (M=0.18) vs.<br>Higher capacity (M=0.17) | .96 |
| Ride with visual distraction | Lower capacity (M=0.21) vs.<br>Higher capacity (M=0.16) | .06 |

*<.05

**B**

| **Attention capacity** | **Scenario** | **p** |
|---|---|---|
| Lower capacity | Ride without cognitive distraction (M=0.17) vs.<br>Ride with cognitive distraction (M=0.18) | .12 |
| Higher capacity | Ride without cognitive distraction (M=0.17) vs.<br>Ride with cognitive distraction (M=0.16) | .02* |
| **Scenario** | **Attention capacity** | **p** |
| Ride without cognitive distraction | Lower capacity (M=0.17) vs.<br>Higher capacity (M=0.17) | .91 |
| Ride with cognitive distraction | Lower capacity (M=0.18) vs.<br>Higher capacity (M=0.16) | .02* |

*<.05

### *3.4.1. Experiment 1: visual distraction*

For SDLP, there was a marginally significant interaction between visual distraction and attention capacity. This interaction was further investigated based on a median split (see statistical analyses; median attention capacity visual distraction sample 516.90ms). There was only a significant main effect of distraction for those with a lower attention capacity, indicating an increase of SDLP with distraction. There was only a marginally significant main effect of group for the driving task with distraction, indicating a higher SDLP in those with lower attention capacity.

For crashes, there was a marginally significant main effect of visual distraction for crashes, indicating more crashes when visually distracted. In addition, for this driving measure, there was a significant main effect of attention capacity for crashes, indicating that attention capacity is negatively related to the number of crashes.

For mean driving speed, there was a significant main effect of speed limit, indicating that with an increase of the speed limit, mean driving speed increased.

### *3.4.2. Experiment 2: cognitive distraction*

For SDLP, there was a marginally significant interaction between cognitive distraction and attention capacity. This interaction was further investigated based on a median split (see statistical analyses; median attention capacity cognitive distraction sample 396.40ms). There was only a significant main effect of distraction for those with a higher attention capacity, indicating a decrease of SDLP with distraction. There was only a significant main effect of group for the driving task with distraction, indicating a lower SDLP in those with a higher attention capacity.

For complete stops at stop signs, brake initiation at pedestrian crossings, and crashes, there was a significant main effect of cognitive distraction, indicating less complete stops at stop signs, later initiation of braking at pedestrian crossings, and more crashes when cognitively distracted.

For mean driving speed, there was a marginally significant interaction between cognitive distraction and speed limit. Additional analyses showed that there was a main effect of cognitive distraction in speed limit 50 km/h ($F=4.44$, $p=0.04$), and 120 km/h ($F=7.47$, $p=0.01$), indicating that mean driving speed decreased on roads with those speed limits when cognitively distracted.

## 4. DISCUSSION

Moderating effects of attention capacity on older drivers' driving performance during visual distraction and cognitive distraction were investigated. In addition, subjective measures of workload and driving performance were investigated.

### 4.1. Distraction

There was a (marginally significant) effect of visual distraction on crashes, indicating that the number of crashes increased when visually distracted. There was an effect of cognitive distraction on complete stops at stop signs, brake initiation at pedestrian crossings and crashes, indicating that the number of complete stops at stop signs decreased, initiation of braking at pedestrian crossings was later, and the number of crashes increased, when cognitively distracted. These results replicate previous research indicating adverse effects of driver distraction on the driving performance of older drivers (Horberry et al., 2006; Ni et al., 2007; Strayer & Drew, 2004). Taken together, based on the taxonomy of driving complexity by Fastenmeier (1995), it can be concluded that there was an adverse effect of distraction on driving measures with a high demand on both vehicle handling and information processing (i.e., complete stops at stop signs, brake initiation at pedestrian crossings and stop signs, and crashes), but not driving measures with a low demand on vehicle handling and/or information processing (i.e., mean driving speed, SDLP, following distance).

Finally, mean driving speed decreased on roads with certain speed limits when cognitively distracted. This finding is in line with other research indicating that older drivers often compensate their driving when being in challenging situations (i.e., being distracted) by driving at a lower speed in order to reduce task demands and increase safety margins (Charlton, Catchlove, Scully, Koppel, & Newstead, 2013; Horberry et al., 2006; Young & Lenné, 2010). Possibly, if participants would not have had the opportunity to adapt their behavior (i.e., driving at a certain speed), more effects of cognitive distraction would have emerged.

### 4.2. Attention capacity

For both the effects of visual and cognitive distraction on driving performance there was a moderating trend effect of attention capacity on the driving measure SDLP: whereas lane keeping improved in those with high attention capacity, it showed a deterioration in those with lower attention capacity for the ride with versus without distraction. Such increase in SDLP with visual distraction and decrease in SDLP with cognitive distraction replicates previous research with young and middle-aged drivers (J. Engström, Johansson, & Östlund, 2005; Törnros & Bolling, 2005). However, the current results add to the literature, showing that the effects of distraction on SDLP are dependent on the attention capacity of older drivers. Hence, the effect of distraction was moderated by cognitive capacity (i.e., attention). This is in line with Lavie's load theory (Lavie et al., 2004) and previous research with young drivers (Ross et al., 2014). Although SDLP was classified as a driving measure with a low demand for both vehicle handling and information processing, effects of distraction were found. This confirms that SDLP is a sensitive measure of driver impairment, for example due to workload or alcohol (De Waard, 1996; Ramaekers, 2003). The result that driving performance sometimes improved during distraction (i.e., decrease in SDLP with cognitive distraction) was also reported by earlier studies (J. Engström et al., 2005; Thompson et al., 2012; Törnros & Bolling, 2005). Recently, this finding was explained by the hierarchical control theory (HCT), indicating that in predictable situations lane keeping is an encapsulated inner loop process that does not require focused attention for success (Medeiros-Ward, Cooper, & Strayer, 2014). Importantly, situations where distraction improves driving performance are scarce, e.g., when driving on a monotonous road, distraction can suppress fatigue (Atchley et al., 2014; Chan & Atchley, 2011; Gershon et al., 2009).

In addition to the moderating effects of attention capacity, there was a main effect of attention capacity on crash occurrence (experiment 1), indicating that attention capacity is negatively related to the number of crashes. This replicates previous studies who found a relation between attention capacity and driving performance (Ball et al., 1993; Jongen et al., 2012; Marmeleira et al., 2007; Owsley et al., 1998; Owsley et al., 1991; Selander et al., 2011). More specifically, these studies indicated that older drivers with a reduction of at least 40% of their attention capacity, as measured with the UFOV test, were more likely to incur a crash than older drivers with less attention capacity reduction (Ball et al., 1993; Owsley et al., 1998).

Altogether, these moderating and main effects of attention capacity indicate that this capacity is important for safe driving, not only in the context of distraction. As mentioned in the introduction, previous research has indicated that attention capacity can be trained and that this training has beneficial effects on every day skills (Ball et al., 2002; Ball et al., 2007; Ball et al., 2010; Ball et al., 2013; Rebok et al., 2014; Roenker et al., 2003). However, it will be necessary to investigate possible negative side effects of capacity training, since participants might overestimate their dual-tasking capacity after training, feeling confident to divide their attention during driving. Similar, adverse capacity training effects, though in a vehicle handling context, have been shown before, as skid control training for younger drivers actually led to capacity overestimation and increased crash rates (Beanland, Goode, et al., 2013).

## 4.3. Subjective measures of driving performance

Interestingly, despite the decrease of driving performance with both types of distraction, participants rated their driving performance during both types of distraction quite high on the NASA TLX. Hence, participants seem to overestimate their driving performance during distraction. The awareness of effects of distraction may influence drivers' willingness to engage in distracting activities: if they are not aware of detrimental effects, they will not be reluctant to engage in these activities (Horrey, Lesch, & Garabet, 2008). Therefore, education programs to increase awareness about adverse effects of driver distraction are important.

## 5. LIMITATIONS AND FUTURE RESEARCH

Unavoidably, these experiments have their limitations. First, the effects of two types of distraction were investigated in two separate experiments. Due to differences in complexity of the distracting tasks (i.e., higher percentage correct answers and lower workload scores on the NASA TLX for the visual task compared to the cognitive task) and sample sizes (i.e., 17 vs. 35 participants), no comparison was made of visual and cognitive distraction. Since both types of distraction were not compared, no conclusions can be made about which type of distraction has the largest adverse effects.

Second, no comparison group of younger and/or middle-aged drivers was included in either of the experiments. It would be interesting to compare these groups to investigate if older drivers are more susceptible to several types of distraction than younger drivers while taking into account the moderating effect of attention capacity.

Third, the possibility of a self-selection bias has to be kept in mind. Especially those drivers that think of themselves as good drivers could be more willing to volunteer to participate in a study investigating driving performance. Indeed, the current sample is not representative for the population of older drivers, since they were all cognitively healthy as indicated by the scores on the MMSE. Previous studies have indicated that the effects of distraction on driving are larger in participants with decreased cognitive ability, e.g., MCI or dementia (Pavlou et al., 2013; Stein & Dubinsky, 2011; Uc, Rizzo, Anderson, Shi, & Dawson, 2005).

Finally, although driving simulators provide the opportunity to investigate dangerous situations in a standardized, safe and controlled environment (Freund et al., 2002; Lee et al., 2003) and positive evidence for simulator validity has been provided (Fisher et al., 2011; Shechtman et al., 2009; Underwood et al., 2011), the current experiments should be replicated during real-world driving to bolster our conclusions. Since the experimental manipulation of distraction in the current experiments may not generalize to distraction in real-world driving, the moderating effect of attention capacity on driver distraction should, for example, be investigated with hands-free phone conversations or operation of a vehicle entertainment system in a naturalistic driving study.

## 6. CONCLUSIONS AND IMPLICATIONS

The results of the current study reveal that in the context of visual and cognitive driver distraction, attention capacity had a moderating effect on lane keeping performance of older drivers. Moreover, attention capacity was negatively related to the number of crashes. These moderating and main effects of attention capacity indicate that attention capacity is important for safe driving, not only in the context of driver distraction. Driver assessment programs might therefore include a module focusing on attention capacity. Those drivers obtaining a low score on a driver assessment attention test, can then be referred to a training targeting attention capacity. It should be noted though that not all driving measures were affected by attention capacity and a training program only targeting the improvement of attention capacity would be too narrow.

Since driver distraction had degrading effects on the majority of driving measures in participants of both lower and higher attention capacity, it is crucial to eliminate driver distraction as much as possible.

Finally, our results showed that the participants seem to overestimate their driving performance during distraction. Therefore, it is important to enhance awareness about performance decrements due to distraction. Traffic safety awareness and education programs might serve this purpose.

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# CHAPTER 3

*Transportation Research Part F: Traffic Psychology and Behaviour. Accepted for publication.*

## Effect of a working memory training on aspects of cognitive ability and driving ability of older drivers: Merits of an adaptive training over a non-adaptive training.

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## Abstract

Working memory (WM), important for driving, declines with age. It was investigated whether a WM training would enhance aspects of cognitive ability and driving ability of older drivers. Thirty-eight drivers (mean age 71 years) were randomly assigned to an adaptive WM training (n=19) or a non-adaptive WM training (n=19). In addition, a no-training control group was collected (n=18). During the pre-test and post-test, aspects of cognitive ability and driving ability were assessed. In between, participants in the adaptive training group and the non-adaptive training group conducted a WM training. We hypothesized that improvement on aspects of cognitive ability and driving ability will be largest in the adaptive training group, smaller in the non-adaptive training group and only minimal in the no-training control group. Results indicated that this hypothesis was confirmed for a measure of WM. For two driving measures (i.e., driving speed and reaction to stop signs), group means were in the expected direction, but results were only marginally significant. In addition, there were general test-retest effects for a measure of attention and one driving measure (i.e., gap acceptance). These results are in line with previous cognitive training studies with older people indicating training can improve performance on the trained tasks, but transfer to untrained tasks is only limited. Suggestions for future research are offered.

## Key words

Training; Working memory; Driving; Aging; Simulator

# 1. INTRODUCTION

Driving is a complex task that requires cognitive, visual and motor abilities (Eby et al., 2009). With age, there is a decline of these abilities. With regard to cognitive abilities, increasing age is, among others, characterized by problems of working memory (Eby et al., 2009). Working memory (WM) is the ability to temporarily store or manipulate information (Baddeley, 1992). Previous research of individual differences has indicated the importance of WM for driving in older drivers: Guerrier, Manivannan, and Nair (1999) found that WM was related to decision time while turning left, more specifically, a higher WM score was related to a longer decision time to turn left. In addition, Adrian, Postal, Moessinger, Rascle, and Charles (2011) found that WM was related to a summarized driving measure taking into account speed control, lane position and responses to road signs. More specifically, a higher WM score was related to a better driving performance.

Since driving cessation can lead to social isolation and even depression (Marottoli et al., 1997), there is a need for interventions to keep drivers safe drivers for as long as possible. Cognitive training might serve this purpose. Indeed, several studies have shown that cognitive training targeting older people can improve their cognitive ability (Rebok et al., 2014; Schmiedek et al., 2010). Hence even people with an advanced age, have considerable plasticity in their cognitive functioning (Kramer & Willis, 2002). Moreover, a limited number of studies have shown transfer of cognitive training effects to driving ability of older people (Edwards, Delahunt, et al., 2009; Roenker et al., 2003). As a consequence, an increasing number of commercially available cognitive training packages for older people have been introduced that claim to improve driving ability.

Since WM declines with age, it can be expected that a cognitive training specifically targeting WM might improve WM of older people. Indeed, several recent studies showed that WM of older people improved as a consequence of WM training (Borella, Carretti, Zanoni, Zavagnin, & De Beni, 2013; Richmond, Morrison, Chein, & Olson, 2011). Some of these studies showed that WM training also improved other cognitive abilities of older people, like attention (Brehmer et al., 2012; Richmond et al., 2011) and inhibition (Borella et al., 2013). However, there is debate about the (transfer) effects of a WM training (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012), since several studies found improvement on the trained tasks after following a WM training, but not on untrained tasks (Lange & Süß, 2015; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012). Interestingly, positive transfer effects of a WM training have been shown in several domains of behavior. For example, after following a WM training, adults showed a decrease of alcoholic drinks intake (Houben, Wiers, & Jansen, 2011), and children with Attention Deficit Hyperactivity Disorder (ADHD) showed an improvement in behavioral symptoms of ADHD (Klingberg et al., 2002). As for driving, to our knowledge, only two studies have so far investigated whether a computerized WM training improves driving ability of older drivers. First, Cassavaugh and Kramer (2009) investigated the effect of a WM training on specific driving measures like lane position, following distance and accelerator response time to lead-vehicle braking and found a positive effect on response time for the trained group. Second, Seidler et al. (2010) investigated the effect of a WM training on a summarized driving measure, taking into account speed control, lane position and crashes, under single task and dual task conditions. Although the results were preliminary, because participants were still completing the training, they showed transfer to the summarized driving measure particularly when driving under dual-task conditions.

The purpose of the present study was to investigate the effect of a computerized WM training on aspects of older drivers' cognitive ability and driving ability. We expected that improvement of cognitive ability and driving ability will be largest in an adaptive training group, smaller in a non-adaptive training group and minimal in a no-training control group. More specifically, the first part of this hypothesis (i.e., improvement in adaptive training group is larger than in non-adaptive training group) is based on previous research that found that an adaptive WM training generally leads to larger training gains than non-adaptive WM training both in older people (Brehmer et al., 2012) and in children (Holmes et al., 2009; Karbach et al., 2015; Klingberg et al., 2005; Klingberg et al., 2002). The final part of this hypothesis (i.e., only minimal improvement in the no-training control group) is based on learning theories that state that participants improve when performing a task for a second time (Boot, Blakely, & Simons, 2011; Collie, Maruff, Darby, & McStephen, 2003). Interestingly, a recent WM training study found similar differential group improvement (i.e., group following adaptive training, non-adaptive training or no training) on a WM task for a sample of undergraduates (Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013).

With regard to cognitive abilities, we expected that the WM training would not only improve WM, but also attention and inhibition. This was based on previous studies that showed an improvement of attention and inhibition after following a WM training (Borella et al., 2013; Brehmer et al., 2012; Richmond et al., 2011) and on the interrelatedness of different cognitive functions and their underlying neural circuits (McNab et al., 2008). With regard to driving ability, in contrast to investigating the effect of a WM training on a summarized driving measure (Seidler et al., 2010), specific measures of driving ability were used, since previous research has indicated the importance of investigating specific measures (Aksan et al., 2015; Anstey & Wood, 2011; Cuenen et al., 2016; Mullen et al., 2008). Although Cassavaugh and Kramer (2009) already investigated the effect of a WM training on specific driving measures, their selection of driving measures was limited (i.e., lane position, following distance and accelerator response times) and investigated under manipulated circumstances (e.g., during car-following, a visual memory task, a monitoring task, or dual tasking). Therefore, this is the first study to investigate the effect of a WM training on several specific measures of driving ability under normal driving circumstances while encountering situations that are known to be difficult for older drivers (i.e., intersections). Driving measures of interest (i.e., speed control, lane position, gap acceptance while turning left, responses to road signs and crashes) were already investigated as part of a summarized driving measure that was related to WM (Adrian et al., 2011). Here, specific measures and their relations to WM were investigated in an exploratory analysis. Since recent research showed that different driving measures have different underlying cognitive abilities, it can be expected that improvements will be limited to a selection of these driving measures (Aksan et al., 2015; Anstey & Wood, 2011; Cuenen et al., 2016; Mullen et al., 2008). There were however no a priori expectations which specific driving measures will be affected by the training. The results of this study can guide future initiatives to attenuate declines in cognitive and driving ability in order to extend the independence of older people.

## 2. METHOD

### 2.1. Participants

Participants aged 60 years or older who were still active drivers, had not had a stroke or sequel in the last six months, had experience with a Personal Computer[2] and had a Mini-Mental State Examination (MMSE)

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[2] Although procedure and time between testing was the same for all three groups, participants of the no-training control group were later recruited compared to participants of the two training groups (i.e., adaptive and non-adaptive) and 'experience with a PC' was not added as an inclusion criteria. Unexpectedly, average OSpan scores of the no-training control group were lower when compared to those of the adaptive training group and the non-adaptive training group. Closer inspection of the data showed that this is due to a higher frequency of zero-scores in the no-training control group (n = 10), than in the adaptive training group (n = 2) or the non-adaptive training group (n = 4). Possibly this is due to later recruitment of the no-training control group. As a consequence, participants were randomized across the two training groups (i.e., adaptive and non-adaptive),

score of 25 or above were recruited. The MMSE is a brief test that examines the cognitive function of an individual. It comprises items assessing orientation to time and place, registration and recall, attention, language and constructional ability (Folstein et al., 1975). Possible scores range from 0 to 30, with higher scores reflecting higher cognitive ability. Recruitment occurred through the community via (local) media and via oral presentations and flyers distributed in senior associations. Given the possibility of simulator sickness, participants were closely watched for signs of this type of sickness. If a participant showed any signs of simulator sickness, the simulation was immediately terminated and the participant was excluded from further participation.

A sample size of around 25 people per group was chosen based on previous WM training studies that had between 7 and 28 participants per group (Cassavaugh & Kramer, 2009; Houben, Wiers, et al., 2011; Klingberg et al., 2002). In total, fifty-four participants volunteered. However, sixteen participants dropped out due to simulator sickness (n=12) or personal circumstances (i.e., hospitalization, n=4). After successful completion of the pre-test (i.e., no simulator sickness), participants were randomly assigned to an adaptive WM training (n=19) or a non-adaptive WM training (n=19). In addition, a no-training control group was collected1. In total, thirty participants volunteered. However, twelve participants dropped out due to simulator sickness (n=9) or personal circumstances (n=3). Hence, the no-training control group consisted of 18 participants.

The adaptive training group can be regarded as an experimental group. An adaptive training ensures an adequate level of difficulty that does not over- or underchallenge participants. This way, participants continuously work at their individual performance limit (Baltes, Sowarka, & Kliegl, 1989; Borella et al., 2013; Brehmer et al., 2012; Klingberg et al., 2002; Lange & Süß, 2015; Richmond et al., 2011). The non-adaptive training group can be regarded as an active control group. In many studies (Borella et al., 2013; Lange & Süß, 2015; Richmond et al., 2011; Seidler et al., 2010) this group follows a different training than the experimental group, however, this brings along the disadvantage that it might affect performance differently (Brehmer et al., 2012). In the present study, the

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thereby distributing zero-scores across the two groups, whereas all low scorers were assigned to the same no-training control group. In addition, this can be due to the difference in recruitment, since for the no-training control group, experience with a PC was not added as an inclusion criterion. There were no significant differences between scores in the no-training control group on each of the cognitive tests for the pre-test and post-test, which supports that the lower OSpan scores are not due to measurement errors.

adaptive and non-adaptive training groups only differ in terms of task difficulty, as this is kept fixed at a low level in the non-adaptive training group. This provides a conservative assessment of training effects, because the influence of various unspecific factors is attenuated (Brehmer et al., 2012; Shipstead, Redick, & Engle, 2010; Zehnder, Martin, Altgassen, & Clare, 2009). The no-training control group can be regarded as a passive control group which allows to determine possible test-retest effects (Brehmer et al., 2012; Chein & Morrison, 2010; Dahlin, Nyberg, Bäckman, & Neely, 2008; Li et al., 2008; Schmiedek et al., 2010).

## 2.2. Driving simulator scenario

Driving ability was measured in a driving simulator since a simulator provides the opportunity to investigate dangerous situations in a standardized, safe and controlled environment (Lee et al., 2003). Furthermore, it allows to investigate specific driving measures, like speed control and lateral position. Recently, positive evidence for simulator validity has been provided (Fisher et al., 2011). The study was conducted with STISIM version 2 on a STISIM M400 fixed-base driving simulator with a force-feedback steering wheel, an instrumented dashboard, brake and accelerator pedals and with a 135 degree field of view. The visual environment of this simulator is presented on three computer screens (each with 1280 x 800 pixels resolution and 60Hz refresh rate). Two practice drives preceded the main drive to get acquainted with the driving simulator. In the first practice drive (2.1 km) almost no curves, no signs, and no other road users were introduced to acquaint drivers with the experience of driving in a simulator. The second practice drive (5.5 km) was similar to the main drive to acquaint drivers with several traffic situations. The main drive solely consisted of inner-city (50 km/hour) segments, and to decrease the risk of simulator sickness did not contain any curves. The main ride included several situations at intersections that are known to be difficult for the older driver, i.e., right of way decisions (Hakamies-Blomqvist, 1993), responses to signs (Bao & Boyle, 2008; Jongen et al., 2012) and gap acceptance for turning left (Jongen et al., 2012; Yan et al., 2007). In addition, road hazards occurred during the scenario (i.e., pedestrians suddenly crossing the road without using a pedestrian crossing). The intersections all were a four-way intersection consisting of a straight piece of road and a minor road to the left and to the right.

## 2.3. Driving ability

A total of six specific driving measures were derived for analyses. Although these driving measures are often combined into a summarized measure of driving ability, here we were interested in specific driving measures. These driving measures were selected since previous research found a relation between a summarized version of these measures and WM (Adrian et al., 2011). The first two driving measures, driving speed (km/h) and standard deviation of lateral lane position (SDLP, m) represent longitudinal and lateral control measures. A measure of longitudinal control (i.e., driving speed) was selected since older drivers compensate for age-related increases in response time, for example by adopting slower speeds (Fisher et al., 2011). A measure of lateral control (i.e., SDLP) was selected since this measure is an index of road-tracking precision (Ramaekers, 2003), which is considered a reliable characteristic of individual driving performance (O'hanlon & Ramaekers, 1995; Vuurman et al., 2007; Wester et al., 2008) and provides a sensitive measure of driver impairment (De Waard, 1996; Ramaekers, 2003). Driving speed and SDLP were measured across separate road segments without any events (Trick et al., 2010). The third and fourth driving measure, giving right of way (yes (coded as 1) or no (coded as 0)) and making a complete stop at stop sign (yes (coded as 1) or no (coded as 0)), were computed from 200m before reaching the intersection (with a stop sign) until the location of the intersection (with a stop sign). It was determined whether drivers complied with Belgian traffic regulations that drivers must give right of way at a non-signalized intersection within an inner-city and make a full stop (i.e., speed = 0 km/h) at a stop sign (Bao & Boyle, 2008; Jongen et al., 2012). The fifth driving measure, left turn gap acceptance decision (s), is the time headway between two vehicles on the major road into which a left-turn driver chooses to turn (Jongen et al., 2012; Yan et al., 2007). When the driver approached the intersection, the instruction to turn left was played. On the major road in the opposite lane, a stream of oncoming cars was driving with a speed equaling the speed limit, forcing the driver to make a stop. The first part of the stream consisted of very small gaps (less than 3 s) and was followed by the second part of the stream that, similar to Yan et al. (2007), consisted of gaps uniformly increasing in duration from 3 s to 16 s. Participants were asked to indicate their decision to turn left when they judged it was safe to do so by pressing a button. This procedure was followed to minimize the chance of simulator sickness that was very high in a previous study where participants actually made the left turn maneuver (Jongen et al., 2012). These three driving measures (i.e., giving right of way, making a complete stop at a stop sign, and left turn gap acceptance decision) occurred two times at four-way intersections consisting of a straight piece of road and minor roads to the left and to the right. Finally, number of crashes was assessed. Crashes occurred with road hazards (i.e., pedestrians suddenly crossing the road without using a pedestrian crossing). All driving measures were averaged measures, with the exception of crashes which illustrates the total number of crashes during the drive.

## 2.4. Cognitive ability – WM

WM was measured with the Automated Operation Span (AOSPAN) task (Unsworth, Heitz, Schrock, & Engle, 2005). This is an adapted version of the original Operation Span (OSPAN) task of Turner and Engle (1989). This task included three practice sessions and one test session. In the first practice session, participants practiced the letter portion of the task. A letter appeared on the screen, and the participants were required to recall the letters in the same order in which they were presented. In the second practice session, participants practiced the math portion of the task. They first saw a math operation, which they needed to solve as quickly as possible. On the next screen a digit was presented and the participants were required to indicate whether it was the correct or false solution of the math operation. After this second practice session, the program calculated each individual's mean time required to solve the math operations. This time (plus 2.5 SD) was then used as a time limit for the math portion of the test session for that individual. In the final practice session, the participants performed both the letter and math portions together, just as they would do in the test session. The participants first saw the math operation and afterwards the letter to be recalled. If the participants took more time to solve the math operations than their average time plus 2.5 SD, the program automatically moved on and counted that trial as an error. This served to prevent the participants from rehearsing the letters when they should be solving the operations. After participants completed all practice sessions, they started with the test session, which consisted of three sets of each set size, with set sizes ranging from 3 to 7. This made for a total of 75 letters and 75 math problems. The order of set sizes was random for each participant. Participants were encouraged to keep their math accuracy at minimum 85% at all times. The AOSPAN score (i.e., the sum of all perfectly recalled sets) was used as a measure of WM. A higher AOSPAN score corresponds with an improved WM.

## 2.5. Cognitive ability – inhibition

The Stop Signal Task (SST) was used as a measure of inhibition (Logan and Cowan (1984); for a review, see Verbruggen and Logan (2008)). This task included two practice sessions (each consisting of 40 trials) and one test session (88 trials). In all sessions, participants were required to press a button (left or right) as quickly as possible in response to a stimulus ('X' or 'O') presented centrally on screen (go trials). In each trial, after 1000ms, a fixation cross was presented for 500ms. After this, a stimulus was presented for 1000ms. The first practice session served to determine the individual's mean Reaction Time (RT), which was used as a reference for the second practice session and the test session. The latter sessions consisted of the same task as the first practice session, but in addition, an auditory stimulus (1000Hz, 70dB, 100ms) was presented on a randomly selected 25% of the trials. Upon presentation of this auditory stimulus, the participant needed withheld their response to the stimulus on that trial (stop trials). Importantly, the Stop Signal Delay (SSD; i.e., the time interval between the stimulus and the stop signal) was initially set 50ms below the individual's mean RT. Subsequently the interval varied dynamically, according to a staircase algorithm, to converge on a SSD at which the probability of stopping on stop trials was 50%. SSD was increased by 50ms if the response was withheld and decreased by 50ms when the response was not withheld. The Stop Signal Reaction Time (SSRT), the time participants need to inhibit their predominant response after hearing the stop signal, was used as a measure of inhibition. This measure can be derived by subtracting the mean SSD from the mean RT. A longer SSRT corresponds with decreased inhibition.

## 2.6. Cognitive ability – attention

Attention was measured with the Useful Field of View (UFOV). This test was PC-based, with stimuli presented on a 19-inch monitor and responses made using a computer mouse. This version of the UFOV has been shown to be both reliable and valid (Edwards et al., 2005). This test consisted of three subtests assessing participants' visual processing speed (UFOV1), divided attention (UFOV2) and selective attention (UFOV3; Ball et al. (1993)). Scores are expressed in milliseconds, representing the exposure duration required for an observer to perform at an accuracy level of 75%. For each subtest, possible scores range from 16.7ms to 500ms. UFOV-total (i.e., the sum of scores on the three subtests) was used as a measure of attention. Lower scores, correspond with improved attention.

## 2.7. WM training

Participants in both the adaptive training and the non-adaptive training group completed a WM training. The training consisted of three WM subtasks: a visuo-spatial task, a backward digit span task and a letter span task (adapted from Klingberg et al. (2002) and Houben, Wiers, et al. (2011)). During the visuo-spatial task, squares in a 4 x 4 grid changed color one at a time. Participants had to reproduce these squares in the correct order. During the backward digit span task, numbers were presented one at a time, and participants had to reproduce these numbers in reverse order. Finally, in the letter span task, letters were presented one at a time in several circles. One of these circles then changed color, and participants had to enter the corresponding letter. Each task consisted of 30 trials. The training consisted of 25 consecutive sessions spread over at least 25 days. Participants had two days to conduct a session. The session was marked as 'missed' if participants did not complete a session in those two days. Participants could miss maximum 5 sessions. Hence, the total number of sessions varied between 20 and 25 sessions. The training was conducted at home, on a PC, via the internet. Responses were given with a computer mouse or number keys on a keyboard.

In the adaptive training group, the difficulty level of the training was automatically adjusted on a trial-by-trial basis. Initially, each task involved a span of three items. The length of the span changed according to participants' performance. When participants succeed on two consecutive trials, one item was added to the span on the next trial hence task difficulty was increased. When participants failed on two consecutive trials, one item was subtracted from the span on the next trial hence task difficulty was decreased. Participants in the adaptive training group could receive a span of maximum 15 items.

In the non-adaptive training group, the difficulty level of the training was not adjusted: each task involved a span of three items. In addition, participants in the non-adaptive training group, started each session with a span of 3 items, whereas participants in the adaptive training group started each session with the number of items of the previous session.

Adherence to the training was monitored for each participant. Each day participants received an automatic invitation mail for a new session. For each day, data was automatically sent to a server if participants finished the session. If no data was received by the server it was marked as "missed". If participants missed a session, they received an automatic mail that they missed the previous session and that they were allowed to only miss five sessions. This overview was checked by the involved researcher. If participants missed two or more sessions, the researcher contacted the person to remind him/her personally of the fact that he/she was allowed to only miss five sessions.

## 2.8. Procedure

First, participants gave informed consent. Then, all participants were screened for cognitive status with the MMSE. After successful completion of the pre-test (i.e., no simulator sickness), participants were randomly assigned to either the adaptive training group (n=19) or the non-adaptive training group (n=19). In addition, a no-training control group1 was collected (n=18). After the training period, all participants completed a post-test. During the pre- and post-test, participants conducted the cognitive tasks (i.e., AOSPAN, UFOV, and SST) and the driving simulator scenario. In between, participants in the adaptive and non-adaptive training group completed the WM training. After the post-test, participants received a gift certificate. Order of the cognitive tasks was counterbalanced between participants during the pre- and post-test.

## 2.9. Data analysis

The data was processed using SPSS. Before analyses, outliers were treated for each variable. Outliers larger than three standard deviations were replaced with the maximum score within the three standard deviation range (Wood et al., 2008).

Univariate analyses of variance (ANOVA) were conducted to check whether there were significant differences between the three groups at pre-test on age, MMSE, the three cognitive measures (i.e., WM, attention and inhibition) and the six driving measures (i.e., driving speed, SDLP, gap acceptance, complete stops at stop signs, giving right of way, and crashes).

A manipulation check was conducted to investigate performance on the training for the two training groups. Performance on the training was assessed by taking the average WM span reached at the end of each training session.

Planned comparisons were conducted to test the hypothesis that improvement of cognitive ability and driving ability will be largest in the adaptive training group, smaller in the non-adaptive training group and minimal in the no-training control group. More specifically, one-way ANOVAs were conducted for each of the dependent measures with the pre-post difference score as the dependent measure (i.e. performance during post-test minus performance during pre-test) and Group (i.e., adaptive training group, non-adaptive training group, no-training control group) as the independent measure. We used a linear contrast for each of the dependent measures with the following contrast weights: 1 0 -1 (Sagi et al., 2012).

To investigate whether general test-retest effects were present, repeated measures ANOVAs were conducted for each of the dependent measures to investigate the main effect of Test (pre-test, post-test). In the ANOVA, Test (i.e., pre-test, post-test) served as within-subjects variable and Group (i.e., adaptive training group, non-adaptive training group, no-training control group) served as between-subjects variable. The Greenhouse–Geisser epsilon correction factor was applied to compensate for possible effects of non-sphericity in the measurements compared. Only the corrected F and probability values are reported. An alpha level of .05 was maintained for all statistical tests. A Bonferroni correction was applied to control for repeated comparisons. Effect sizes for the main effect of Test were reported with Cohen's delta. A Cohen's delta of 0.2 indicates a small effect size, 0.5 indicates a medium effect size, and 0.8 indicates a large effect size.

## 3. RESULTS

### 3.1. Differences at pre-test

See Table 1 for the descriptive statistics of the demographic, cognitive and driving measures in the three groups, for the pre- and post-test. At pre-test, participants did not significantly differ in Age, MMSE, on the majority of cognitive measures (i.e., attention, inhibition), or on the majority of driving measures (i.e., driving speed, SDLP, gap acceptance, complete stops at stop signs, and crashes, all p-values >.10). For one cognitive measure (i.e., WM), there was a significant difference between groups (F(2,51)=6.86, p=.002), as participants in the no-training control group had a lower WM capacity than those in the non-adaptive and adaptive training group. For one driving measure (i.e., giving right of way), there was a significant difference between groups (F(2,53)=8.61, p=.001), as participants in the no-training control group gave less right of way than those in the non-adaptive and adaptive training group.

**Table 1.** Means and standard deviations (SDs) for the demographic, cognitive and driving measures, in the three groups for the pre-test and post-test.

| **Measure** | **Pre-test** | | | **Post-test** | | |
|---|---|---|---|---|---|---|
| | *Adaptive training group* | *Non-adaptive training group* | *No-training control group* | *Adaptive training group* | *Non-adaptive training group* | *No-training control group* |
| *Demographic measures* | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Age (years) | 70.84 (4.66) | 69.84 (4.39) | 73.06 (6.20) | n.a. | n.a. | n.a. |
| MMSE (number) | 28.74 (1.37) | 28.74 (1.20) | 28.72 (1.49) | n.a. | n.a. | n.a. |
| *Cognitive measures* | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Working memory[1] (AOSPAN - number) | 18.79 (15.17) | 20.32 (17.44) | 3.73 (6.87) | 29.21 (18.18) | 27.84 (22.81) | 4.74 (7.50) |
| Attention (UFOV-total - ms) | 240.50 (217.63) | 204.08 (130.57) | 332.50 (201.85) | 187.74 (143.47) | 130.67 (48.60) | 293.26 (168.86) |
| Inhibition (SSRT - ms) | 222.29 (46.14) | 227.14 (50.27) | 205.54 (50.69) | 204.74 (50.39) | 203.64 (50.40) | 199.26 (54.23) |

| **Measure (continued)** | **Pre-test** | | | **Post-test** | | |
|---|---|---|---|---|---|---|
| | *Adaptive training group* | *Non-adaptive training group* | *No-training control group* | *Adaptive training group* | *Non-adaptive training group* | *No-training control group* |
| *Driving measures* | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Driving speed (km/h ) | 41.49 (4.89) | 41.93 (6.06) | 41.14 (6.97) | 45.16 (5.12) | 43.05 (5.75) | 41.50 (6.75) |
| SDLP (m) | 0.22 (0.05) | 0.19 (0.05) | 0.20 (0.06) | 0.22 (0.07) | 0.18 (0.03) | 0.22 (0.06) |
| Gap acceptance (s) | 5.36 (0.89) | 5.54 (1.17) | 5.68 (1.12) | 4.93 (1.25) | 4.96 (0.80) | 5.18 (1.05) |
| Complete stops at stop signs (0= no/1 = yes) | 0.58 (0.42) | 0.76 (0.35) | 0.72 (0.35) | 0.71 (0.35) | 0.63 (0.40) | 0.58 (0.43) |
| Giving right of way (0 = no/1 = yes) | 0.90 (0.21) | 0.84 (0.24) | 0.56 (0.34) | 0.87 (0.23) | 0.90 (0.21) | 0.72 (0.39) |
| Crashes (number) | 0.53 (0.70) | 0.47 (0.70) | 0.50 (0.62) | 0.21 (0.42) | 0.41 (0.72) | 0.33 (0.59) |

n.a. = not applicable

### 3.2. Manipulation check

On average, 23.05 sessions (SD=2.32) out of 25 training sessions were completed by participants in the adaptive training group and 23.63 sessions (SD=1.64) were completed by participants in the non-adaptive training group. As shown in Figure 1, performance of participants in the adaptive training group increased on the training sessions during the training period. This is because in this group, the number of items of the training was adjusted adaptively to participants' performance. The error bars show that variability in terms of training improvement is limited. In contrast, in the non-adaptive training group, the number of items of the training was not adjusted adaptively to participants' performance, but fixed to three items.

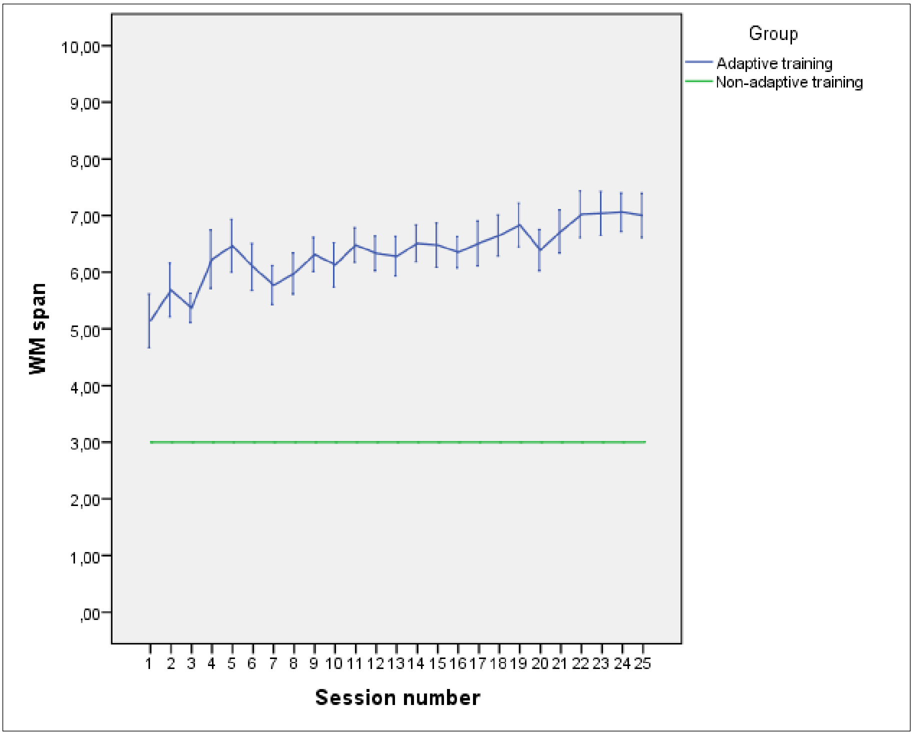


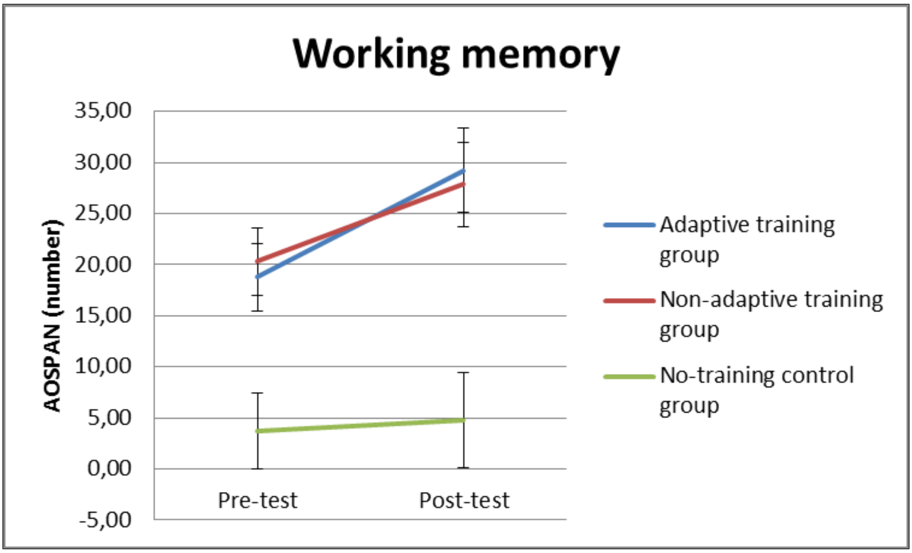
**Figure 1.** Mean WM span at the end of each training session of participants in the adaptive training and non-adaptive training groups. WM span was averaged across the three tasks for each training session. Error bars represent standard errors of the mean.

## 3.3. Planned comparisons

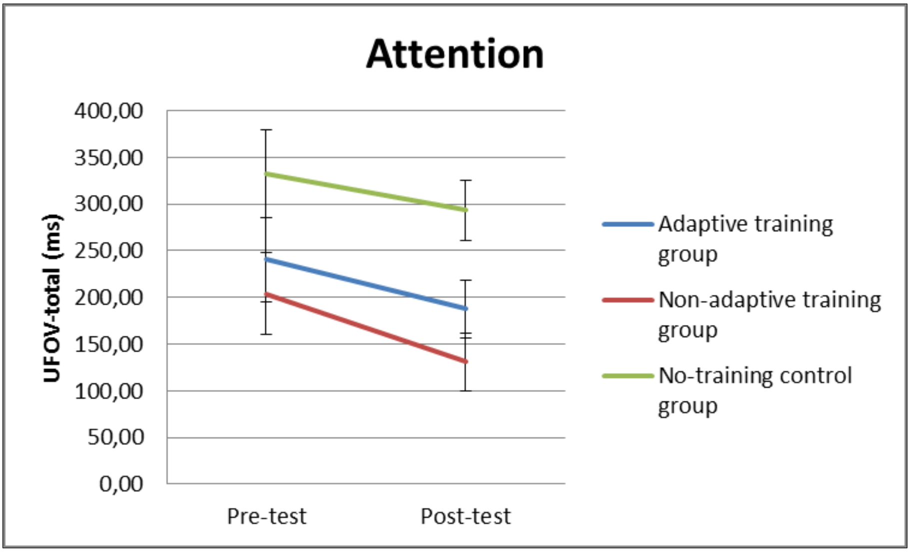
With regard to cognitive ability, as shown in Figure 2, our hypothesis (i.e., improvement will be largest in the adaptive training group, smaller in the non-adaptive training group and only minimal in the no-training control group) was supported for WM (t(21.34)=2.30, p=.03). For the other cognitive measures (i.e., attention and inhibition) there was no support for our hypothesis (all p-values >.10).

With regard to driving ability, as shown in Figure 3, effects were in the expected direction, but only marginally significant, for driving speed (t(53)=1.96, p=.06) and complete stops at stop signs (t(53)=1.87, p=.07). For the other driving measures (i.e., SDLP, gap acceptance, giving right of way, and crashes) there was no support for our hypothesis (all p-values >.10).

A



B



C

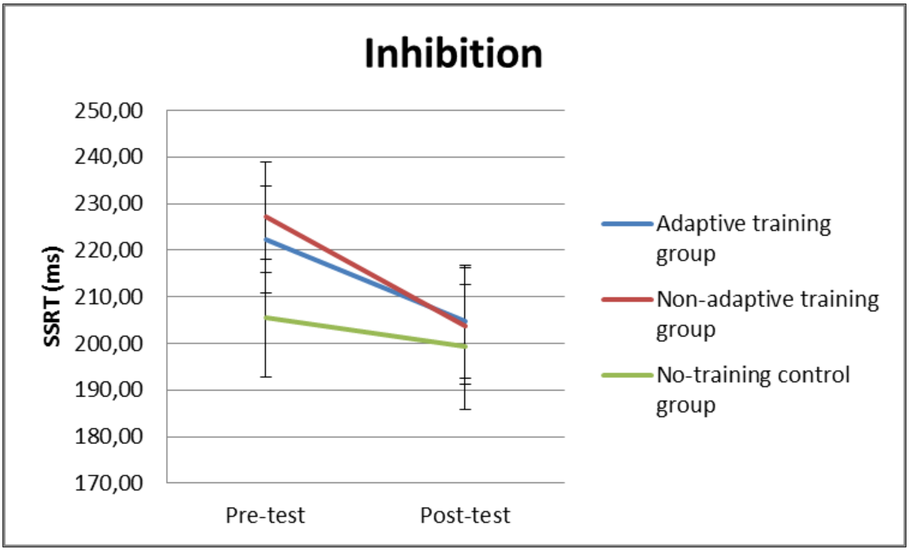
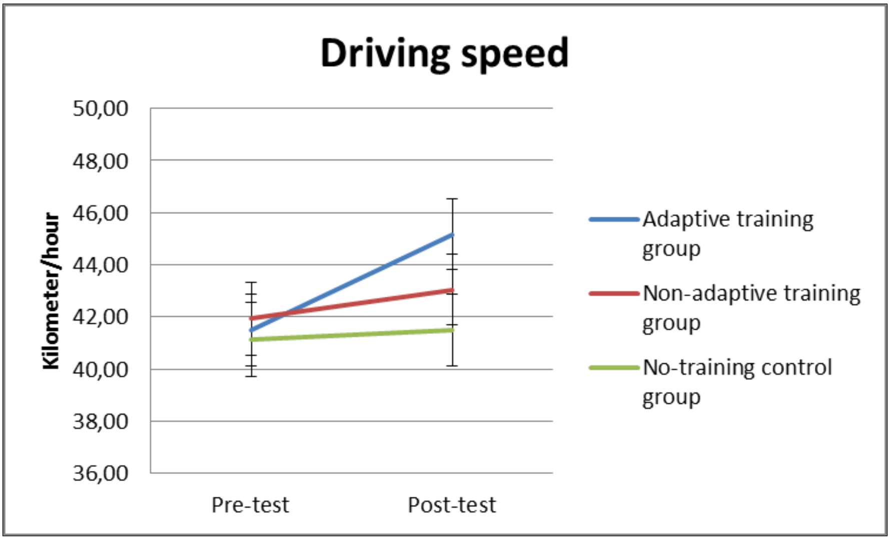
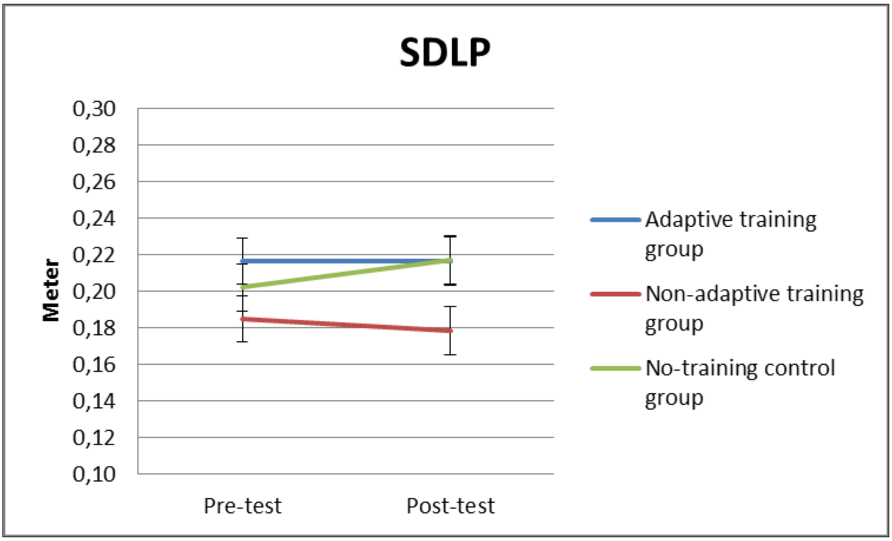


**Figure 2**. Estimated marginal means for the cognitive measures at pre-test and post-test, separately for participants in the adaptive training, non-adaptive training and no-training control group: Working memory (A), Attention (B) and Inhibition (C). Error bars represent standard errors of the mean.

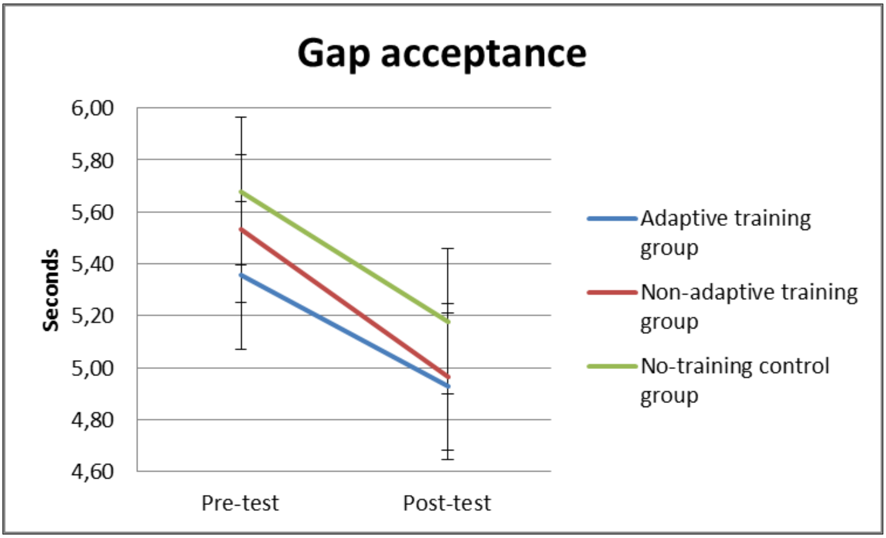
A


Driving speed
Kilometer/hour
50,00
48,00
46,00
44,00
42,00
40,00
38,00
36,00
Pre-test
Post-test
Adaptive training group
Non-adaptive training group
No-training control group

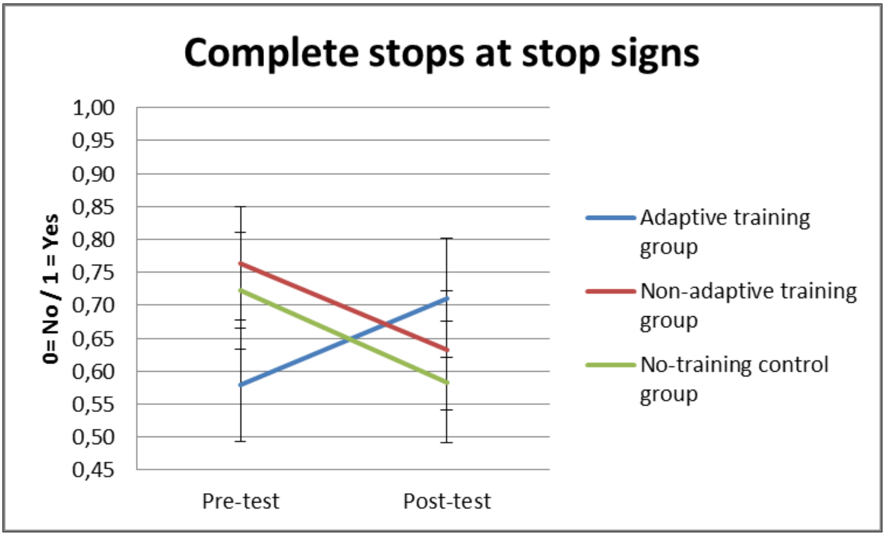
B


SDLP
Meter
0,30
0,28
0,26
0,24
0,22
0,20
0,18
0,16
0,14
0,12
0,10
Pre-test
Post-test
Adaptive training group
Non-adaptive training group
No-training control group

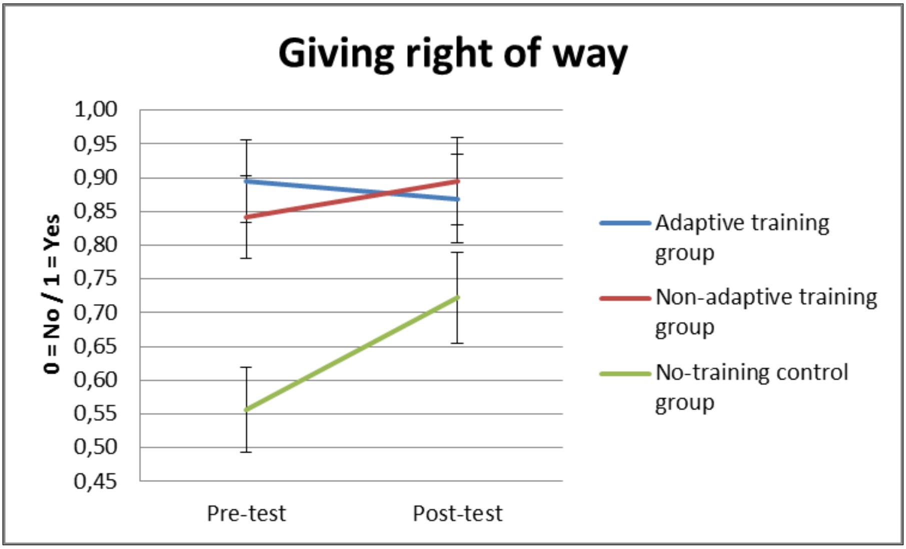
C


Gap acceptance
Seconds
6,00
5,80
5,60
5,40
5,20
5,00
4,80
4,60
Pre-test
Post-test
Adaptive training group
Non-adaptive training group
No-training control group

D


Complete stops at stop signs
0= No / 1 = Yes
1,00
0,95
0,90
0,85
0,80
0,75
0,70
0,65
0,60
0,55
0,50
0,45
Pre-test
Post-test
Adaptive training group
Non-adaptive training group
No-training control group

E



F

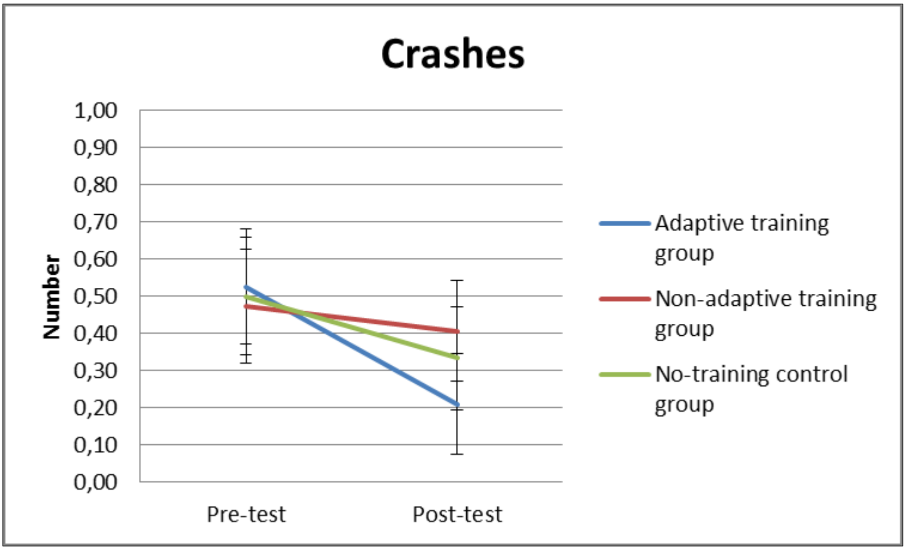


**Figure 3**. Estimated marginal means for the driving measures at pre-test and post-test, separately for participants in the adaptive training, non-adaptive training and no-training control group. Error bars represent standard errors of the mean: Driving speed (A), SDLP (B), gap acceptance (C), complete stops at stop signs (D), giving right of way (E), crashes (F).

### 3.4. Repeated measures ANOVA

See Table 2 for the results of the repeated measures ANOVAs (i.e., main effect Test) for the cognitive and driving measures to investigate whether general test-retest effects were present.

With regard to cognitive ability, there was a significant main effect of Test for the WM and the attention task, indicating a test-retest effect for these cognitive measures. For the inhibition task, there was a marginally significant main effect of Test, indicating that a test-retest effect for this cognitive measure is possible.

With regard to driving ability, there were significant main effects of Test for driving speed and gap acceptance, indicating a test-retest effect for these specific driving measures.

**Table 2.** Corrected F and probability values per dependent cognitive and driving measure.

| **Measure** | **F** | **p** | **Cohen's d** |
|---|---|---|---|
| *Cognitive measures* | | | |
| Working memory (AOSPAN) | 10.41 | .002** | 0.37 |
| Attention (UFOV) | 10.81 | .002** | 0.33 |
| Inhibition (SSRT) | 3.44 | .07 | n.a. |
| *Driving measures* | | | |
| Driving speed | 6.32 | .015** | 0.29 |
| SDLP | 0.17 | .68 | n.a. |
| Gap acceptance | 8.47 | .006** | 0.48 |
| Complete stop at stop signs | 0.62 | .43 | n.a. |
| Giving right of way | 1.71 | .20 | n.a. |
| Crashes | 2.24 | .14 | n.a. |

*<.05, **<.01
n.a. = not applicable

## 4. DISCUSSION

The present study investigated whether a WM training would enhance aspects of cognitive ability and driving ability of older drivers. Based on previous studies, we hypothesized that improvement of cognitive ability and driving ability would be largest in the adaptive training group, smaller in the non-adaptive training group and only minimal in the no-training control group (Brehmer et al., 2012; Holmes et al., 2009; Karbach et al., 2015; Klingberg et al., 2005; Klingberg et al., 2002; Lilienthal et al., 2013).

More specifically, based on previous studies, we expected (a) that the WM training would improve WM, but also attention and inhibition (Borella et al., 2013; Brehmer et al., 2012; Richmond et al., 2011), and (b) that the WM training would improve several specific measures of driving ability (e.g., speed control, lane position, gap acceptance while turning left, responses to road signs and crashes).

With regard to cognitive ability, after following an adaptive training, older people had a significantly larger improvement of WM, compared to older people following a non-adaptive training or no training. This improvement in WM after following a cognitive training specifically targeting WM is in line with previous research (Borella et al., 2013; Richmond et al., 2011). It is important to note that although, as indicated by Figure 2, there is a cross-over effect for WM between the adaptive training group and the non-adaptive training group, the hypothesis of a linear improvement was nevertheless confirmed. Although we found near transfer effects that are a requirement for far transfer effects (T. L. Harrison et al., 2013), we found no differential group improvement for the other cognitive functions. For attention, all groups improved, regardless of type of training, indicating a general test-retest effect. For inhibition, group means were in the same direction, but results were only marginally significant. A general test-retest effect for this measure is therefore also possible. These results are in line with learning theories that state that participants improve when performing a cognitive task for a second time (Boot et al., 2011; Collie et al., 2003). Moreover, these results are in line with recent studies indicating that cognitive training specifically improves only the cognitive function that was trained (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012).

With regard to driving ability, results indicated that for driving speed and reaction to stop signs group means were in the expected direction (i.e. largest improvement with adaptive training, smaller improvement with non-adaptive training and minimal improvement with no training), but results were only marginally significant. It has to be noted that for reactions to stop signs, although the hypothesis of a linear improvement was confirmed, unexpectedly the non-adaptive training group and no-training group deteriorated, showing a lower number of stops in the post-test than in the pre-test. The reason why these groups deteriorated remains unclear. It is known that older drivers typically fail to make a complete stop at stop signs and drive slower (McKnight, 1988). Interestingly, it has been argued that driving slower reflects a way to compensate for the decline in cognitive abilities (Fisher et al., 2011). Our result may be regarded as in line with this, as participants drove faster after improvement of their WM. We found no differential group improvement for the other driving measures. Whereas for gap acceptance, all groups improved, regardless of type of training, indicating a general test-retest effect, for SDLP, giving right of way and crashes, no improvements were found. Taken together, transfer of the improvement of WM to driving performance was only limited. This is in line with recent studies indicating an effect of training solely on the cognitive function being trained, and lack of transfer to daily life activities, like driving (Gaspar et al., 2012; Mayhew, Robertson, et al., 2014). Moreover, improvement of driving after WM improvement was expected for only a selection of driving measures based on recent research showing that different driving measures have different underlying cognitive abilities (Aksan et al., 2015; Anstey & Wood, 2011; Cuenen et al., 2016; Mullen et al., 2008). Possibly, in order to have an effect on more driving measures, a multifactorial cognitive training is necessary, (i.e., a training that includes tasks addressing a variety of cognitive abilities as used by Schmiedek et al. (2010) or a more direct type of a training targeting driving ability is necessary (e.g. a driving simulator training as used by Casutt, Theill, et al. (2014)).

These results illustrate the importance of investigating training effects on specific measures of driving ability, since summarized measures of driving ability do not provide a detailed enough view of training effects: whereas the training can have an effect on some aspects of driving, it is possible that it has no effects on other aspects of driving. Indeed, Cassavaugh and Kramer (2009) also only found that improvement was limited to one measure of driving ability (i.e., accelerator response time to lead-vehicle braking) after following a WM training. Consequently, the same training cannot necessarily be used as an intervention for all driving problems. Importantly, effective training programs are tailored to the individual or a group of individuals with common characteristics, targeting those specific abilities that are hampered. Hence, our results suggest that those older people that experience difficulty with speed control and responses to stop signs could benefit most from WM training.

## 5. LIMITATIONS AND FUTURE RESEARCH

Some limitations have to be noted. First, although the investigated training only caused improvements of WM and two driving measures, particularities of the aging population may be responsible for the lack of transfer effects (Lange & Süß, 2015). Although cognitive plasticity can be assumed even in old age, it is more constrained compared to that of younger people (Lange & Süß, 2015). Compared to training studies with younger people, training studies with older people have typically reported smaller transfer effects (Lange & Süß, 2015; von Bastian & Oberauer, 2014). In order to know whether the lack of transfer effects is due to the training or due to the target group, future research should investigate the transfer effects of this WM training in younger people. Since previous studies indicated the relation between WM and driving ability of younger drivers (Mäntylä, Karlsson, & Marklund, 2009; Ross et al., 2015), transfer effects of a WM training to aspects of driving ability of younger drivers can be expected. However, since older people are the fastest growing segment of the population and with age there is a decrease in abilities necessary for daily life activities like driving, there is a need for effective interventions for older people to ensure their quality of life. Future initiatives should be explored to attenuate declines in cognitive ability and driving ability. As for cognitive training, in a recent meta-analysis a group-based training consisting of maximum three sessions was advised (Lampit, Hallock, & Valenzuela, 2014).

Second, the present study only investigated immediate training effects, therefore the longer-term effects remain unclear. Future research should examine the sustainability of effects. Previous research found effects maintained for several months (Borella et al., 2013; Li et al., 2008).

Third, the training was conducted at home. Although this has several advantages, it reduces experimenter control (i.e., standard testing environment and procedures). Related to this limitation, although the no-training control group received no training, we cannot be sure that this group did not train their WM during the study. However, based on our results that WM improvement was minimal in the no-training control group, there were no indications that people trained their WM.

Fourth, we used a non-adaptive training group, that can be regarded as an active control group, who performs the same training as the adaptive training group but on a fixed low level. This was done to provide a conservative assessment of training effects, because the influence of various unspecific factors is attenuated (Brehmer et al., 2012; Shipstead et al., 2010; Zehnder et al., 2009). Although there are no indications that the non-adaptive training is less stimulating than the adaptive training, since the number of completed sessions is comparable (i.e., 23.05 sessions completed by participants in the adaptive training group and 23.63 sessions completed by participants in the non-adaptive training group), it might be interesting for future research to incorporate an active control group performing an equal amount of training time as the adaptive training group but on tasks that are not expected to improve cognitive abilities or driving abilities. This might help to further establish that the specific training under investigation, rather than any challenging training task, is directly related to improvements in cognitive and driving ability (Cassavaugh & Kramer, 2009).

Fifth, driving ability in the present study was investigated with a driving simulator. Although simulators have several advantages and positive evidence for simulator validity has been provided (Fisher et al., 2011), the present study should be replicated during real-world driving to bolster our conclusions. By replicating the study during real-world driving, the practical relevance of the results can be investigated. Looking at the results, it seems that the adaptive training group (the group who improved the most compared to the other groups) drove 3.67 km/h faster and stopped 0.13 times more at a stop sign in the driving simulator after following the training. However, it has to be noted that for the driving simulator, there is evidence for relative validity, not for absolute validity. This means that the direction of change of a simulated driving measure is in the same direction as a corresponding driving measure in the real world, but does not produce the same numerical change. As a consequence, investigating the effect of the training on driving in real-world conditions would cause an increase in speed and number of complete stops, however, the amount of increase can be different than observed in the simulator (Fisher et al., 2011).

Finally, the present study investigated the effect of a WM training on specific measures of driving ability under normal driving circumstances (e.g., not during car-following) while encountering situations that are known to be difficult for older drivers (i.e., intersections). In order to guide future initiatives to increase driving safety of older people, future research should investigate other measures related to driving ability, e.g., gaze behavior. In addition, it would be interesting to further investigate the reasons behind certain driving behaviors. In the present study, participants did not always follow the traffic rules (e.g., not making a complete stop at a stop sign). This could be due to an error or due to a violation of the traffic rule.

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# CHAPTER 4

*Human factors. Ready for submission.*

## The effect of driving simulator based training on specific measures of driving ability of older drivers.

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## Abstract

Since driving is important for quality of life, it is important to keep older drivers safe drivers for as long as possible. Therefore, this study investigated whether driving simulator based training can enhance specific measures of driving ability of older drivers. Forty older drivers participated in the study, but due to drop-out, 30 participants (mean age 69.93) remained in the sample. Participants were randomly assigned to an experimental (N=15) or a control group (N=15). During the training session, participants in the experimental group received driving-specific feedback on their driving ability, while participants in the control group received general information about traffic and conducted a traffic-related quiz. During the pre-test and post-test, specific measures of driving ability were assessed in the driving simulator (i.e., mean driving speed, standard deviation of lateral position, complete stops at stop signs, giving right of way and crashes). Results indicated that both groups had improved lateral control and less crashes after the training session. In addition, participants in the experimental group gave more right of way after the training session and participants in the control group drove faster after the training session. These results demonstrated that driving multiple times in a simulator, improves performance on some measures of driving ability like lateral control. However, in order to improve on measures of driving ability like giving way, driving-specific feedback is necessary.

## Key words

Older drivers; Driving simulator; Training; Feedback

# 1. INTRODUCTION

The number of older drivers is increasing. Previous research has indicated that older drivers have problems with some driving situations, e.g., giving right of way at intersections (Eby et al., 2009). If these problems are tackled by training, driving cessation, that leads to a decline of out-of-home activities, social isolation and even depression (Marottoli et al., 1997), can be postponed. Several studies have investigated the effect of cognitive training on driving ability of older people since cognitive abilities are important for driving ability and are trainable, indicating considerable plasticity even at old age (Kramer & Willis, 2002). These studies have shown that cognitive training can improve cognitive ability (Ball et al., 2002; Ball et al., 2007; Karbach & Kray, 2009; Rebok et al., 2014; Schmiedek et al., 2010) and even driving ability of older people (Ball et al., 2010; Ball et al., 2013; Cassavaugh & Kramer, 2009; Edwards, Delahunt, et al., 2009; Edwards, Myers, et al., 2009; Roenker et al., 2003). However, the number of studies showing transfer effects from cognitive training to driving ability are limited. As a consequence, there is debate about the transfer effects of cognitive training (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012). Several studies found improvement on the trained tasks after following cognitive training, but not on untrained tasks (Gaspar et al., 2012; Lange & Süß, 2015; Mayhew, Robertson, et al., 2014; Zinke et al., 2012). According to the law of identical elements and the practice-specificity approach of learning abilities, the best training conditions are those allowing learning of the same underlying processes that will be used in the transfer task (Schmidt & Lee, 2005; Thorndike & Woodworth, 1901). Therefore, if the final purpose is to transfer to the road, they must be acquired in a driving-specific context. Hence, a training more directly targeting driving ability might be more successful in improving driving ability (Gaspar et al., 2012; Mayhew, Robertson, et al., 2014). Indeed, recent research has investigated the effect of driving simulator-based training in older drivers and found promising on road effects on driving ability after training (Casutt, Theill, et al., 2014; Lavallière et al., 2012; Roenker et al., 2003; Romoser & Fisher, 2009). Casutt, Theill, et al. (2014) compared the effects of driving simulator based training and cognitive training on older drivers' overall driving score during an on-road test and found improvements only in those who followed driving simulator based training. Romoser and Fisher (2009) and Lavallière et al. (2012) compared the effects of driving simulator based training with and without feedback on older drivers' visual search. They found that the visual search of participants who received driving-specific feedback improved by (nearly)

100% after the training, while there was no improvement in participants who did not receive feedback.

Interestingly, these studies investigated the effect on overall driving ability (Casutt, Theill, et al., 2014) or on only one measure of driving abilitiy (i.e., visual search, Lavallière et al. (2012) and Romoser and Fisher (2009)). Although overall measures of driving ability do incorporate different aspects of driving, they do not provide a detailed enough view of driving ability. Since driving is a complex task, it can be expected that not all driving measures will be affected by a training. Indeed, Roenker et al. (2003) investigated the effect of driving simulator based training on specific measures of on-road driving ability of older drivers and found that participants, with a decreased useful field of view, showed improvements in turning into the correct lane and proper signal use. They found no improvement in other driving measures like maintaining lane position and speed, accelerating and decelerating smoothly and selecting gaps.

Given that older drivers are the fastest growing segment of the driving population and that it is important to keep older drivers safe drivers for as long as possible, it is suprising that only a limited number of studies investigated the effect of driving simulator based training on the driving ability of older drivers (Casutt, Theill, et al., 2014; Lavallière et al., 2012; Roenker et al., 2003; Romoser & Fisher, 2009). Therefore, the aim of the present study was to investigate whether driving simulator based training leads to an improvement of driving ability of older drivers. Since previous research found improvement on solely a few measures of driving ability (Roenker et al., 2003), we hypothesized that driving simulator based training will improve performance on some driving measures, but not on all. Therefore, contrary to an overall driving measures or solely one specific measure of driving ability, several specific measures of driving ability were assessed like mean driving speed, standard deviation of lateral position, complete stops at stop signs, giving right of way and crashes. Since previous research found beneficial effects of providing driving-specific feedback, we randomly assigned participants to a group with driving-specific feedback (i.e., experimental group) and a group without driving-specific feedback (i.e., active training group). Although we expected larger improvements in the group receiving driving-specific feedback, we also expected improvements in the group not receiving driving-specific feedback, since both groups actively trained in the simulator and learning theories state that participants' performance improves with practice (Boot et al., 2011; Collie et al., 2003).

# 2. METHOD

## 2.1. Participants

Participants aged 65 years or older who were still active drivers, had not had a stroke or sequel in the last six months and had a Mini-Mental State Examination (MMSE) score of 25 or above were recruited. The MMSE is a brief test that examines the mental status of an individual. It comprises items assessing orientation to time and place, registration and recall, attention, language and constructional ability (Folstein et al., 1975). Possible scores range from 0 to 30, with higher scores reflecting better mental status. Recruitment occurred through the community via (local) media and via oral presentations and flyers distributed in senior associations. Given the possibility of simulator sickness, participants were closely watched for signs of this type of sickness. If a participant showed any signs of simulator sickness, the simulation was immediately terminated and the participant was excluded from further participation. In total, forty participants volunteered. However, ten participants dropped out due to simulator sickness (n=9) or personal circumstances (n=1). Participants were randomly assigned to an experimental (N=15) or a control group (N=15). The study was approved by the ethical review committees of Hasselt University

## 2.2. Driving simulator

The experiment was conducted on a driving simulator with STISIM version 3 running as software. a force-feedback steering wheel, an instrumented dashboard, brake and accelerator pedals and with a 135 degree field of view. The visual environment of this simulator was presented on three computer screens (each with 4800 x 900 pixels resolution and 60Hz refresh rate). Two practice rides served to get acquainted with the driving simulator and preceded the main ride. In the first practice ride (3 km) almost no curves, no signs, and no other road users were introduced to acquaint drivers with the experience of driving in a simulator (i.e., speed, lane position). The speed limit increased from 50 km/hour to 70 km/hour to 90 km/hour to 120 km/hour. The second practice ride (3 km) consisted solely of an inner-city section (50 km/hour). Turning left at an intersection and changing lanes in order to pass a road obstacle were introduced to acquaint drivers further with the experience of driving in a simulator (i.e., steering, signal use, looking behavior). The main ride (11 km) consisted of inner-city (50 km/hour) and outer-city sections (70 km/hour and 90 km/hour). The ride did not contain any curves in order to decrease the risk of simulator sickness (Romoser, 2008). The ride included several situations that are known to be difficult for the older driver, for example right of way decisions (i.e., making a complete stop at a stop sign and giving right of way). These situations were also trained in the simulator during the training session. Importantly, in the pre-test and post-test main ride, participants encountered situations that were identical (i.e., directly trained) and situations that were comparable though not identical (i.e., indirectly trained) to situations in the training session. For example, during the training session they encountered a two-lane intersection with a stop sign, while during the pre- and post-test, they also encountered a four-lane intersection with a stop sign.

A total of five specific driving measures were considered for analyses: mean driving speed (km/h), standard deviation of lateral lane position (SDLP, m), crashes (number), making a complete stop at a stop sign (yes (coded as 1) or no (coded as 0)) and giving right of way (yes (coded as 1) or no (coded as 0)). All driving measures were averaged measures, with the exception of crashes where the total number of crashes during the ride was calculated. Crashes occurred with road hazards (i.e., pedestrians suddenly crossing the road without using a pedestrian crossing). Mean driving speed and SDLP were measured across separate road segments without any events (Trick et al., 2010). Left turn gap acceptance decision is defined as the time headway between two vehicles on the major road into which a left-turn driver chooses to turn (Jongen et al., 2012; Yan et al., 2007).

## 2.3. Driving simulator based training

During the training session, participants of the experimental group viewed a replay of their own ride that they made during the pre-test. During this replay, they received both reinforcing and corrective feedback from the researcher tailored to the participant’s (un)safe driving behavior during specific traffic situations. In addition, they saw a replay of a comparable ride including pre-recorded commentaries from a certified driver instructor. These were commentaries on how to react best in the specific driving situations (e.g., when entering a four lane road one needs to drive in the lane at the right side). Participants of the control group received general traffic information about possible decreases in functional abilities (i.e., cognitive, motor and visual abilities) due to aging, and information about driving speed, following distance, etc. Afterwards, they filled in a traffic-related quiz. At the end, they received feedback about the correct answer on the questions of the quiz including a brief explanation. Finally, participants of the control group also drove in the driving simulator to assure that participants of both groups had equal experience in the driving simulator. During driving in the simulator, they encountered several situations that are known to be difficult for the older driver, for example right of way decisions (i.e., making a complete stop at a stop sign and giving right of way).

### 2.4. Procedure

First, participants gave informed consent. Then, all participants were screened for cognitive status with the MMSE. After successful completion of the pre-test (i.e., no simulator sickness), participants were randomly assigned to either an experimental group (n=15) or a control group (n=15). During the pre- and post-test, participants drove in the driving simulator. In between, participants in the experimental and control group completed driving simulator based training. After the post-test, participants received a gift certificate. Order of the driving situations within a scenario was counterbalanced between and within participants during the pre- and post-test. A one-week interval was set between pre-test and training, and between training and post-test.

### 2.5. Data analysis

The data was processed using SPSS. Before analyses, outliers were treated for each variable. Outliers larger than three standard deviations were replaced with the maximum score within the three standard deviation range (Wood et al., 2008). Univariate analyses of variance (ANOVA) were conducted to check for pre-test differences between the two groups on age, MMSE, the three cognitive measures (i.e., WM, attention and inhibition) and the five driving measures (i.e., mean driving speed, SDLP, complete stops at stop signs, giving right of way, and crashes). Repeated measures ANOVA were conducted for each of the dependent measures. The specific driving measures served as the dependent variables, Test (i.e., pre-test, post-test) and Situations (i.e., directly trained, indirectly trained) served as within-subjects variables, and Group (experimental group, control group) served as between-subjects variable. For one driving measure (i.e., crashes) the within-subjects variable 'Situations' was not applicable. The Greenhouse–Geisser epsilon correction factor was applied to compensate for possible effects of non-sphericity in the measurements compared. Only the corrected F and probability values are reported. An alpha level of .05 was maintained for all statistical tests. Effect sizes were reported with Cohen's d. A Cohen's d of 0.2 indicates a small effect size, 0.5 indicates a medium effect size, and 0.8 indicates a large effect size.

## 3. RESULTS

### 3.1. Differences at pre-test

See Table 1 for the descriptive statistics of the demographic measures and driving measures for the pre-test and post-test, separately for each group. Participants had a mean age of 69.93 years and on average had a MMSE score of 28.80/30. At pre-test, participants did not significantly differ in Age, MMSE, or on the majority of driving measures (i.e., speed, SDLP and crashes (all p-values ≥.10)). There was a marginally significant difference between groups on giving right of way (F(1,28)=4.27, p=.05), as participants in the control group gave more right of way than those in the experimental group. For one driving measure (i.e., making a complete stop at a stop sign), there was a marginally significant difference between groups (F(1,28)=3.57, p=.07), as participants in the experimental group made more complete stops at a stop sign than those in the control group.

**Table 1.** Means and standard deviations (SDs) for the demographic measures and driving measures, in the two groups for the pre-test and post-test.

| **Measure** | **Pre-test** | | | | **Post-test** | | | |
|---|---|---|---|---|---|---|---|---|
| *Demographic measures* | *EG Mean (SD)* | | *CG Mean (SD)* | | *EG Mean (SD)* | | *CG Mean (SD)* | |
| Age (years) | 71.27 (5.12) | | 68.60 (3.11) | | n.a. | | n.a. | |
| MMSE (number) | 28.53 (1.25) | | 29.07 (0.96) | | n.a. | | n.a. | |
| *Driving measures* | *EG Mean (SD)* | *CG Mean (SD)* | *EG Mean (SD)* | *CG Mean (SD)* | *EG Mean (SD)* | *CG Mean (SD)* | *EG Mean (SD)* | *CG Mean (SD)* |
| | Directly trained situations | | Indirectly trained situations | | Directly trained situations | | Indirectly trained situations | |
| Mean driving speed (km/h ) | 56.43 (6.26) | 59.54 (5.26) | 59.87 (5.14) | 62.30 (4.09) | 56.70 (5.99) | 60.04 (5.30) | 58.70 (4.55) | 65.58 (4.42) |
| SDLP (m) | 0.19 (0.06) | 0.20 (0.06) | 0.20 (0.12) | 0.21 (0.07) | 0.17 (0.03) | 0.17 (0.04) | 0.15 (0.04) | 0.17 (0.04) |
| Complete stops at stop signs (0= no/ 1=yes) | 0.73 (0.46) | 0.60 (0.51) | 0.73 (0.46) | 0.40 (0.51) | 0.73 (0.46) | 0.53 (0.52) | 0.80 (0.41) | 0.60 (0.51) |
| Giving right of way (0=no/1=yes) | 0.80 (0.41) | 0.73 (0.46) | 0.53 (0.52) | 0.87 (0.35) | 1.00 (0.00) | 0.94 (0.22) | 1.00 (0.00) | 0.94 (0.22) |
| Crashes (number) | 0.93 (0.88) | 0.93 (1.22) | n.a. | | 0.07 (0.26) | 0.13 (0.52) | n.a. | |

n.a. = not applicable

### 3.2. Repeated measures ANOVA

See Table 2 for the results of the repeated measures ANOVA. There was a significant main effect of Test for SDLP and crashes, indicating that all participants had an improved lateral control and had less crashes after the training session. Cohen’s d was 0.74 for SDLP, indicating a medium effect, and 1.09 for crashes, indicating a large effect. In addition, there was a significant three-way interaction between Test, Group and Situations for mean driving speed. This interaction was further investigated. There was only a significant main effect of Test for those in the control group during situations that were not trained in the simulator during the training session, indicating a higher driving speed at post-test compared to pre-test (F(1,14)=6.05, p=.028). Cohen’s d was 0.77, indicating a medium effect. In addition, there was a significant three-way interaction between Test, Group and Situations for giving right of way. This interaction was further investigated. There was only a significant main effect of Test for those in the experimental group during situations that were not trained in the simulator during the training session, indicating more giving right of way at post-test compared to pre-test (F(1,14)=12.25, p=.004). Cohen’s d was 1.29, indicating a large effect.

**Table 2.** Corrected F and probability values per driving measure.

| **Driving measure** | ***F*** | ***p*** |
|---|---|---|
| Mean driving speed | | |
| Test | 0.77 | .39 |
| Situations | 31.43 | .00** |
| Test x Group | 2.02 | .17 |
| Test x Situations | 0.60 | .45 |
| Situations x Group | 1.38 | .25 |
| Test x Group x Situations | 5.84 | .02* |
| Group | 6.68 | .02* |
| SDLP | | |
| Test | 8.99 | .006** |
| Situations | 0.06 | .80 |
| Test x Group | 0.001 | .98 |
| Test x Situations | 0.49 | .49 |
| Situations x Group | 0.24 | .63 |
| Test x Group x Situations | 0.06 | .81 |

| | | |
|---|---|---|
| Group | 0.56 | .46 |
| Complete stop at stop signs | | |
| Test | 0.29 | .59 |
| Situations | 0.11 | .75 |
| Test x Group | 0.03 | .86 |
| Test x Situations | 0.84 | .37 |
| Situations x Group | 0.97 | .33 |
| Test x Group x Situations | 0.30 | .59 |
| Group | 4.18 | .05* |
| Giving right of way | | |
| Test | 15.68 | <.001** |
| Situations | 0.56 | .46 |
| Test x Group | 2.48 | .13 |
| Test x Situations | 0.56 | .46 |
| Situations x Group | 5.04 | .03* |
| Test x Group x Situations | 5.04 | .03* |
| Group | 0.22 | .65 |
| Crashes | | |
| Test | 24.49 | <.001** |
| Test x Group | 0.03 | .87 |
| Group | .01 | .91 |

*<.05, **<.01
n.a. = not applicable

## 4. DISCUSSION

This study aimed to investigate whether driving simulator based training can improve specific measures of driving ability in older drivers. The results showed that there was an improvement of SDLP and crashes after the training in both groups. Hence, as expected and in line with learning theories, participants' performance improved by driving multiple times in a driving simulator. Surprisingly, the results showed that driving simulator based training without driving-specific feedback (i.e., the control group) leads to a change in mean driving speed. We did not expect a change in driving performance in the control group, without a change in driving performance in the experimental group since this group received no driving-specific feedback and previous research indicated that feedback is important in order to have an effect (Lavallière et al., 2012; Romoser & Fisher, 2009). Interestingly, the change occurred only in situations that were not trained in the simulator. This might be due to the general information about traffic this group received during the training session before driving in the simulator. Possibly, the increase in mean driving speed can be attributed to the fact that during this general information, it was highlighted that "it is not only important not to exceed the speed limit, but also important not to drive too slow since this can hinder other road users". Finally, the results showed that driving simulator based training with driving-specific feedback (i.e., the experimental group) leads to an improvement of giving right of way. Since previous research demonstrated the importance of driving-specific feedback (Lavallière et al., 2012; Romoser & Fisher, 2009), the improvement is probably due to the feedback participants received during the training session before driving in the simulator (i.e., when driving in inner-city sections you need to give right of way). Interestingly, the improvement occurred only in situations that were not trained in the simulator (e.g., a four-lane intersection with a stop sign). When comparing the situations that were trained directly and indirectly in more detail we have to conclude that the situations that were not trained directly could be perceived as more complex (e.g., four-lane intersection vs. two-lane intersection). Hence, the situations that were not trained in the simulator possibly received more attention since these were perceived as more complex. However, since we did not measure this, we can only speculate about this reason.

Taken together, driving simulator based training had an effect on some, but not all driving measures. This is in line with previous research who also found improvements on only some driving measures after following driving simulator based training (Roenker et al., 2003). Possibly, given the complexity of driving, some aspects of driving are more difficult to train than others. Since training often has an influence on some but not all driving measures the training should be offered to participants having difficulties with these driving measures. The finding that training does not improve all driving measures is not problematic since drivers who can benefit from training merely have problems with only a selection of driving measures instead of problems with almost all driving measures where driving cessation should be more appropriate than training. However, it is important that the training is tailored to the needs of the individual, tackling especially those aspects that are needed the most. Also drivers who do not yet experience difficulties with driving can benefit from training since the driving environment is constantly changing to conditions of modern life.

## 5. LIMITATIONS AND FUTURE RESEARCH

Some limitations have to be noted. First, both groups improved on SDLP and crashes. In order to distinguish training effects from test-retest effects, future research should incorporate a no-training control group. Second, although driving-specific feedback in the current study seems to have beneficial effects on giving right of way, it is not clear whether the benefits are due to the customized feedback and/or due to the pre-recorded commentaries of the certified driving instructor. Future research should therefore not only evaluate the programs overall effect, but also evaluate the effect of the separate components. This should not only been applied to driving simulator based training, but also to other types of driver training, since, although simulators offer several advantages, due to simulator sickness, not all drivers can be trained in a driving simulator (Fisher et al., 2011). In addition, the present study included solely one training session, while other studies incorporated several training sessions (i.e., ten sessions, Casutt, Theill, et al. (2014)). Therefore, future research should investigate the number of training sessions. Third, the present study only investigated immediate training effects. As a consequence, the longer-term effects remain unclear. Future research should therefore examine the sustainability of effects. Interestingly, previous studies investigating the effects of driving simulator based training on the driving performance of older drivers found effects maintained for two years (Romoser, 2012). Fourth, the possibility of a self-selection bias has to be kept in mind. Especially those drivers that think of themselves as good drivers could be more willing to volunteer to participate in a study investigating driving performance. Indeed, the current sample is not representative for the whole population of older drivers, since they were all cognitively healthy as indicated by the scores on the MMSE. As a consequence, results of this study in some way could be an underestimation of the program’s true effectiveness. Finally, the effects of driving simulator based training were investigated with a driving simulator. Although simulators have several advantages and positive evidence for simulator validity has been provided (Fisher et al., 2011), the present study should be replicated during real-world driving to bolster our conclusions. Interestingly, several studies investigating the effect of driving simulator based training found improvements on on-road driving performance (Casutt, Theill, et al., 2014; Lavallière et al., 2012; Romoser & Fisher, 2009).

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# CHAPTER 5

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## Evaluating the effectiveness of a post-license education program for young novice drivers in Belgium.

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## Abstract

The disproportionately large number of traffic accidents of young novice drivers highlights the need for an effective driver education program. The Goals for Driving Education (GDE) matrix shows that driver education must target both lower and higher levels of driver competences. Research has indicated that current education programs do not emphasize enough the higher levels, for example awareness and insight. This has raised the importance of insight programs. On the Road (OtR), a Flemish post-license driver education program, is such an insight program that aims to target these higher levels. The program focus is on risky driving behavior like speeding and drink driving. In addition, the program addresses risk detection and risk-related knowledge. The goal of the study was to do an effect evaluation of this insight program at immediate posttest and 2 months follow-up. In addition, the study aimed to generalize the results of this program to comparable programs in order to make usable policy recommendations. A questionnaire based on the Theory of Planned Behavior (TPB) was used in order to measure participants' safety consciousness of speeding and drink driving. Moreover, we focused on risk detection and risk-related knowledge. Participants (N=366) were randomly assigned to a baseline – follow-up group or a post-test – follow-up group. Regarding speeding and driving driving, we found OtR to have little effect on the TPB variables. Regarding risk detection, we found no significant effect, even though participants clearly needed substantial improvement when stepping into the program. Regarding risk-related knowledge, the program did result in a significant improvement at posttest and follow-up. It is concluded that the current program format is a good starting point, but that it requires further attention to enhance high level driving skills. Program developers are encouraged to work in a more evidence-based manner when they select target variables and methods to influence these variables.

## Key words

Young novice drivers; Education; Insight program; Evaluation

## 1. INTRODUCTION

Compared to other age groups, young novice drivers are involved in a disproportionately large number of traffic accidents (Evans, 2004; Hatakka et al., 2003; Kweon & Kockelman, 2003; Rhodes et al., 2005). Compared to older experienced drivers, the accident risk of young novice drivers (18-24 years) is up to twice as high (EC, 2012). In the European Union (EU), 17% of the traffic victims are young adults (as a driver as well as a passenger), while young adults represent only 8.9% of the total population.

The first few months of solo-driving are critical, posing the greatest risk of collision for novice drivers, but also for their passengers and other road users (Mayhew et al., 2003). For each young novice driver who dies in a traffic accident, 1.3 other individuals give life (EC, 2012). Young novice drivers have mainly single-vehicle accidents, head-on collisions and accidents at intersections (Clarke, Ward, Bartle, & Truman, 2006; W. Harrison, Triggs, & Pronk, 1999; Laapotti & Keskinen, 1998; McKnight & McKnight, 2003). Their high accident rates could be contributed to the fact that they more often expose themselves to dangers than older, more experienced drivers (e.g., driving with an excessive speed and driving under influence of alcohol). Underlying causes for this exposure can be their lack of driving skills due to inexperience, but also the propensity to take and accept risks due to their youthfulness and pressure exerted by peers (Keating, 2007). According to McKnight and McKnight (2003), young novice drivers are more often clueless rather than careless when they take risks.

## 2. THEORETICAL BACKGROUND

### 2.1. Current trends and views on education and training

The European Commission has the ambitious goal of reducing the number of deaths on the road in 2020 by half against the number in 2010 (EC, 2001). In order to achieve this goal, several safety efforts are initiated. These efforts can be divided into engineering, education and enforcement (“the three E’s”). With respect to education, the GADGET project developed a matrix to determine which aspects certainly must be included in driver education. This matrix, known as the Goals for Driving Education (GDE) matrix, provides a framework for defining the detailed competencies needed to be a safe driver. The matrix is based on the assumption that the driving task can be decomposed into a hierarchy of competences and skills. The idea of the hierarchical approach is that the demands, decisions and behavior on a lower level are influenced by the abilities and preconditions on a higher level. The matrix entails four levels. The lowest level, skills for vehicle maneuvering, includes the skills needed to control and operate the vehicle. The second lowest level, mastering traffic situations, includes speed, knowledge of traffic rules and interaction with other road users. At the second highest level, i.e., goals and context of driving, the focus is on why, where, when and with whom the driving is carried out. The highest level entails goals for life and skills for living, and thus refers to the person’s self including the driver’s perceptions of how to behave in traffic situations (EC, 2009; Porter, 2011). The matrix has been instrumental in various EU projects where the primary focus was on driving education and training such as GADGET (Siegrist, 1999), DAN (Bartl, 2000), BASIC (Hatakka et al., 2003), Advanced (Sanders, 2003), NovEV (Sanders & Keskinen, 2004), and HERMES (Bartl, 2009). Benchmarking this matrix with countries’ current practices with respect to driver licensing and education in Europe, U.S. (McKnight, 2001) and Australia (Senserrick & Haworth, 2005), leads to the conclusion that the focus is primarily on the two lower levels of driver behavior. Hence driver education programs fail to appropriately address the two higher levels of behavior.

Education generally covers a broader range of topics than training and is carried out over a longer period. Therefore, driver training can be viewed as a specific component of driver education. Education makes use of the insight approach which addresses poor, driving-related attitudes and motivational orientations associated with greater risk-taking behavior including overconfidence, overestimation of skills, and underestimation of risk. In other words, it addresses the highest level of the GDE-matrix. This approach intends to raise awareness and improve insight into factors that contribute to road trauma (Senserrick & Haworth, 2005). Rather than focusing on physical skills, insight programs focus on attitudinal-motivational skills (Senserrick & Swinburne, 2001). They typically address the intrinsic motivation of people to prevent danger (instead of coping with it) and to prioritize the safety of oneself as well as that of others above all when participating in traffic.

Insight-based education programs have flourished enormously over the last few years (Carcary et al., 2001; Kuiken & Twisk, 2001; Molina et al., 2007; Nolén et al., 2002; Nyberg & Engström, 1999; Senserrick & Swinburne, 2001). Especially popular are post-license (or second phase) education programs. These are provided several months after the driving test has been passed, since novice drivers by that time have encountered new traffic situations, have started to develop their own driving style, and regard car driving as a means to an end (e.g., go to a party) rather than as a meaningful activity in itself (de Craen et al., 2005). Beanland, Goode, et al. (2013) highlight that these programs either target (lower-order) procedural skills or (higher-order) cognitive skills. Teaching procedural skills includes teaching advanced vehicle handling skills such as advanced braking, maneuvering and skid control. In contrast, teaching cognitive skills includes teaching the broader driving context, particularly anticipating or avoiding dangerous situations.

## 2.2. Evaluation

Despite the rising popularity of the above mentioned education programs, there is no clear view on their effectiveness (Beanland, Goode, et al., 2013). Evidence implies that teaching cognitive skills has the potential to reduce accident risk, but this has not been directly tested (Beanland, Goode, et al., 2013). Overall, it is concluded that rigorous evaluation studies of driver education programs to find out effective program elements and inform future program development are indispensable (Delhomme et al., 2009; Dragutinovic & Twisk, 2006)

Since insight programs focus on attitudinal-motivational skills, evaluations of such programs are often done with the help of social psychological theories, in particular the Theory of Planned Behavior (TPB; Ajzen (1985)) and its successor the Reasoned Action Approach (RAA; Fishbein and Ajzen (2010)). The TPB is one of the empirically most supported behavioral theories and has been validated in diverse research domains (Godin & Kok, 1996; Stutton, 1998). TPB and RAA help to understand the specific variables that need to be influenced in order to obtain behavior change. The theories postulate that behavioral intention, the most proximal determinant of behavior, is determined by three conceptually independent variables: attitude, subjective norms and perceived behavioral control. The attitude toward the behavior is determined by beliefs about outcomes of performing the behavior under study. Subjective norms, also called perceived social expectations, refer to the beliefs that important individuals or groups have about the behavior. Perceived behavioral control (PBC), which is highly similar to Bandura’s conceptualization of self-efficacy (Fishbein & Ajzen, 2010), refers to the subjective probability that a person is capable of executing a certain course of action. This variable influences behavior both directly and indirectly. Some authors have suggested other variables to be added to the model in addition to the three described above, for example personal norms (Godin, Fortin, Michaud, Bradet, & Kok, 1997) and past behavior (Sheeran & Orbell, 1999).

## 3. ON THE ROAD (OTR)

OtR is a Flemish post-license driver education program. It is positioned and promoted as an insight program with a focus on cognitive skills and motivational aspects. Yet, a more detailed analysis of the program content reveals the OtR intervention cannot be qualified as an insight-only program. Indeed, as can be derived from Table 1, the OtR program also addresses lower-order procedural skills (such as emergency braking, seating position and steering wheel handling) and in terms of teaching style, the classic 'instructive' approach still prevails over a more 'coaching' oriented approach. The first edition of OtR started in 2007. The program is organized by the Flemish Foundation for Traffic Knowledge and the Flemish Automobile Association and is subsidized by the Flemish Ministry of Transportation. The Flemish network of local driving schools has adopted the program, hence courses are implemented by experienced driving school instructors. The program focuses on young novice drivers. As such, participants with a maximum age of 25 years can take part. The program is not compulsory. Young novice drivers who are interested in this program register through a website (http://www.ikvolgontheroad.be/) and give their preference for a certain location and day. The program costs 20 euro and takes three and a half hours. At the end of the program, participants receive a certificate of attendance, by means of which they can get reduction on their car insurance. There is a maximum of 15 participants per session and 1000 participants per year.

Promoting a preventive (defensive) driving style is the main objective of the course. It is about anticipating danger and in case dangerous situations are not preventable, coping safely with them. Examples of discussed topics are driving under influence and negative peer pressure and ways to avoid or cope with these circumstances (e.g., appointing a designated driver, learning resistance skills). In general, the program consists of 5 components: classroom session, practical session on an exercise area, on road drive, group discussion, and follow-up feedback through mail. A detailed overview of OtR is presented in Table 1.

**Table 1.** Description of the training program.

| **Program components** | **Methods & strategies** | **Content** |
|---|---|---|
| PART 1: 1h<br>Classroom<br>1 instructor | Interactive lecture:<br>• The instructor mainly is a moderator. The instructor raises questions in a structured fashion and then guides participants in finding answers themselves through the confrontation of different opinions with each other (brainstorming).<br>• In addressing unsafe behaviors, the instructor tries to objectify as much as possible the true risks. For instance, with respect to speeding, the increased chance of being unable to avoid a collision as well as the increased severity of the impact of a collision is demonstrated by means of calculating stopping distances and through discussing the kinematic aspects of the impact of a collision.<br>• The instructor supports discussions with slides, videos, and a course map. | Speeding<br>Seatbelt use<br>Impaired driving<br>Fatigue<br>Aggression |
| PART 2: 1h<br>Exercise track<br>5 instructors | Active learning (learning by doing):<br>• The instructor always starts from the participant's own actual experience, hence the instructor does not 'set the good example' first.<br>• The instructor then stimulates participants to reflect and comment upon each other's experience. | Seating position<br>Handling steering wheel<br>Emergency brake |
| PART 3: 1h<br>On road<br>5 instructors | Verbal feedback:<br>• Instructors are mainly 'observers' giving verbal feedback to participants while they are driving on road.<br>• Participants are free to decide on which trajectory to follow which leaves them the initiative to take decisions themselves on where to go and what to do.<br>• Special attention is devoted to where to allocate attention to in complex situations (such as roundabouts, intersections, dangerous curves etcetera). Instructors try as much as possible to let participants themselves identify the 'where to expect danger' zones instead of explicitly telling them where to look at. Participants however are not stimulated to actively comment their own driving style or risk detection strategies. | Driving style<br>Risk detection |

|  |  |  |
|---|---|---|
| PART 4:<br>30min<br>Classroom<br>5 instructors | Group discussion :<br>• Participants evaluate their own driving style as well as that of their fellow group members.<br>• Instructors trigger participants in these assessments by means of challenging questions rather than accentuating themselves what went good and what went wrong. | Peer- and self-assessment |
| PART 5:<br>e-mail | Individualized feedback:<br>• Over the first three weeks after program attendance, participants on a weekly basis receive a mail with personalized feedback on behalf of the instructor that accompanied them. This is mainly intended as a reminder of things to keep in mind. The feedback was tailored to the individual, hence not all participants received the same feedback. | Do’s and don’ts |

## 4. AIMS OF THE STUDY

The aim of the study was to empirically evaluate the immediate and extended effect of the Flemish education program ‘On the Road’ (OtR). The study focused on psychosocial variables of risky driving behavior, i.e., speeding and drink driving, risk-related knowledge and risk detection. The study aimed to answer two research questions: ‘Is there an immediate OtR effect on psychosocial variables of speeding and drink driving, risk-related knowledge and risk detection?’ and ‘Is there an OtR effect on these measures two months after session attendance?’. Moreover, the study aimed to generalize the results of this program to comparable programs in order to make usable policy recommendations.

## 5. METHODOLOGY

### 5.1. Questionnaire

A questionnaire based on the content of OtR and TPB was developed. It consisted of five parts. The first two parts consisted of questions about speeding and drink driving. Thirteen variables were measured with questions about speeding. These variables consisted of beliefs, descriptive norm, injunctive norm, personal norm, risk perception, self-efficacy, past behavior and behavioral intentions. The same variables were measured using questions about drink driving. These psychosocial variables were questioned by multiple items in order to increase the reliability and validity of the questionnaire. All questions had a 7-point Likert scale format going from totally disagree to totally agree. Higher scores reflect more positive concerns with regard to traffic safety (see Table 2 for item examples).

The third part of the questionnaire measured risk detection. This part included 4 pictures of different traffic situations (see Figure 1). Participants had to indicate in the picture where there was potential danger. These situations as well as the answering procedure were derived from the literature (Fisher et al., 2002; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Pradhan et al., 2005) and analyzed and validated by an independent expert. Scores on the 4 pictures were summarized into one average risk detection score (range 0-4.25).

The fourth part of the questionnaire consisted of 10 true-false questions based on the course materials used to test risk-related knowledge (i.e., if I drive 100 km/h, my braking distance is 100 m). Scores were recoded into 1 = correct and 0 = incorrect and then summed into one risk-related knowledge score (range 0-10).

The final part of the questionnaire consisted of questions about program reception (i.e., would you recommend OtR to others) and background variables consisting of age, gender, licensure and accident involvement.

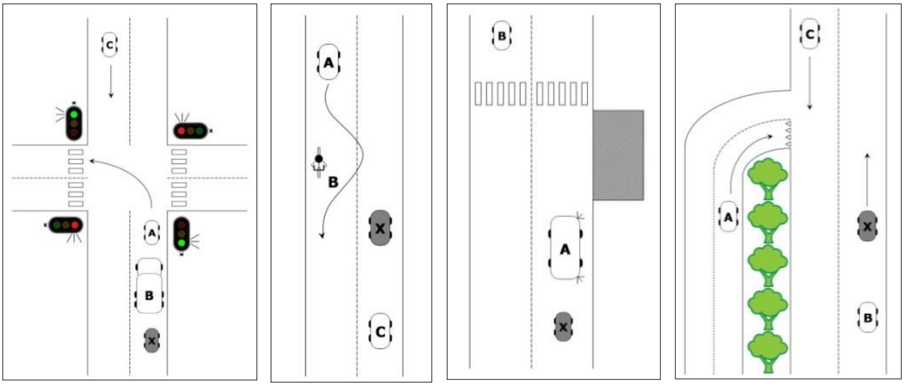

**Figure 1.** Risk detection pictures.

## 5.2. Design and procedure

The evaluation took place during the second edition of the program (December 2008 – September 2009). Participants voluntarily participated in the evaluation study. Those who filled in both questionnaires (first and second measurement) could win one out of ten film tickets or a Global Positioning System (GPS) through a lottery where the experimenters randomly assign the prizes to eleven participants.

Because of the restricted time available for measurements and the worry expressed by the program organizers that sending a questionnaire upon registration would put potential participants off and thus lower the total number of participants in the program, we were not able to use a fully controlled experimental design with random assignment and pre- and posttests in both the intervention group and the control group. Instead we adopted a quasi experimental design that in which participants were randomly assigned to a baseline – follow-up group or a post-test – follow-up group on the day of participation in the program (see Figure 2). Both groups were twice measured with a two months gap. The first measurement took place at the start (pretest - follow-up group) or at the end (posttest – follow-up group) of the OtR session between December 2008 – June 2009. The second measurement was done through the Internet between February 2009 – September 2009.

The first measurement used an anonymous paper-and-pencil survey and was administered by a total of eight trained data collectors who went to 9 locations in Flanders where OtR sessions took place. They first gave a short introduction to the participants, then they collected contact information for the second measurement. Next the questionnaire was distributed and filled in, and last there was a short debriefing. Taken together, the measurement took approximately 30 minutes.. The second measurement for both groups was done by email two months after the first measurement. Participants were given a link with which they could access an Internet page containing the questionnaire. Filling in the questionnaire took approximately 15 minutes (follow-up).

The current experimental design allows for testing immediate intervention effects by comparing scores between the pretest measurement in the baseline-follow-up group and the posttest measurement in the posttest-follow-up group, as in a post-test only experimental design comparing a no intervention (control) group vs. an intervention group. To test whether effects are present at 2 month follow-up, we compared the scores between pretest and follow-up measurements within the baseline – follow-up group. However, to exclude the possibility of having a questionnaire effect instead of an intervention effect at 2-month follow-up we in addition tested the difference between the follow-up measures in both groups and the difference between the posttest and follow-up measures in the posttest-follow-up group. Finding no significant differences in the comparisons involving the follow-up measurements in both groups, but finding a significant difference between the pretest and posttest measures is indicative of an intervention effect over a questionnaire effect at 2 month follow-up.

During the first measurement, 366 persons completed the questionnaire. Of these persons, 150 belonged to the baseline – follow-up group, while 216 belonged to the post-test – follow-up group. During the second measurement, 210 persons completed the questionnaire. The data of 176 persons could be matched with the data of the first measurement. Of these persons, 72 belonged to the baseline – follow-up group, while 104 belonged to the post-test – follow-up group.

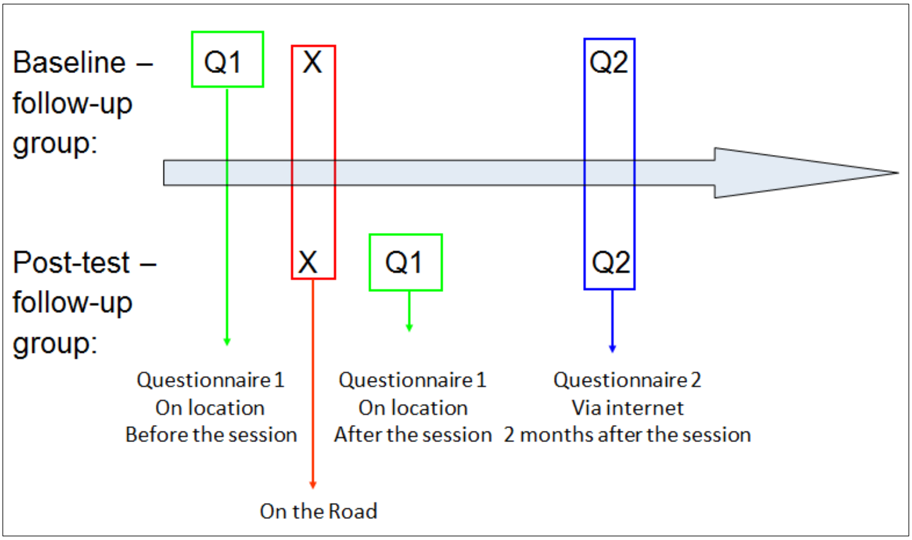

**Figure 2**. Design.

## 5.3. Analysis

First, preparatory steps were carried out to arrange the data. For instance, items were recoded so that a higher score always implies more positive concerns with regard to traffic safety. Then, reliability analyses were conducted to determine if data could be reduced. Due to the relative low number of items per measure, a Cronbach's alpha of .65 or higher was considered satisfactory to conduct data clustering (Field, 2013). These analyses were followed by exploratory analyses to describe background variables and the scores on the psychosocial variables and program reception. In addition, independent samples t-tests and chi-square analyses were conducted to check whether there were significant differences between the baseline – follow-up group and the post-test – follow-up groups regarding the background variables.

Afterwards, effect analyses were done to determine the immediate and extended effects of OtR on measures towards speeding, drink driving, risk-related knowledge and risk detection. Yet, before looking at program effects, we wanted to exclude the possibility that results were influenced by repeated exposure to the questionnaire. Hence, additional analyses were conducted to check for questionnaire effects.

Effect analyses started with analyses of variance (ANOVA's) to answer the first research question 'Is there an immediate effect of OtR on the outcome measures?'. For these analyses, data of the first measurement in the baseline – follow-up group was compared against the data of the first measurement in the post-test – follow-up group (N=366). For speeding and drink driving, multivariate ANCOVA's with past behavior as covariate were conducted to control for Type 1 errors due to multiple testing (i.e., chance capitalization). In case of a significant multivariate effect of participation in OtR, univariate ANCOVA's were conducted to test the effect of OtR on the psychosocial variables of speeding and drink driving. Separate univariate analyses were conducted on the outcome measures risk-related knowledge and risk detection. To answer the second research question 'Is there an effect of OtR on the outcome measures two months after session attendance', repeated measures multivariate ANCOVA's were conducted for speeding and drink driving. In case of a significant multivariate effect of participation in OtR, univariate ANCOVA's were conducted to test the effect of OtR on the psychosocial variables of speeding and drink driving. Separate repeated measures univariate analyses were conducted on the outcome measures risk-related knowledge and risk detection. Because of the design, only data from the first and second measurement in the baseline – follow-up group was used (N=72). Effect sizes were reported with Cohen's d. A Bonferroni correction was applied to control for Type 1 errors due to multiple testing (i.e., chance capitalization).

Questionnaire effect analyses started with (multivariate) analyses of variance (ANOVA's) to check if there was a difference between the second measurement in the baseline – follow-up group (N= 70) and the second measurement in the post-test – follow-up group (N= 102) on the outcome measures. A difference between both groups on the outcome measures at follow-up might indicate a questionnaire effect in addition to or instead of an intervention effect. Besides that, we conducted paired samples t-tests (two-tailed) to check if there was a difference between the first and second measurement in the post-test – follow-up group (N= 102). Again, finding differences here might suggest a repeated questionnaire exposure effect.

## 6. RESULTS

### 6.1. Questionnaire effect analyses

Results of (multivariate) ANOVA suggested that there was no significant difference between the post-test – follow-up group and baseline – follow-up group at follow-up on the measures related to speeding (p=.32), drink driving (p=.23), risk-related knowledge (p=.98), and risk detection (p=.12). Results of the paired samples t-tests highlighted that there was no significant difference either between both measurements in the post-test - follow-up group on risk-related knowledge (p=.91) and risk detection (p=.13). However, there were significant results on some of the measures related to speeding and drink driving. For speeding, scores between the first and second measurement in the post-test – follow-up group differed significantly on positive beliefs (p=.001), injunctive norm (p=.04), risk perception (p=.05) and general behavioral intention (p=.001). For drink driving, a significant effect was found on injunctive norm (p=.05). Yet, it can be concluded that it is rather unlikely that results for the program effect are confounded by a repeated questionnaire exposure effect.

### 6.2. Reliability analyses

The Cronbach's alpha per psychosocial variable of speeding and drink driving is reported in Table 2. Since the majority of Cronbach's alphas reached the threshold of .65, scores on the separate items were averaged for each psychosocial variable.

**Table 2.** Number of items, Cronbach's alpha, mean, standard deviation and p-value per psychosocial variable of speeding and drink driving.

| **Psychosocial variables** | **Number of items** | **Cronbach's α** | **Measurement 1 baseline – follow-up group Mean (SD)** | **Measurement 1 post-test – follow-up group Mean (SD)** | **p-value[a] Measurement 1 baseline – follow-up group vs. Measurement 1 post-test – follow-up group** |
|---|---|---|---|---|---|
| Speeding – Positive beliefs<br>(i.e. It is exciting) | 5 | .83 | 2.68 (1.12) | 2.83 (1.23) | 0.21 |
| Speeding – Negative beliefs<br>(i.e. It is expensive) | 5 | .71 | 5.60 (0.96) | 5.74 (0.95) | 0.15 |
| Speeding – Descriptive norm<br>(i.e. The majority of my friends sometimes speed) | 1 | - | 2.55 (1.46) | 2.86 (1.58) | 0.04* |
| Speeding – Injunctive norm<br>(i.e. My friends think I should respect the speed limits) | 2 | .53 | 4.80 (1.41) | 4.63(1.49) | 0.26 |
| Speeding – Personal norm<br>(i.e. I feel a personal obligation to respect the speed limits) | 2 | .81 | 5.16 (1.47) | 5.33 (1.51) | 0.23 |
| Speeding – Risk perception<br>(i.e. Speeding increases the risk of a traffic accident) | 2 | .85 | 4.23 (1.43) | 4.05 (1.64) | 0.29 |
| Speeding – Self-efficacy under situational pressure<br>(i.e. You are on your way to an important meeting: do you think that you can respect the speed limits in this situation?) | 4 | .85 | 3.80 (1.47) | 4.03 (1.40) | 0.05* |

| **Psychosocial variables (continued)** | **Number of items** | **Cronbach's α** | **Measurement 1 baseline – follow-up group Mean (SD)** | **Measurement 1 post-test – follow-up group Mean (SD)** | **p-value[a] Measurement 1 baseline – follow-up group vs. Measurement 1 post-test – follow-up group** |
|---|---|---|---|---|---|
| Speeding – Self-efficacy under social pressure (i.e. Together with some friends, you are on your way to a party: do you think that you can respect the speed limits in this situation?) | 2 | .86 | 5.68 (1.37) | 5.57 (1.38) | 0.41 |
| Speeding – Behavioral intention under situational pressure (i.e. You are on your way to an important meeting: how big is the chance that you will respect the speed limits in this situation?) | 4 | .91 | 4.05 (1.53) | 4.30 (1.48) | 0.03* |
| Speeding – Behavioral intention under social pressure (i.e. Together with some friends, you are on your way to a party: how big is the chance that you will respect the speed limits in this situation?) | 2 | .96 | 5.60 (1.44) | 5.61 (1.41) | 0.93 |
| Speeding – Behavioral intention - general (i.e. I intend to respect the speed limits in the next 3 months) | 3 | .95 | 4.57 (1.88) | 4.85 (1.80) | 0.06 |
| Drink driving – Negative beliefs - deterioration of skills (i.e. It decreases my reaction time) | 8 | .60 | 6.41(0.97) | 6.27 (1.00) | 0.40 |
| Drink driving – Negative beliefs - financial/health risk (i.e. It increases the risk of a fine) | 2 | .90 | 6.58 (0.66) | 6.42 (0.89) | 0.17 |

| **Psychosocial variables (continued)** | **Number of items** | **Cronbach's α** | **Measurement 1 baseline – follow-up group Mean (SD)** | **Measurement 1 post-test – follow-up group Mean (SD)** | **p-value[a] Measurement 1 baseline – follow-up group vs. Measurement 1 post-test – follow-up group** |
|---|---|---|---|---|---|
| Drink driving – Descriptive norm (i.e. The majority of my friends sometimes drive under influence of alcohol) | 1 | - | 4.86 (1.79) | 4.43 (1.85) | 0.07 |
| Drink driving – Injunctive norm (i.e. My parents think that I should drive sober) | 2 | .45 | 6.43(0.84) | 6.12 (1.05) | 0.02* |
| Drink driving – Personal norm (i.e. I feel a personal obligation to drive sober) | 2 | .80 | 6.69 (0.67) | 6.36 (1.07) | 0.01** |
| Drink driving – Risk perception (i.e. My risk of an accident due to drink-driving is…) | 2 | .89 | 3.67 (2.29) | 3.26 (2.27) | 0.04* |
| Drink driving – Self-efficacy under situational pressure (i.e. You had a drink with friends and you need to bring them home: do you think that you can leave the car there?) | 6 | .92 | 4.89 (1.65) | 5.00 (1.68) | 0.24 |
| Drink driving – Behavioral intention under situational pressure (i.e. You had a drink with friends and you need to bring them at home: how big is the chance that you do not drive?) | 6 | .93 | 5.17 (1.54) | 5.21(1.62) | 0.44 |
| Drink driving – Behavioral intention – general (i.e. I intend to drive sober in the next 3 months) | 3 | .98 | 6.64 (1.07) | 6.34 (1.39) | 0.11 |

*p<.05, **p<.01

## 6.3. Exploratory analyses

### *6.3.1. Participants*

The descriptive statistics of the background variables are reported in Table 3. Independent samples t-tests indicated that across the baseline - follow-up group and the post-test - follow-up group, age, t(364)= -2.18, p=.03 was significantly distributed differently, with participants in the post-test – follow-up group having a higher mean age (20.15 year) compared to participants in the baseline- follow-up group (19.74 year). While, independent samples t-tests indicated that across the baseline- follow-up group and the post-test – follow-up group, number of months driving license hold, t(337.18)= -1.89, p=.06, was not significantly distributed differently. Chi square tests indicated that there was no difference between the groups regarding gender, χ2(1, N=366) = 0.02, p=.88 and number of times involved in a traffic accident, χ2(3, N=365)= 1.00, p=.80.

In the past 3 months, 95.6% of the participants almost never drove under influence of alcohol, while just 44.4% of the participants almost never drove faster than allowed. Participants in the control group (M=4.01, SD=1.60) and experimental group (M=4.94, SD=1.57) had on average less than 50% of the answers correct on the risk-related knowledge test (M=4.56, SD=1.65, range 0-10). Participants in the control group (M=1.40, SD=0.48) and experimental group (M=1.35, SD=0.53) detected on average one third of the risks on the risk detection test (M=1.37, SD=0.51, range 0-4.25).

**Table 3.** Mean and standard deviation per background variable.

| **Background variable** | **Measurement 1 Baseline – follow-up group Mean (SD)** | **Measurement 1 Post-test – follow-up group Mean (SD)** | **Measurement 1 Total sample Mean (SD)** |
|---|---|---|---|
| Age | 19.74 (1.70) | 20.15 (1.80) | 19.98 (1.77) |
| Gender | | | |
| Male | 94 (62.70%) | 137 (63.40%) | 231 (63.10%) |
| Female | 56 (37.30%) | 79 (36.60%) | 135 (36.90%) |
| Duration of car driving license (months) | 13.87 (13.37) | 16.91 (16.60) | 15.68 (15.43) |
| Number of times involved in a traffic accident (%) | | | |
| Never | 102 (68.00%) | 144 (67.00%) | 246 (67.40%) |
| One time | 33 (22.00%) | 43 (20.00%) | 76 (20.80%) |
| Two times | 11 (7.30%) | 19 (8.80%) | 30 (8.2%) |
| Multiple times | 4 (2.70%) | 9 (4.20%) | 13 (3.60%) |

### *6.3.2. Psychosocial variables*

The descriptive statistics of the psychosocial variables for speeding and drink driving are reported in Table 2. Taken together, most mean scores indicate positive concerns with regard to traffic safety in the domains of speeding and drink driving, with for drink driving even higher positive concerns compared to speeding.

### *6.3.3. Program reception*

The majority of the participants labeled OtR as a good or even a very good program (83.6%) and the instructors as good or even very good instructors (96.1%). Also, most participants (92.8%) would recommend OtR to others.

## 6.4. Effect analyses

### *6.4.1. Research question 1: Is there an immediate OtR effect on speeding, drink driving, risk-related knowledge and risk detection?*

The results of the univariate analyses of variance for speeding and drink driving are reported in Table 2. For speeding, there was a significant multivariate effect of participation in OtR, F(11, 350)=2.63, p=.003. Univariate analyses showed significant effects on three psychosocial variables: descriptive norm, self-efficacy when being under situational pressure (i.e., when driving to an important meeting), and behavioral intention when being under situational pressure (i.e., when driving to an important meeting). Results on these variables changed in the positive direction after participating in OtR, with the post-test – follow-up group having more positive concerns with regard to traffic safety than the baseline – follow-up group. Cohen’s d was 0.20 for descriptive norm, 0.16 for self-efficacy, and 0.17 for behavioral intention, indicating small effect sizes. For drink driving, there was also a significant multivariate effect of participation in OtR, F(9, 352)=2.40, p=.012. Univariate analyses showed significant effects on three psychosocial variables: injunctive norm, personal norm, and risk perception. Unfortunately, these effects were in the undesired direction with the baseline – follow-up group having more positive concerns with regard to traffic safety than the post-test – follow-up group. Cohen’s d was 0.33 for injunctive norm, 0.37 for personal norm, and 0.18 for risk perception, indicating small effect sizes. For risk detection, there was no univariate effect of participation in OtR, F(1,364)=1.02, p =.31). However, there was an univariate effect of participation in OtR on the risk-related knowledge test, F(1,35)=29.31, p=.001. Cohen’s d was 0.59, indicating a medium effect size. This effect was in the desired direction, with participants in the post-test – follow-up group scoring higher (M=4.94, SD=1.57) than participants in the baseline – follow-up group (M=4.01, SD=1.6).

### *6.4.2. Research question 2: Is there an OtR effect two months after session attendance on speeding, drink driving, risk-related knowledge and risk detection?*

For speeding and drink driving, there was no significant multivariate effect of participation in OtR, F(11,60)=1.29, p=.26 and F(9,61)=0.90, p=.53 respectively. For risk detection, there was also no univariate effect of participation in OtR, F(1,71)=.18, p=.67.
However, there was an univariate effect of participation in OtR on the risk-related knowledge test, F(1,70)=18.28, p=.00. Cohen’s d was 0.50, indicating a medium effect size. This effect was in the desired direction, with participants on the second measurement (M=4.79, SD=1.61) scoring higher than on the first measurement (M=3.99, SD=1.61). Compared to the first measurement, risk-related knowledge increased with 0.80 on the second measurement.

## 7. DISCUSSION

Overall, there were small effects of participation in OtR on psychosocial variables related to speeding and drink driving. For speeding, participation in OtR had a desired effect on descriptive norm, self-efficacy and behavioral intention while for drink driving, it had an undesired effect on injunctive norm, personal norm and risk perception. Important is that each of these psychosocial variables are crucial for behavior change. Behavioral intention is a key predictor of behavior (Sheeran & Orbell, 1999) and external social norms (i.e., descriptive and injunctive norms) as well as internal norms (i.e., personal norms) are important if the objective is to create voluntary safe behavior (Heath & Gifford, 2002). Self-Determination theory (SDT) for instance, highlights the importance of intrinsic motivation (i.e., personal norms) for behavioral self-regulation (Ryan & Deci, 2000). Risk perception (i.e., subjective experience of risk in potential traffic hazards) also is important to explain behavior (Machin & Sankey, 2008). For example, Protection Motivation Theory (PMT) highlights the importance of perceived severity (i.e., degree of harm from the risk) and perceived vulnerability (i.e., probability that one will experience harm) for threat appraisal as a means to motivate more safe behavior (Rogers, 1975). When behavior is not under complete volitional control, self-efficacy is especially important to explain behavior (Armitage & Conner, 2001).

Left aside a few small positive effects of participation to OtR, the program overall had no effect and sometimes even effects in the undesired direction, where persons in the baseline – follow-up group had more positive concerns with regard to traffic safety than persons in the post-test - follow-up group. These results generally reflect findings reported by a couple of recently published evaluation studies (Beanland, Goode, et al., 2013; Boele, de Craen, & Erens, 2013). Beanland, Goode, et al. (2013) conducted a literature review by examining evaluation studies of post-license driver education programs. They concluded that teaching procedural skills at times had no effect or even effects in the undesired direction, leading to increased crash rates (i.e., teaching skid control). Boele et al. (2013) did an evaluation study of an advanced rider education program for motorcyclists and also failed to establish effects for several of the targeted variables. In line with their findings, they mentioned that previous evaluation studies of (post-license) education programs for motorcyclists also failed to find (desirable) effects on some of the outcome variables. Even though the results of our study are in line with these findings, we think it is important to take into account the already good baseline scores on the psychosocial variables for speeding and drink driving. Since the majority of the participants to this study were already favorably disposed towards traffic safety, the range for further improvement of their overall disposition towards safety issues like speeding or drink driving was in fact rather small. Consequently, small positive intervention effects are maybe what we could have expected.

Despite the low baseline levels for risk detection, the program was not able to generate a significant improvement in participants' ability to spot potentially dangerous objects/events while driving. Possibly, this is related to the teaching method being applied. Even though participants themselves were not actively practicing the search for latent hazards, i.e., hazards that novice drivers find so much more difficult than experienced drivers (Borowsky, Shinar, & Oron-Gilad, 2010; Vlakveld, 2011), instructor's feedback regarding hazards during the ride on road drive was not only oriented towards visible hazards, but to where to expect potential latent hazards as well. However, this is a rather passive teaching method and the effectiveness of such an approach can be expected to be low, taking into account the specialized literature. Research has indicated that relatively simple but more active methods like driving simulators, cd-roms or videos can be very successful in improving the risk detection skills of young novice drivers (Crundall, Andrews, Van Loon, & Chapman, 2010; Isler, Starkey, & Williamson, 2009; Ivancic & Hesketh, 2000; Pradhan, Fisher, & Pollatsek, 2006).

Participation in OtR had the largest effect on risk-related knowledge even though it cannot be ignored that the level of risk-related knowledge remains very low even after exposure to the program. In addition to that, taking into account the recommendations forwarded by the GDE-matrix, OtR should prioritize the improvement of higher-order skills over increasing knowledge (lower-order skills).

## 8. POLICY RECOMMENDATIONS

Having conducted this study, we see five recommendations for the practical implementation of insight programs like OtR. First of all, the higher baseline scores on psychosocial variables for speeding and drink driving suggest that, maybe, young novice drivers are not the ones most in need of insight programs targeting these variables. Probably, programs targeting those variables will have more effect in other target groups, for example as an alternative sanction for particular groups of traffic offenders. Indeed, offenders can be expected to have less favorable inner dispositions towards road safety than young novice drivers ((White & Gasperin, 2007). OtR addresses an appropriate 'at risk' population, but safety consciousness is not the variable to target in that population, while risk detection and risk-related knowledge are.

Secondly, we recommend designers of short duration programs not to be overambitious in the number of objectives to be reached. Indeed, what often recurs is that those programs are simply overloaded with program objectives, which seriously undermines an intervention's effectiveness. For the case of OtR, half a day is simply too short to address a variety of issues like speeding, drink driving, risk detection and risk-related knowledge. Put differently, in determining a program's focus, 'less could be more'.

Thirdly, from a strategic point of view, an important lesson comes out of this study, namely that it is of absolutely crucial importance for program developers to thoroughly investigate the true underlying needs within a specific 'at risk' population before deciding on which variables to target and which methods and strategies to use in order to influence these variables. It is a well-known problem within the literature on health- and road safety education that a 'needs assessment' is often not (well) carried out by practitioners. As a consequence, strategic decisions are many times taken intuitively rather than being evidence-based, which is known to have an unfortunate impact on an intervention's effectiveness

(Bartholomew, Parcel, Kok, Gottlieb, & Fernández, 2011). Hence, we propose program designers to work in a more structured and evidence-based manner, which is in line with the basic philosophy behind some well-known frameworks for the development of health and safety interventions such as the Intervention Mapping approach of Bartholomew et al. (2011). Bartholomew et al. (2011) indeed stress it is of crucial importance for a program’s effectiveness to back up selected training methods and strategies as much as possible by the available theoretical and empirical scientific evidence. In the case of OtR, this specific issue is particularly relevant for the program component that focuses on training risk detection. As indicated above, we think more actively engaging techniques should be used for which enough support has been found in the literature on risk detection (Crundall et al., 2010; Isler et al., 2009; Ivancic & Hesketh, 2000; Pradhan et al., 2006).

Fourthly, the two risk mechanisms (i.e., careless and clueless driving; McKnight and McKnight (2003)) predominantly associated with the crashes that young novice drivers have the most (i.e., single-vehicle crashes, head-on crashes and intersection crashes) are part of OtR. However, the amount of attention that goes to each of these two risk mechanisms (i.e., careless and clueless driving) might not always be properly in balance. In addition, some important issues are still missing. For example, an important contributing factor to the types of accidents young novice drivers have is distraction, e.g., due to in-vehicle devices like GPS, since it can cause drivers to take long glances away from the roadway (Horrey & Wickens, 2007; Wikman, Nieminen, & Summala, 1998). Taken together, it is recommended to reconsider the content of the program in order to take the contributing factors to their crashes more into account and balance them in an appropriate way.

Finally, insight programs try to focus more on the higher-order competences of driving. This means attitudinal and motivational aspects as well as a sense of personal criticism and (social) responsibility become more important than just training and optimizing basic practical skills. According to Bartl (2009) and Beanland, Goode, et al. (2013) this should reflect in the teaching styles adopted by the driving instructors who carry out such programs. More in detail, instructors should shift from a more traditional ‘instructive’ style to a ‘coaching’ model where young novice drivers are encouraged to be more self-conscious, to realistically evaluate their personal driving skills, and to prioritize safety before anything else. Also in this respect, the current OtR format could be further optimized as it still relies more on instruction and the passive reception of feedback.

# 9. LIMITATIONS AND FUTURE RESEARCH

Unavoidably, this study has its limitations.

First, although the program consisted of multiple components, we were unable to assign any program effects to individual program components. However, this is a limitation other effect evaluation studies were faced with as well (Beanland, Goode, et al., 2013; Ker et al., 2005; Molina et al., 2007).

Second, for this study, we used a self-report questionnaire. Off course, self-report questionnaires could be vulnerable to several forms of answering bias (af Wåhlberg, 2012). Instead of using self-report measures, more objective outcome measures could be used, for example observational data or accident data (Gravetter & Forzano, 2006; Taylor et al., 2006). For this study, observational data would have been too time consuming due to the comprehensiveness of the study. Accident data was not an option either for this study due to the short evaluation period, i.e., two months. It should not be overlooked however, that questionnaires also have their benefits. They allow to investigate psychosocial variables (i.e., attitudes), which is exactly what insight programs like OtR are trying to influence. Moreover, there is growing support for the predictive validity of the use of questionnaires with respect to objective behavior measures (Armitage, 2005, 2008; Begg et al., 1999; Boufous et al., 2010; Conner et al., 2007; Elliott et al., 2007; Elliott et al., 2013; Hatakka et al., 1997). In addition, reliability analyses indicated sufficient reliability (i.e., Cronbach's alpha 0.65) for the majority of items. However, for some items (i.e., injunctive norm of speeding and drink driving and negative beliefs about skills of drink driving), reliability was insufficient.

Third, even though the risk detection test method we used was derived from the literature (Fisher et al., 2002; Pollatsek et al., 2006; Pradhan et al., 2005), the way in which the format of the pictures was used could benefit would have been more easier to comprehend if they were from the driver's perspective.

Fourth, for the majority of psychosocial variables for driving-related risk behaviors (i.e., TPB variables for speeding and drink driving), we found no significant intervention effect, however, participants appeared to be safety conscious 'above average' already before attendance to the intervention. Hence, one has to be cautious in drawing the conclusion that OtR failed to be effective in improving participants' safety consciousness with respect to speeding and drink driving. In cases alike it is difficult to decide on whether this absence of significant effects is to be attributed to the intervention failing to be effective or to the participants not really needing the intervention anymore (i.e., the so-called 'ceiling effect'). For the other two variables (i.e., risk detection and risk-related knowledge), a ceiling effect can be excluded since baseline scores for these two variables were low. OtR had a significant effect on risk-related knowledge, however it did not had a significant effect on risk detection, hence OtR seems to be ineffective in the way it deals with risk detection.

Finally, the baseline – follow-up group (as well as the post-test – follow-up group) was composed exclusively by means of people who had already registered themselves on the OtR website. Hence, participants were self-selective in such a manner that they expressed their willingness to participate to the intervention. Yet, this does not automatically imply that the sample was also self-selective in terms of speeding and drink driving related safety consciousness. In addition, the design does not control for differences between the different samples on psychosocial variables of speeding and drink driving, risk detection and risk-related knowledge. However, the different samples did not differ on background variables, with the exception of age. The different samples differed significantly on age, however, the difference was small (0.41 year).

In sum, future research could evaluate the effect of the program by using a control group and focusing on target variables more relevant for the target group, with a reduced number of program objectives (e.g., risk detection) and more active learning methods (e.g., co-roms).

## 10. CONCLUSIONS

This study investigated the effectiveness of a Flemish insight program on psychosocial variables for driving-related risk behaviors (i.e., speeding and drink driving), on risk detection, and on risk-related knowledge. Immediate (short term) effects were rather limited. OtR only had small effects on a limited number of psychosocial variables related to speeding and drink driving. Only effects for speeding were in the desired direction. OtR had no significant ‘immediate’ effect on risk detection. Even though we found a large effect on risk-related knowledge, participants on average had less than 50% of the answers correct after attendance to an OtR session. Two months after program attendance, none of the effects on the psychosocial variables for speeding and drink driving prevailed. No effect on risk detection was found either. Only the large effect on risk-related knowledge sustained.

Regarding safety consciousness, we overall conclude that OtR has little effect on the TPB variables for speeding and drink driving. However, this might not be related to the program itself, but to the fact that program participants were already safety conscious regarding speeding and drink driving before being exposed to the intervention. OtR neither has an effect on risk detection, albeit that rather than due to a ceiling effect, this is the consequence of the teaching methods that were used to train risk detection. Finally, for risk-related knowledge, we do find a significant effect, even though the levels of risk-related knowledge still remain low after program attendance. In general, we believe insight programs like OtR could benefit from a more delineated focus (i.e., a suitable amount of objectives for the time available to carry out a program session), a more decent (i.e., evidence-based) consideration of training methods and strategies, and a teaching style that is more coaching- than instruction-oriented.

# CHAPTER 6

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## Effect evaluation of a road safety education program based on victim testimonials in high schools in Belgium.

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## Abstract

For several decades policy makers worldwide have experimented with testimonials as a strategy to promote road safety supportive views in a wide variety of target populations such as offenders and students. In its basic format, a (relative of) a victim or an offender brings a personal testimonial of what it is to experience a traffic accident. The underlying idea is that such a testimonial will emotionally affect participants, thereby stimulating them to cognitively reflect upon their own behavior and responsibility as a road user. Unfortunately, empirical literature on the effectiveness of this strategy is rather scarce and inconsistent. This study investigated the effect of a large-scale program with victim testimonials for high schools in Belgium on five socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior (i.e., attitude, subjective norm, perceived behavioral control, behavioral intention and behavior). Moreover, this study investigated program effects on participants' cognitive and emotional estate and whether this influences the program's impact on socio-cognitive and behavioral variables. Our test sample included 1,362 students, who were assigned to a baseline – follow-up group and a post-test – follow-up group. We questioned both groups, a first time (just before or after session attendance) on paper, and a second time (two months after session attendance) online. Results indicate the program had, both immediate and two months after attendance, small to medium positive effects on most socio-cognitive and behavioral variables. However, effects depended on participants' demographic profile, their baseline values on the socio-cognitive and behavioral variables, and the degree to which they were cognitively/emotionally affected by the program. We discuss the practical implications of these findings and formulate recommendations for the development of future interventions based on victim testimonials.

## Key words

Victim testimonials; Theory of Planned Behavior; Effect Evaluation; Pre-Driver Education

# 1. INTRODUCTION

## 1.1. The use of victim testimonials as an intervention strategy

Testimonials by (relatives of) people who were involved in a traffic accident are frequently used in order to sensitize people to behave safely in traffic. The underlying idea is that such a testimonial will emotionally affect participants, thereby stimulating them to cognitively reflect upon their own behavior and responsibility as a road user. Over the years, victim testimonials came in use worldwide as a safety promoting intervention strategy. Even though the basic format is always roughly the same, there are differences in terms of which populations are targeted as program participants and how such a testimonial is implemented. Concerning the populations being targeted, while some initiatives are aimed at traffic offenders, others focus primarily at learner drivers or high school students. As mentioned, there is variation in the implementation too. While in some cases testimonials are brought by (relatives of) victims of a traffic accident, others are delivered by offenders. What also differs in the program implementation, is the emotional mechanism to be induced by a testimonial. For instance, some programs clearly focus on the arousal of negative risk-aversive emotions such as threat, worry, guilt, or anticipated regret, while other initiatives are rather aimed at evoking positive emotions such as sympathy or respect for the victims. Another varying aspect related to the implementation of such victim testimonials is the medium used to bring the message to program participants. These range from mass media like television spots (such as in Sweden; Linderholm (2000)) to more interactive formats such as road shows (e.g., “Never saw the day” in Ireland (O’Brien, Rooney, Carey, & Fuller, 2002); “Being dead isn’t cool” in Norway (Moan & Ulleberg, 2007); and “Too much punch for Judy” in Scotland (Powney, Glissov, & Hall, 1995), and discussion groups in a classroom setting, which is the most popular format.

The use of victim testimonials originates from the United States where in 1982 an initiative called ‘Mothers Against Drunk Driving’ (MADD) was organized. The MADD program used testimonials of (relatives of) drunk-driving victims to sensitize Driving Under the Influence (DUI) recidivists in the hope to reduce alcohol-related fatalities. These victim testimonials were meant to operate as a therapeutic experience for the victims and an opportunity for convicted DUI drivers to understand the injuries that their behavior can inflict upon other road users (Shinar & Compton, 1995). Later, several equivalent programs were set up in other countries. However, the focus shifted from DUI drivers to high school students (Feenstra, Ruiter, & Kok, 2014; Glendon, McNally, Jarvis, Chalmers, &

Salisbury, 2014; King, Vidourek, Love, Wegley, & Alles-White, 2008; Poulter & McKenna, 2010; Rosenbloom, Levi, Peleg, & Nemrodov, 2009; Twisk et al., 2014) and learner drivers (Pfeiffer et al., 2006).

Despite the rising popularity of victim testimonials, there is not that much empirical research available on the effectiveness of this method. Most of the evaluation studies applying to victim testimonials are done with the help of a questionnaire (Feenstra et al., 2014; King et al., 2008; Pfeiffer et al., 2006; Polacsek et al., 2001; Poulter & McKenna, 2010; Rosenbloom et al., 2009; Twisk et al., 2014). The empirical literature available on the effectiveness of victim testimonials contains mixed results and therefore remains inconclusive. While some studies find positive effects (Feenstra et al., 2014; King et al., 2008; Pfeiffer et al., 2006; Polacsek et al., 2001; Poulter & McKenna, 2010; Rosenbloom et al., 2009; Shinar & Compton, 1995; Twisk et al., 2014), others fail to do so (Glendon et al., 2014; Polacsek et al., 2001; Shinar & Compton, 1995; Twisk et al., 2014) or even report negative effects (Feenstra et al., 2014; Glendon et al., 2014; Poulter & McKenna, 2010). As a consequence, for academics as well as for policy makers and practitioners, this is a research topic that requires further attention.

## 1.2 Aims of the study

The aim of the study was to empirically evaluate the effectiveness of the Flemish school-based road safety education program 'Traffic Informers'. We decided to evaluate the effectiveness on socio-cognitive and behavioral variables from the Theory of Planned Behavior (TPB, Ajzen (1985)). Our decision to do so was not only based on the acknowledged predictive validity of the variables appearing in the TPB-model (Conner et al., 2007; Elliott et al., 2007; Elliott et al., 2013), but also on a careful analysis of the program's targeted objectives as they were formulated in preliminary discussions with the program developers. In addition, several evaluation studies applying to victim testimonials were done by means of a TPB-based questionnaire (Feenstra et al., 2014; Poulter & McKenna, 2010; Rosenbloom et al., 2009). The TPB is one of the empirically most supported behavioral theories and has been validated in diverse research domains (Godin & Kok, 1996; Stutton, 1998). The theory postulates that behavioral intention (i.e., a person's expression of support for the behaviors under study), the most proximal determinant of behavior, is determined by three conceptually independent variables: (1) attitude (i.e., the expression of (dis)favor towards the behaviors under study), (2) subjective norm (i.e., perceived social expectations about the behaviors under study), and (3) Perceived Behavioral Control (PBC, i.e., the subjective probability that a person is capable of executing (or not) the behaviors under study).

Altogether this study aimed to answer the following four specific research questions. First of all: 'Is there an immediate effect of the program on socio-cognitive and behavioral variables (i.e., attitude, subjective norm, PBC, behavioral intention and behavior)?'. Secondly: 'Is there an effect of the program on socio-cognitive and behavioral variables two months after session attendance?'. Thirdly: 'Does the program have an immediate effect on participants' cognitive and emotional estate?'. Finally: 'Does the program's immediate effect on participants' cognitive and emotional estate influence the program's impact on socio-cognitive and behavioral variables?'.

## 2. METHODOLOGY

### 2.1. Traffic informers

Traffic Informers is a large-scale school-based road safety education program that runs in the Flemish speaking part of Belgium. The first edition of the program was held in 2012-2013 with a total of 14,763 students attending a session. The program is organized by a non-profit organization (i.e., 'Rondpunt') and is subsidized by the Flemish Ministry of Transportation and Public Works. The program targets (male and female) 16-17 year old high school students of three education types (i.e., general, technical and occupational). General education, sometimes called transition education, prepares students for university. The education is focused on theory and general knowledge. Technical education like general education, offers a theoretical education but includes also courses that are focused on practical experience. It prepares students both for university or a specific job or function. Occupational education as a rule prepares students for a specific job or function. This education is focused on practical experience. Although all these education types offer the possibility to go to university, students of occupational education need to follow an extra year of high school before they are allowed to go to university. The majority in this population does not have a driver license yet (in Belgium, a learner license can be obtained from the age of 16 years and nine months, while a permanent driver's license can be obtained only from the age of 18 years). As such, this program focuses primarily on pre-drivers and only marginally on young novice drivers. Schools that are interested in this program register through a website (http://rondpunt.be/getuigen/61/) and give their preference in terms of time and location. The program costs 50 euro and takes two hours. There is an imposed maximum of 35 students per session. The first hour is dedicated to the testimonial of a (relative of a) traffic victim. Informers talk about their life before the traffic accident, the circumstances of the accident itself and their life afterwards. During the second hour there is room for a group discussion. Students share their opinions and impressions with the informer and with each other.

The program developers deliberately avoid a fear appeal-like style with bloody and excessively shocking pictures since there are indications that an over-fixation on the severity of the immediate ‘physical’ consequences of a traffic accident, will miss effect or even result in counterproductive effects (Carey et al., 2013; Peters et al., 2013; Ruiter et al., 2001; Ruiter et al., 2014; Ruiter et al., 2004; Witte, 1992). The informers adopt a serene rather than a sensational style and try to have an impact on participants not by means of emphasizing the most traumatic immediate consequences of the traffic accident but by elaborating on the longer-term physical, emotional, social, financial and professional impact of such an event. In addition to that, informers pay special attention to the establishment of an empathetic connection with the group. The latter is done for instance, through a careful and detailed sketch of the informer’s personal life before the traffic accident. Informers try to show participants that their life was basically not that different from theirs and that the situational circumstances of the traffic accident itself are perfectly imaginable instead of being exceptional. Also, they try to make participants aware of the fact that a traffic accident is never just a matter of bad luck, but rather a process of inappropriately coping with a complex of risk facilitating conditions and a matter of socially shared responsibility.

Before becoming an actual informer, candidate-informers first receive a concise formal training in which the above mentioned principles are addressed and where they learn ways to bring a personal testimonial in a serene way. If necessary, a personal buddy accompanies the informer and assists during the sessions.

## 2.2. Questionnaire development

We developed a questionnaire consisting of three sections. The first section probed for demographic variables such as age, gender and education type. The second section contained a total of 55 items and was dedicated to socio-cognitive and behavioral variables. We addressed several types of (un)safe traffic behavior (e.g., using safety helmet, drink driving, speeding, crossing red lights) and questioned the following variables: Attitude (23 items, e.g., A safety helmet can prevent serious injuries), subjective norm (11 items, e.g., My parents find it good that I wear a safety belt), PBC (11 items, e.g., If I go to a party, I drink alcohol despite that I have to ride/bike to home), behavioral intention (5 items, e.g., I intend to take into account other road users) and behavior (5 items, e.g., Usually I do not exceed the speed limits). In the third section, 10 items were added to investigate the extent to which participants were inclined to respond in a socially desirable manner since this is a frequently mentioned potential response bias in the methodological literature on questionnaire surveys (af Wåhlberg, 2012; W. Harrison, 2010; Lajunen, Corry, Summala, & Hartley, 1997; Lajunen & Özkan, 2011; Paulhus, 1984; Paulhus & Reid, 1991). Socially desirable responding consists of two factors: (1) the tendency towards 'impression management' (i.e., the deliberate tendency to give favorable self-descriptions to others) and (2) the tendency towards 'self-deception' (i.e., a positively biased but subjectively honest self-description). The items were derived from the Driver Social Desirability Scale (DSDS) developed by Lajunen et al. (1997). Impression management was questioned with 5 items (e.g., I always keep sufficient distance between the driver in front of me and myself), as was self-deception (e.g., I always remain calm and rational in traffic). The final section of the questionnaire contained 8 items assessing the program's impact on participants' cognitive and emotional estate: 5 items measured cognitive program impact (e.g., The testimonial was useful) and 3 items assessed emotional program impact (e.g., The testimonial was shocking). Both the second and third section of the questionnaire used 5-point Likert scales going from 1 (totally agree) to 5 (totally disagree).

Before its final implementation, we first pilot tested the questionnaire. High school students (N= 67) offered comments on the readability and clarity of the statements and the instructions. Only a few minor adjustments needed to be done.

## 2.3. Design and procedure

This study evaluated the program's first edition (September 2012 – June 2013). Because of the restricted time available for measurements, we were not able to use a fully controlled experimental design with random assignment and pre- and post-tests in both an experimental group and a control group. Therefore, we adopted a quasi experimental design wherein participants were assigned to a baseline – follow-up group or a post-test – follow-up group on the day of session attendance (Brijs et al., 2014). Both groups completed a questionnaire twice with a two months gap in between. As illustrated in Figure 1, the baseline – follow-up group received the questionnaire before the program session and two months after attendance. The post-test – follow-up group received the questionnaire immediately after and two months after the program session.

Although the design does not control for differences between the different groups on the socio-cognitive and behavioral variables, it does control for differences between the different groups on demographic variables. Moreover, it allows for testing immediate program effects by comparing scores between the first measurement in the baseline-follow-up group and the first measurement in the post-test - follow-up group, as in a post-test only design comparing a no program (control) group vs. a program group. Finally, it allows to test whether effects are present two months after session attendance, by comparing the scores between the first and second measurements within the baseline – follow-up group. Importantly, the design allows to investigate the presence of a repeated questionnaire exposure effect which can arise since people fill in the same questionnaire twice (Shadish, Cook, & Campbell, 2002).

The first measurement was on paper at the start (baseline - follow-up group) or at the end (post-test – follow-up group) of the program session somewhere between September 2012 and March 2013. The second measurement happened online two months after session attendance (in both groups) somewhere between November 2012 and May 2013.

The first measurement was an anonymous paper-and-pencil survey administered by a total of five trained data collectors who went to different locations across Flanders where program sessions were organized. They first shortly introduced the study to the students and asked formal consent together with contact information for participation to the second measurement. Next students completed the questionnaires. Taken together, the whole procedure took approximately 15 minutes. The second measurement was done by e-mail two months after the first measurement for both groups. Students received a link by means of which they could access an internet page containing the questionnaire. Filling in the online questionnaire took approximately 10 minutes. The online questionnaire contained exactly the same items as the questionnaire used at the first measurement, except for the items assessing the program’s impact on participants’ cognitive and emotional estate. This is simply because too much time elapsed between session attendance and the second measurement in order for participants to be able to make an accurate and reliable estimation of their cognitive and emotional estate at that point in time.

Recruitment of students for the first measurement was as follows: The organizing non-profit organization (i.e., Rondpunt) informed the research team about schools that registered for one or more sessions of Traffic

Informers. These schools were contacted (by e-mail or a phone call) to invite them to participate in the study. Schools that were interested gave their preference for the timing of the measurement (i.e., just before or after the session), taking into account their internal time schedules (e.g., breaks, mandatory lessons). In case the measurement was before the session, students following that session automatically belonged to the baseline – follow-up group, while in case the measurement was after the session, students following that session automatically belonged to the post-test – follow-up group. Schools were kept unaware of the study's aim. In case schools did not express any preference as to the timing of the measurement, the research team randomly assigned the students to one of the two groups.

Recruitment of students for the second measurement was as follows: invitation messages were sent two months after session attendance (by e-mail or Short Message Service (SMS)) to students who left their contact details during the first measurement. Students received two reminder messages within the week after the invitation messages were sent.

Students who filled in both questionnaires (first and second measurement) could win one out of twenty film tickets or one out of three smart phones through a lottery where the experimenters randomly assigned the prizes to twenty-three students.

During the first measurement, 1,362 students filled in the questionnaire. Of these, 658 (48.30%) belonged to the baseline – follow-up group, while 704 (51.70%) belonged to the post-test – follow-up group. During the second measurement, 449 students completed the questionnaire. The data of 277 students could be matched with the data of the first measurement. Of these students, 136 (49.10%) belonged to the baseline – follow-up group, while 141 (50.90%) belonged to the post-test – follow-up group.

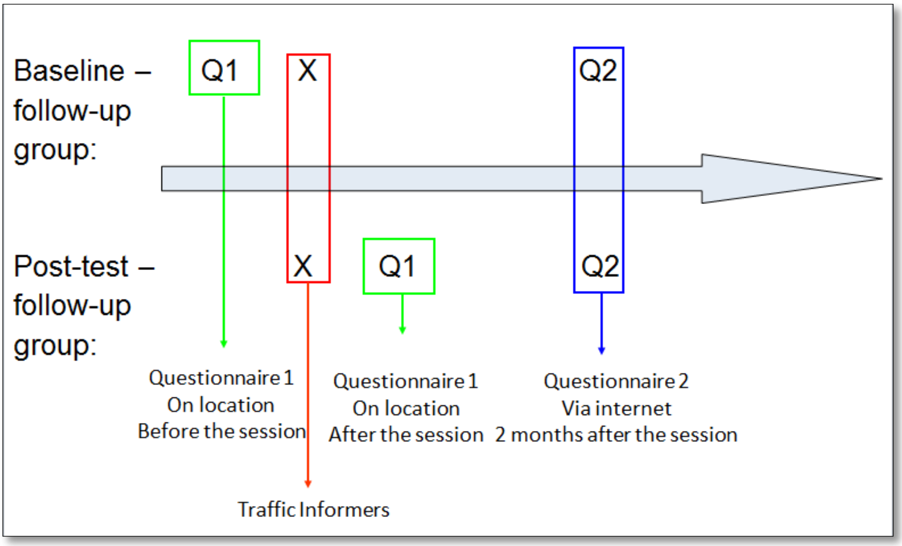

**Figure 1.** Design.

### 2.4. Analyses

The data was processed using SPSS (IBM Statistics 20). First, we recoded items dedicated to socio-cognitive and behavioral variables, so that lower scores always imply a more road safety supportive view. Then, we conducted reliability analyses to determine if the separate items could be averaged for the different variables. A Cronbach's alpha of .65 or higher was considered satisfactory for data clustering (Field, 2013). Test-retest reliability for the different variables was verified by checking statistical significance of the correlation between variables' Cronbach's alpha at the first and second measurement. Next, we checked whether there were significant differences between the baseline – follow-up group and the post-test – follow-up group during the first measurement on demographic variables by conducting t-tests and chi-square tests. Moreover, to check whether students differed on socio-cognitive and behavioral variables at baseline, we performed a multivariate analysis of covariance (MANCOVA), with Gender and Education type as between-subjects (BS) variable and Social desirability as a covariate for the baseline – follow-up group during the first measurement (N=658).

To answer the first research question ('Is there an immediate effect of the program on socio-cognitive and behavioral variables?'), we performed a MANCOVA with data of the first measurement (N=1,362). In the MANCOVA, the socio-cognitive and behavioral variables served as dependent variables, with Group (i.e., Baseline – follow-up group and Post-test – follow-up group), Gender and Education type as BS variables and Social desirability as a covariate.

To answer the second research question ('Is there an effect of the program on socio-cognitive and behavioral variables two months after session attendance?'), we conducted repeated measures MANCOVA with data of the baseline – follow-up group (N=136) with Measurement (i.e., First measurement and Second measurement) as within-subjects (WS) variable, Gender and Education type as BS variables and Social desirability as a covariate. Additional analyses were conducted to investigate the occurrence of a repeated questionnaire exposure effect. Finding no significant differences in the comparison of the follow-up measurements in both groups, but finding a significant difference between the baseline and post-test measurements indicates any effects found are attributable to the program rather than to repeated exposure to the questionnaire.

To answer the third research question ('Does the program have an immediate effect on participants' cognitive and emotional estate?'), we conducted univariate ANCOVA with Gender and Education type as BS variables and Social desirability as a covariate, separately for cognitive and emotional program impact.

To answer the fourth research question ('Does the program's immediate effect on participants' cognitive and emotional estate influence the program's impact on socio-cognitive and behavioral variables?'), we divided participants into those scoring high and low on (cognitive/emotional) program impact, by means of a median split. We then conducted MANCOVA with Group (i.e., lower/higher program impact), Gender and Education Type as BS variables and Social desirability as a covariate, separately for cognitive and emotional program impact. For answering these last two research questions, we only used data from the first measurement in the Post-test – follow-up group (N=704).

A Bonferroni correction served to control for Type 1 errors due to multiple testing (i.e., chance capitalization). The Greenhouse–Geisser epsilon correction factor was applied to compensate for possible effects of non-sphericity in the measurements compared. Only the corrected F and probability values are reported. An alpha level of .05 was maintained for all statistical tests. For the first two research questions, we reported effect sizes with Cohen's delta. A Cohen's delta of 0.2 indicates a small effect size, 0.5 indicates a medium effect size, and 0.8 indicates a large effect size.

# 3. RESULTS

## 3.1. Reliability analyses

Since the Cronbach's alpha was sufficient for each variable (with the exception of Behavior in the baseline – follow-up group), scores on the separate items were averaged for the different variables. Test-retest reliability also proved to be sufficient (Table 1).

**Table 1.** Reliability and mean scores for socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior at time of and two months after session attendance to Traffic Informers in Belgian high school students, 2012-2013.

| **Variables** | **Cronbach's α First measurement (N=1,362)** | **Cronbach's α Second measurement (N=136)** | **Test-retest reliability (N=136)** | **Mean (SD) baseline – follow-up group (N=658)** | **Mean (SD) post-test – follow-up group (N=704)** |
|---|---|---|---|---|---|
| Attitude | .79 | .78 | .70** | 2.32 (0.44) | 2.28 (0.43) |
| Subjective norm | .66 | .73 | .40** | 2.64 (0.48) | 2.60 (0.46) |
| PBC | .70 | .69 | .70** | 2.90 (0.63) | 2.88 (0.58) |
| Behavioral intention | .69 | .70 | .48** | 2.18 (0.59) | 2.17 (0.59) |
| Behavior | .63 | .69 | .56** | 2.24 (0.55) | 2.22 (0.52) |
| Social desirability | .77 | .85 | .65** | 2.43 (0.65) | 2.45 (0.61) |
| Cognitive program impact | .90 | n.a. | n.a. | n.a. | 1.36 (0.54) |
| Emotional program impact | .78 | n.a. | n.a. | n.a. | 2.16 (0.84) |

*p<.05; **p<.01; n.a. = not applicable

### 3.2. Group differences for the demographic variables

Between the baseline - follow-up group and the post-test - follow-up group, there was a statistically significant difference on mean age, t(1353.61)= 2.93, p=.003, with students in the post-test – follow-up group having a lower mean age (16.77 year) compared to students in the baseline - follow-up group (16.91 year). There was also a significant difference between the groups on Gender, χ2(1, N=1358) = 7.32, p=.007, with more female students compared to male students in the baseline – follow-up group (55.50%) and less female students compared to male students in the post-test – follow-up group (48.20%). In addition, both groups significantly differed in terms of Education type, χ2(2, N=1302) = 8.78, p=.012, with both groups consisting mostly out of students of technical education, followed by students of general and occupational education (Table 2).

**Table 2.** Mean scores and significance values at time of session attendance to Traffic Informers in Belgian high school students, 2012-2013.

| **Demographic variable** | **Mean (SD) Baseline – follow-up group (N=658)** | **Mean (SD) Post-test – follow-up group (N=704)** | **p-value** |
|---|---|---|---|
| Age | 16.91 (0.90) | 16.77 (0.92) | .003** |
| Gender | Number (%) | Number (%) | .007** |
| Male | 292 (44.40%) | 363 (51.80%) | |
| Female | 365 (55.60%) | 338 (48.20%) | |
| Education type | Number (%) | Number (%) | .012* |
| General education | 206 (33.00%) | 205 (30.20%) | |
| Technical education | 227 (36.40%) | 300 (44.20%) | |
| Occupational education | 191 (30.60%) | 173 (25.50%) | |

*p<.05; **p<.01

### 3.3. Baseline values for the socio-cognitive and behavioral variables

Prior to session attendance, students were already quite road safety supportive (Table 1). We found a significant main effect of Gender, F(5,572)=20.74, p=.00 (Table 3). More specifically, for all socio-cognitive and behavioral variables (i.e., attitude, subjective norm, PBC, behavioral intention and behavior), female students, at baseline, are significantly more road safety supportive than male students (p<.001). In addition, there was a significant main effect of Education type, F(10,1144)=6.79, p=.00 (Table 3). With regard to attitude, behavioral intention and behavior, students of general and technical education, at baseline, are significantly more road safety supportive than students of occupational education (p=.00). Turning to subjective norm, students of general education report, at baseline, a significantly more road safety supportive social environment than students of occupational education (p=.01). There were no differences between the education types for PBC (p>.10).

**Table 3.** Mean scores for socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior separately per gender and education type before session attendance to Traffic Informers in Belgian high school students, 2012-2013.

| **Demographic variable** | **Socio-cognitive and behavioral variables** | **Mean (SE) Baseline – follow-up group (N=658)** |
|---|---|---|
| Gender – female | Attitude | 2.19 (0.02) |
| | Subjective norm | 2.59 (0.02) |
| | PBC | 2.75 (0.03) |
| | Behavioral intention | 2.06 (0.03) |
| | Behavior | 2.15 (0.02) |
| Gender – male | Attitude | 2.46 (0.02) |
| | Subjective norm | 2.70 (0.02) |
| | PBC | 3.08 (0.03) |
| | Behavioral intention | 2.34 (0.03) |
| | Behavior | 2.32 (0.03) |
| Education - general | Attitude | 2.25 (0.03) |
| | Subjective norm | 2.59 (0.03) |
| | PBC | 2.92 (0.04) |
| | Behavioral intention | 2.13 (0.03) |
| | Behavior | 2.14 (0.03) |

| **Demographic variable (continued)** | **Socio-cognitive and behavioral variables** | **Mean (SE)<br>Baseline – follow-up group (N=658)** |
|---|---|---|
| Education – technical | Attitude | 2.27 (0.03) |
| | Subjective norm | 2.64 (0.03) |
| | PBC | 2.87 (0.04) |
| | Behavioral intention | 2.12 (0.03) |
| | Behavior | 2.20 (0.03) |
| Education - occupational | Attitude | 2.47 (0.03) |
| | Subjective norm | 2.70 (0.03) |
| | PBC | 2.96 (0.04) |
| | Behavioral intention | 2.36 (0.04) |
| | Behavior | 2.37 (0.03) |

Note. Social desirability was entered as a covariate

### 3.4. Research question 1: Is there an immediate effect of the program on socio-cognitive and behavioral variables?

We found a significant interaction between Group and Education type, F(10,2416)=2.21, p=.02 (Table 4). More specifically, a significant program effect was established for students of general education, F(5,381)=3.26, p=.01, and occupational education, F(5,330)=3.96, p=.00, but not for students of technical education F(5,487)=1.18, p=.32. For students of general education, the program had an effect on all socio-cognitive variables (i.e., attitude, subjective norm, PBC, and behavioral intention), but not on the behavioral variable (i.e., behavior), although this effect was marginally significant. For students of occupational education, the program had an effect on all socio-cognitive and behavioral variables (i.e., attitude, subjective norm, behavioral intention, and behavior), except for PBC, although this effect was marginally significant.

The significant program effects found for students of general and occupational education were small but positive with students being significantly more road safety supportive immediately after session attendance (i.e., at post-test) than prior to session attendance (i.e., at baseline). However, the effects for students of occupational education were smaller than the effects for students of general occupation.

**Table 4.** Mean scores, significance values and effect sizes for socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior at time of session attendance to Traffic Informers in Belgian high school students of general and occupational education, 2012-2013.

| **Education type** | **Socio-cognitive and behavioral variables** | **Mean (SE) Baseline – follow-up group (N=658)** | **Mean (SE) Post-test – follow-up group (N=704)** | **p-value** | **Cohen's d** |
|---|---|---|---|---|---|
| General education | Attitude | 2.28 (0.02) | 2.16 (0.02) | .00** | 0.40 |
| | Subjective norm | 2.63 (0.03) | 2.54 (0.03) | .02* | 0.25 |
| | PBC | 2.96 (0.03) | 2.86 (0.04) | .03* | 0.27 |
| | Behavioral intention | 2.17 (0.03) | 2.03 (0.03) | .00** | 0.38 |
| | Behavior | 2.18 (0.03) | 2.11 (0.03) | .05 | n.a. |
| Technical education | Attitude | 2.28 (0.03) | 2.29 (0.02) | .65 | n.a. |
| | Subjective norm | 2.65 (0.03) | 2.64 (0.02) | .71 | n.a. |
| | PBC | 2.88 (0.04) | 2.84 (0.03) | .38 | n.a. |
| | Behavioral intention | 2.13 (0.03) | 2.20 (0.03) | .15 | n.a. |
| | Behavior | 2.21 (0.03) | 2.26 (0.03) | .18 | n.a. |
| Occupational education | Attitude | 2.45 (0.03) | 2.30 (0.03) | .00** | 0.17 |
| | Subjective norm | 2.68 (0.04) | 2.53 (0.04) | .00** | 0.14 |
| | PBC | 2.94 (0.04) | 2.83 (0.05) | .09 | n.a. |
| | Behavioral intention | 2.34 (0.04) | 2.14 (0.04) | .00** | 0.09 |
| | Behavior | 2.35 (0.04) | 2.22 (0.04) | .01* | 0.01 |

*p<.05; **p<.01; n.a. = not applicable
Note. Social desirability was entered as a covariate

### 3.5. Research question 2: Is there an effect of the program on socio-cognitive and behavioral variables two months after session attendance?

We found a significant interaction between Measurement and Gender, F(5,94)=3.64, p=.01. More specifically, a significant program effect was established both for male students, F(5,27)=8.42, p=.00, and female students, F(5,62)=2.32, p=.05 (Table 5). For male students, the program had an effect on all socio-cognitive and behavioral variables (i.e., attitude, subjective norm, behavioral intention, and behavior), except for PBC, although this effect was marginally significant. For female students, the program only had an effect on PBC, although the program had marginally significant effects on behavioral intention and behavior.

The significant program effects found for male and female students were small to medium-sized but positive with students being significantly more road safety supportive two months after session attendance (i.e., at follow-up) than prior to session attendance (i.e., at baseline). However, the effects for female students were smaller than the effects for male students. Results of additional analyses indicate that it is unlikely that results for the program effect are confounded by a repeated questionnaire exposure effect.

**Table 5.** Mean scores, significance values and effect sizes for socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior at time of and two months after session attendance to Traffic Informers in male and female Belgian high school students, 2012-2013.

| **Gender** | **Socio-cognitive and behavioral variables** | **Mean (SE) First measurement (N=658)** | **Mean (SE) Second measurement (N=136)** | **p-value** | **Cohen's d** |
|---|---|---|---|---|---|
| Male | Attitude | 2.45 (0.08) | 2.29 (0.08) | .01* | 0.34 |
| | Subjective norm | 2.84 (0.08) | 2.55 (0.07) | .00** | 0.56 |
| | PBC | 3.01 (0.11) | 2.87 (0.10) | .06 | n.a. |
| | Behavioral intention | 2.20 (0.08) | 1.85 (0.08) | .00** | 0.55 |
| | Behavior | 2.25 (0.07) | 2.00 (0.08) | .00** | 0.34 |
| Female | Attitude | 2.11 (0.03) | 2.08 (0.04) | .44 | n.a. |
| | Subjective norm | 2.58 (0.04) | 2.58 (0.05) | .85 | n.a. |
| | PBC | 2.70 (0.07) | 2.54 (0.06) | .01* | 0.30 |
| | Behavioral intention | 1.94 (0.05) | 1.82 (0.05) | .06 | n.a. |
| | Behavior | 2.04 (0.05) | 1.93 (0.05) | .05 | n.a. |

*p<.05; **p<.01; n.a. = not applicable
Note. Social desirability was entered as a covariate

### 3.6. Research question 3: Does the program have an immediate effect on participants' cognitive and emotional estate?

Students were both cognitively and emotionally affected by the program (Table 1). Paired samples t-test (t(597)= 25.99, p=.00) indicate that they were more cognitively (M=1.36, SD=0.55) than emotionally affected (M=2.16, SD=0.84) by the program. Furthermore, ANCOVA indicated that cognitive program impact differed in function of Gender (F(1,552)=30.36, p=.00), with female students (M=1.23, SD=0.03) significantly more affected by the program than male students (M=1.49, SD=0.04, p=.00). Cognitive program impact did not differ in function of Education type (F(2,552)=1.82, p=.16). In addition, emotional program impact differed in function of gender (F(1,544)=19.76, p=.00), with female students (M=2.00, SD=0.05) significantly more affected by the program than male students (M=2.33, SD=0.06, p=.00). Emotional program impact also differed in function of Education type (F(2,544)=3.10, p=.05). More in particular, students of occupational education (M=2.02, SD=0.08) were emotionally marginally significantly more affected by the program than students of general education (M=2.25, SD=0.06, p=.06). Emotional program impact did not significantly differ between students of general and technical education (p=1.00).

### 3.7. Research question 4: Does the program's immediate effect on participants' cognitive and emotional estate influence the program's impact on socio-cognitive and behavioral variables?

Analyses based on median split (median cognitive program impact 1.00; median emotional program impact 2.00) revealed a significant main effect of group for both cognitive, F(5,542)=4.73, p=.00, and emotional program impact, F(5,534)=5.10, p=.00 (Table 6). Participants that were more cognitively and emotionally affected by the program were overall more road safety supportive compared to participants that were less cognitively and emotionally affected by the program.

**Table 6.** Mean scores and significance values for socio-cognitive and behavioral variables drawn from the Theory of Planned Behavior at time of session attendance to Traffic Informers in Belgian high school students in function of program impact (high vs. low), 2012-2013.

| **Program impact** | **Socio-cognitive and behavioral variables** | **Mean (SE)**<br>**Higher program impact**<br>**(group 0, N=311)** | **Mean (SE)**<br>**Lower program impact**<br>**(group 1, N=248)** | **p-value** |
|---|---|---|---|---|
| Cognitive | Attitude | 2.22 (0.02) | 2.34 (0.02) | .00** |
| | Subjective norm | 2.57 (0.03) | 2.66 (0.03) | .02* |
| | PBC | 2.81 (0.03) | 2.93 (0.03) | .01* |
| | Behavioral intention | 2.07 (0.03) | 2.26 (0.03) | .00** |
| | Behavior | 2.17 (0.03) | 2.29 (0.03) | .00** |
| Program impact | Socio-cognitive and behavioral variables | Mean (SE)<br>Higher program impact<br>(group 0, N=287) | Mean (SE)<br>Lower program impact<br>(group 1, N=264) | p-value |
| Emotional | Attitude | 2.22 (0.02) | 2.33 (0.02) | .00** |
| | Subjective norm | 2.59 (0.03) | 2.67 (0.03) | .03* |
| | PBC | 2.84 (0.03) | 2.92 (0.03) | .06 |
| | Behavioral intention | 2.07 (0.03) | 2.29 (0.03) | .00** |
| | Behavior | 2.18 (0.03) | 2.32 (0.03) | .00** |

*p<.05; **p<.01
Note. Social desirability was entered as a covariate

## 4. DISCUSSION

This study examined the effectiveness of a Flemish road safety program that uses testimonials by (relatives of) people who were involved in a traffic accident in order to stimulate 3rd grade high school students to behave safely in traffic. In total, 1,362 students who were assigned to a baseline – follow-up group and a post-test – follow-up group participated to the study. Two demographic variables (i.e., gender and education type) were taken into account and we controlled for social desirability biases.

Immediately after attendance, the program had small but significant and positive effects on the socio-cognitive and behavioral variables (i.e., attitude, subjective norm, PBC, behavioral intention and behavior). Interestingly, a more detailed analysis showed that these immediate program effects differed in function of education type. While students of general and occupational education were both significantly more road safety supportive after session attendance, no such effect could be established for students of technical education. As far as we know, there is no straightforward evidence for or insight into the more precise underlying reasons that might explain why in some cases students of a particular education type are significantly affected by road safety programs while others not. Therefore, we can only speculate about these reasons. One possible explanation for the significant program effect in the group of occupational education might be the fact that in this particular group, students held the least road safety supportive view at baseline (see Table 3), and thus, leaving a broader margin for the program to improve students' scores on the socio-cognitive and behavioral variables. Another possible explanation for the significant program effect in the group of occupational education might be the fact that in this particular group, students were significantly more emotionally affected by the program compared to students of general and technical education. Yet, these possible explanations for the significant program effect in the group of occupational education cannot explain the results found for the group of general education. No significant program effects were found in the group of technical education even when on the one hand, the majority of baseline values for students in technical education were not statistically different from those in the group of general education, and on the other hand, students in technical education were not significantly less affected by the program than students in general education. The possibility that the difference in program effectiveness between technical education on the one hand and general and occupational education on the other hand is to be attributed to a systematic difference in the way of bringing the testimonial sessions, is very unlikely because (a) the victims are all trained in standardizing as much as possible their testimonial style, (b) sometimes, a testimonial was brought in the different educational groups by the same victim, and (c) there is no reasonable argument to assume that testimonials would be brought the same way in groups of general and occupational education, while they would be brought differently in the group of technical education.

Two months after session attendance, there were significant, small to medium-sized positive effects on most of the socio-cognitive and behavioral variables. However, deviate from what we found for immediate program effects, the effects did not differ in function of education type anymore while they did differ in function of gender. That is, both male and female students were significantly more road safety supportive after session attendance. However, the program had more effect on males than on females. More specifically for males, the program had an effect on all socio-cognitive and behavioral variables, except for PBC, albeit this effect was marginally significant. For females, the program had an effect on PBC, although the program also had marginally significant effects on behavioral intention and behavior. These effects can be explained by the finding that male students held a less road safety supportive view than female students at baseline (see Table 3), thus leaving a broader margin for the program to improve students' scores on the socio-cognitive and behavioral variables. In contrast, female students scored higher on both cognitive and emotional program impact than male students. The finding that effects of road safety promoting programs can vary in function of gender is not surprising, and in line with previous research. For instance, King et al. (2008) examined the effectiveness of a road safety promoting program, and found more significant positive effects for females. Shinar and Compton (1995) examined the effectiveness of a road safety promoting program and indicated that the program might have the largest effect for males. The reason why a significant gender interaction occurred at the second measurement while no such interaction effect was found at the first measurement remains unclear. One would expect that an eventual gender interaction would occur rather at both the first and second measurement than at the second measurement only. Also, we have no direct explanation for the fact that there is no significant interaction anymore with education type at the second measurement.

Interestingly, the program had an immediate effect on participants' cognitive and emotional estate. More specifically, the program had more cognitive and emotional impact on female students than male students and more emotional impact on students of occupational education than students of general or technical education.

Finally, this study was the first to show that the impact of programs with victim testimonials on participants' cognitive and emotional estate is relevant for determining such programs' effect on the targeted socio-cognitive and behavioral variables. Interestingly, our results seem to suggest that, while there is enough support available in the literature for the finding that too high levels of cognitive/emotional arousal might result in counterproductive effects (Carey et al., 2013; Peters et al., 2013; Ruiter et al., 2001; Ruiter et al., 2014; Ruiter et al., 2004; Witte, 1992), too low levels of cognitive/emotional arousal should be avoided as well. Indeed, we found that less aroused participants became road safety supportive to a lesser extent than participants declaring they were more aroused by the program. Put together, these findings appear to be in line with the view that the relationship between stimulus arousal and message acceptance can best be represented as an inverted U-shaped curve with moderate arousal levels leading to optimal results (Janis, 1967; McGuire, 1968, 1969).

## 5. RECOMMENDATIONS

Based on the results of this study, we formulate the following three recommendations. First of all, victim testimonials have targeted a variety of road user populations. Originally, such testimonials were often meant to serve as a 'curative' or a 'corrective' measure for clinical use in adult road user populations with elevated risk-taking levels such as occasional offenders. Gradually, the focus shifted to the use of such testimonials as a 'preventive' measure in the sensitization and education of students. Our study is in support of other work (King et al., 2008; Rosenbloom et al., 2009) indicating that personal testimonials by accident victims can stimulate high school students to reflect upon their participation in traffic in such a way that they become more road safety supportive. Despite the fact that such positive effects have not been found in other studies (Feenstra et al., 2014; Glendon et al., 2014; Twisk et al., 2014), and that positive effects found are not always persistent over time (Poulter & McKenna, 2010), we think victim testimonials have increased influencing potential in high school student populations. We therefore recommend policy makers and practitioners considering the use of victim testimonials as a safety promoting strategy to focus more specifically on these age groups. Importantly, the effect of the program depends on characteristics of the student (i.e., education type, gender). This is in line with previous studies evaluating road safety campaigns among high school students (King et al., 2008; Rosenbloom et al., 2009; Ulleberg, 2001) and again illustrates that high school students are not a homogenous group. Therefore, different strategies are needed for the different subtypes of high school student to make them more road safety supportive.

Secondly, in line with already published work, this study shows that the effectiveness of victim testimonials is dependent upon several aspects related to how such testimonials are practically implemented. For example, while the objective of victim testimonials is to stimulate (self-) reflection by means of an emotional trigger (i.e., the personal testimonial of a traumatic experience), care must be taken of fact that the right emotions are being activated at the appropriate strength levels. As for the latter, we recommend practitioners to aim at moderate arousal levels since these can be expected to result in optimal message processing (Janis, 1967; McGuire, 1968, 1969). On the one hand, excessive emotional reactions can be prevented to a large extent already by avoiding too explicit emphasis on the immediate physical consequences of the accident itself. On the other hand, the risk of program participants not being or feeling engaged at all can be avoided by means of relatively simple arousal energizing strategies such as self-activation and social interaction.

Our third and final recommendation is based on a finding that resulted from item-level observation. There it came out that when generically formulated (i.e., stated in general rather than context-specific terms), participants' intentions to behave safely in traffic significantly increased after session attendance while this was not always the case when such behaviors were linked to a specific risk-facilitating or protection-inhibiting situation. For instance, while the intention to wear a safety helmet in general significantly improved after session attendance, the PBC to wear a safety helmet when accompanied by friends did not improve. In our opinion, this is an argument in support of the idea that victims when they bring their testimonial and reflect upon monitoring risks in traffic, should stay away as much as possible from vague and non-contextualized discourse. Otherwise, the risk remains that positively influenced general intentions will not translate into the desired behavior whenever participants are exposed to risk-facilitating or protection-inhibiting pressures. The creation of implementation plans might be a helpful technique to make sure that good behavioral intentions can result in the desired behavior. Such plans specify in detail the various steps that are needed to protect a person from the obstacles, frustrations, and temptations likely to be encountered, keeping in mind the demands of the current goal (i.e., to behave safely) that is being pursued (Gollwitzer, 1999). By designating a specific if-then contingency between an environment and a plan of action (i.e., if situation X arises, I will perform behavior Y), individuals construct a mental association between a specific situational cue and the appropriate goal-directed behavior response, e.g., 'when accompanied by friends, I will wear my safety helmet when bicycling' instead of 'I will wear my safety helmet' (Baumeister & Vohs, 2004). Research has indicated that this method is effective in translating behavioral intentions into behavior because it allows people to pass control over their behavior to the environmental cues contained in the implementation intention (Brewster, Elliott, & Kelly, 2015; Sheeran & Orbell, 1999).

## 6. LIMITATIONS AND FUTURE RESEARCH

Unavoidably, this study has its limitations. Firstly, participants in this study were already quite road safety supportive prior to session attendance (see Table 1 and 3). This might have created a 'ceiling effect' in a sense that the margin available for the program to have an effect on participants' road safety supportive view was limited beforehand. Put differently, the results of this study in some way could be an underestimation of the program's true effectiveness. Relevant also in respect to an appropriate interpretation of the above mentioned, is to be precise enough in determining the program's true objective. For instance, while program developers position Traffic Informers as being aimed at the formation of a road safety supportive view, the alternative might be to state that the program's primary purpose is to positively reinforce favorable road safety supportive views that were already formed.

Secondly, the Traffic Informers program in its current format is a combination of a testimonial on the one hand, and an in-depth group discussion on the other hand. Our study has not examined what the impact is of each of these two program components. This is to a certain degree a limitation, more particularly for those practitioners who would be interested in finding out what the contribution of the different program components is like. Also, based on our study, we are unable to identify which specific aspects of the testimonial on the one hand, and of the group discussion on the other hand, do (or do not) work well.

Thirdly, even though a self-selection bias during the first measurement at the level of individual participants is not likely (i.e., inscription to the program was a decision taken at the school level, not at the individual student level), there still is a chance that such a bias occurred at the school level. Indeed, it could be the case that schools paying more attention to road safety were more motivated to inscribe to the program than schools paying less attention to road safety, creating an according bias in the data. A self-selection bias at the individual respondent level might however have occurred in the second measurement (i.e., two months after session attendance) in a sense that only those respondents truly caring about road safety were the ones motivated enough to fill out a questionnaire twice.

Finally, external validity of this study is limited in different ways. For instance, the results apply only to programs adopting a comparable format. Also, our study results cannot be generalized to programs addressing different target populations than the one we addressed here. In addition, our study was conducted in high schools in Flanders only, so there is a geographical restriction on the validity of our results as well.

Future research on the effectiveness of road safety interventions using victim testimonials to sensitize and educate high schools students is thus warranted. Such research could go in many directions. As a first avenue, it would be interesting to determine what the impact would be of the separate components (e.g., the personal testimonial and group discussion) within a combined program. Until now, the majority of evaluation studies have been carried out at the program overall level rather than adopting a component-specific perspective.

Furthermore, it would be valuable to know more precisely whether the inclusion of multiple victims within a single program generates any between-victim variability in the effectiveness of the program. Most program developers often foresee a (short duration) training of the victims before they go out to bring their stories. These training sessions are not only aimed at practicing certain skills and raising victims' self-confidence, but also serve to somewhat standardize the program format. It is still unclear whether these sessions reach that objective.

Moreover, it would be insightful to examine whether embedding victim testimonials into a multi-delivery program format (Elkington, 2005) with pre- and follow-up sessions to foster the key-messages raised and discussed during the testimonial sessions, enhances the impact of victim testimonials.

Finally, we think the inclusion of other variables (e.g., implementation intentions) than the ones included in this study could be useful to learn what are the potential purposes for which policy makers can use victim testimonials.

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# GENERAL DISCUSSION

# 1. MAIN FINDINGS

In this doctoral thesis, both ends of the driver age spectrum (i.e., both older and younger drivers) have been investigated. For older drivers, driving behavior under neutral and distracting circumstances has been assessed by investigating specific measures of driving behavior and the role of functional abilities in driving. For both older and younger drivers, the immediate and extended effects of traffic safety interventions on (socio-cognitive determinants of) behavior have been investigated. The main findings are summarized below.

## 1.1. Assessment of driving behavior of older drivers

By investigating **the relations between specific measures of driving behavior and demographic measures and functional abilities of older drivers,** it became clear that the importance of functional abilities depends on the specific driving measure under investigation. This is in line with previous studies with older drivers investigating only cognitive abilities (Aksan et al., 2015; Anstey & Wood, 2011; Mullen et al., 2008). This is not surprising given the multifactorial nature of driving where not only cognitive, but also visual and motor abilities are important for safe driving (Bédard et al., 2008).

By investigating **the strength of the relations between specific measures of driving behavior and demographic measures and functional abilities of older drivers**, it became clear that demographic measures like age explain only a very small proportion of the variance in measures of driving behavior (i.e., between 3% and 15%). This is in line with the previous finding that age alone as the mere passage of time, is not an adequate predictor of driving ability (Anstey et al., 2012; Barrash et al., 2010). In addition, it became clear that, although functional abilities explain a larger amount of the variance in measures of driving behavior compared to demographic measures, the amount of the variance explained in measures of driving behavior is still rather limited (i.e., between 7% and 36%). This is in line with previous studies with older drivers (Backs et al., 2011; Mullen et al., 2008; Shanmugaratnam et al., 2010).

By investigating **the effect of distraction on specific measures of driving behavior of older drivers** it became clear that driver distraction had adverse effects on some measures of driving behavior of older drivers. This was in line with other studies with older drivers (Horberry et

al., 2006; Ni et al., 2007; Strayer & Drew, 2004). There was especially an adverse effect of distraction on driving measures with a high demand on both vehicle handling and information processing, but not on driving measures with a low demand on vehicle handling and/or information processing.
Drivers seemed to compensate for this challenging situation by driving at a lower speed when distracted. This is in line with previous studies where older drivers reduced task demands and increased safety margins by adopting a lower speed when distracted (Charlton et al., 2013; Horberry et al., 2006; Young & Lenné, 2010).

By investigating **whether attention capacity moderates the effect of distraction**, it became clear that there was a moderating trend effect of attention capacity on a measure of lateral control which is a sensitive measure of driver impairment (De Waard, 1996; Ramaekers, 2003): whereas lateral control improved during distraction in those with higher attention capacity, it deteriorated during distraction in those with lower attention capacity for the ride with distraction. The finding that attention capacity has a moderating effect is in line with Lavie's load theory (Lavie et al., 2004) and previous research with young drivers (Ross et al., 2014).
In addition to this moderating trend effect, attention capacity was negatively related to the number of accidents. These moderating and main effects of attention capacity indicate that cognitive capacity is important for measures of safe driving, not only in the context of driver distraction. This is in line with the finding in the first study of this doctoral thesis (Chapter 1) that cognitive abilities are related to measures of driving behavior.

By investigating **how people rate their driving performance during distraction**, it was clear that despite the decrease of driving performance with distraction, participants rated their driving performance during distraction quite high. The awareness of effects of distraction may influence drivers' willingness to engage in distracting activities: if they are not aware of detrimental effects, they will not be reluctant to engage in these activities (Horrey et al., 2008).

### 1.2. Evaluation of traffic safety interventions for older drivers

By investigating **the effect of an adaptive cognitive working memory training vs. a non-adaptive cognitive working memory training on cognitive abilities of older drivers**, it was clear that the training caused improvement in the cognitive ability being trained (i.e., working memory) with largest improvements in participants who followed adaptive training, smaller improvements in participants who followed non-adaptive training and only minimal improvements in participants who followed no training. This is in line with studies finding more effects with adaptive training compared to non-adaptive training (Brehmer et al., 2012; Holmes et al., 2009; Karbach et al., 2015; Klingberg et al., 2005; Klingberg et al., 2002). For attention, all groups improved, regardless of type of training, indicating a general test-retest effect. For response inhibition, group means were in the same direction, but results were only marginally significant. These results for attention and response inhibition are in line with learning theories that state that participants improve when performing a cognitive task for a second time (Boot et al., 2011; Collie et al., 2003).

By investigating **the effect of an adaptive cognitive working memory training vs. a non-adaptive cognitive working memory training on measures of driving behavior of older drivers,** it was clear that the training caused a marginally significant improvement on a limited amount of driving measures with largest improvements in participants who followed adaptive training, smaller improvements in participants who followed non-adaptive training and only minimal improvements in participants who followed no training. This rather limited effect of cognitive training on measures of driving behavior is not surprising given the finding in the first study of this doctoral thesis (Chapter 1) that specific driving measures are differently related to different functional abilities. This is also in line with studies where it is found that the specific cognitive ability being trained improves, with minimal or no transferring to untrained tasks (Gaspar et al., 2012; Mayhew, Robertson, et al., 2014; Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012).

In addition, effects on the limited amount of driving measures found were small. This is maybe what we could have expected given the relatively low amount of variance in driving behavior that is explained by cognitive abilities as found in the first study of this doctoral thesis (Chapter 1). In addition, the finding that cognitive training has limited effects on driving behavior is in line with previous research (Gaspar et al., 2012; Lange & Süß, 2015; Mayhew, Robertson, et al., 2014) and is the reason for the debate about cognitive training effects (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012).

By investigating **whether driving simulator based training improves specific measures of driving behavior of older drivers**, it was clear that by driving multiple times in the simulator, older drivers improved on some driving measures. This is in line with learning theories that performance improves with practice (Boot et al., 2011; Collie et al., 2003). Interestingly, for some driving measures, driving-specific feedback is necessary in order to improve. This is in line with recent research investigating older drivers (Lavallière et al., 2012; Romoser & Fisher, 2009). These findings indicate that driving simulator based training can serve as a method to attenuate deficits in measures of driving behavior.

Taking together the results of these two interventions for older drivers (i.e., cognitive working memory training and driving simulator based training) which are illustrated in Table 1, it seems that driving simulator based training had an effect on more driving measures and had larger effects compared to cognitive training. This is not surprising, since according to the law of identical elements and the practice-specificity approach of learning abilities, the best training conditions are those allowing the learning of the same underlying processes that will be used in the transfer task (Schmidt & Lee, 2005; Thorndike & Woodworth, 1901). Hence, if the final purpose is to transfer to the road, training must be conducted in a driving-specific context. As a consequence, a training more directly targeting driving behavior will have more effect. This is in line with other studies comparing the effects of cognitive training and driving simulator based training on driving behavior of older drivers (Casutt, Theill, et al., 2014; Devos et al., 2009). Hence, although cognitive abilities are important for driving, indirectly training driving behavior by training these cognitive abilities is not enough to have improvements in driving behavior.

**Table 1.** Effects of traffic safety interventions for older people on cognitive and driving measures

| | **Cognitive working memory training (Chapter 3)** | **Driving simulator based training (Chapter 4)** |
|---|---|---|
| **Cognitive measures** | | |
| Working memory | Adaptive training group > non-adaptive training group > no training group:<br>Post-test>Pre-test | n.a. |
| Attention | All groups:<br>Post-test>Pre-test | n.a. |
| Response inhibition | All groups:<br>Post-test>Pre-test<br>(marginally significant, p<0.10) | n.a. |
| **Driving measures** | | |
| Mean driving speed | Adaptive training group > non-adaptive training group > no training group:<br>Post-test > Pre-test<br>(marginally significant, p<0.10) | Control group:<br>Post-test > Pre-test |
| Standard deviation of lateral position | / | All groups:<br>Post-test < Pre-test |
| Accidents | / | All groups:<br>Post-test < Pre-test |
| Complete stops at stop signs | Adaptive training group > non-adaptive training group > no training group:<br>Post-test > Pre-test<br>(marginally significant, p<0.10) | / |
| Giving right of way | / | Experimental group:<br>Post-test > Pre-test |
| Gap acceptance when turning left | All groups:<br>Post-test < Pre-test | n.a. |

n.a. = not applicable

## 1.3. Evaluation of traffic safety interventions for younger people

By investigating **the immediate effects of a post-license education program for young novice drivers on socio-cognitive variables for driving-related risk behaviors (i.e., speeding and drink driving), on risk detection, and on risk-related knowledge,** it was clear that after session attendance, the program had small effects on some socio-cognitive variables of driving behavior. Possibly, this is due to the finding that participants already had a quite safety supportive view prior to session attendance. In addition to some desired effects (i.e., increased intention to respect the speed limits), the program also had some counterproductive effects (e.g., decreased risk perception of drink driving) on socio-cognitive variables. The program had no effect on risk detection. Even though we found a large effect on risk-related knowledge, the levels of risk-related knowledge still remain low after session attendance.

By investigating **the extended effects of a post-license education program for young novice drivers on socio-cognitive variables for driving-related risk behaviors (i.e., speeding and drink driving), on risk detection, and on risk-related knowledge,** it became clear that two months after session attendance, none of the effects on the socio-cognitive variables for driving-related risk behaviors prevailed. Only the effect on risk-related knowledge sustained.

By investigating **the immediate effects of a pre-license education program for high school students on socio-cognitive and behavioral variables,** it became clear that after session attendance, the program had small but positive effects on the socio-cognitive and behavioral variables. These program effects differed in function of education type. While students of general and occupational education were both significantly more traffic safety supportive after session attendance, no such effect could be established for students of technical education. One possible explanation for the significant program effect in the group of occupational education might be the fact that in this group, students held the least traffic safety supportive view at baseline and were more emotionally affected by the program compared to students of general and technical education.

By investigating **the extended effects of a pre-license education program for high school students on socio-cognitive and behavioral variables,** it became clear that two months after session attendance, there were significant, small to medium-sized positive effects on most of the socio-cognitive and behavioral variables. These program effects differed in function of gender. Both male and female students were significantly more traffic safety supportive after session attendance. However, the program had more effect on males than on females. These effects can be explained by the finding that male students held a less traffic safety supportive view than female students at baseline. In contrast, female students were more cognitively and emotionally affected by the program than male students.

By investigating **the effect of a pre-license education program for high school students on participants' cognitive and emotional state**, it can be concluded that personal testimonials by (relatives of) traffic victims can stimulate high school students to reflect upon their participation in traffic in such a way that they become more traffic safety supportive.

By investigating **whether the impact of a pre-license education program on high school students' cognitive and emotional state influenced the program's effect on socio-cognitive and behavioral variables**, it became clear that the impact of the program on participants' cognitive and emotional state was indeed relevant for determining the programs' effect on the targeted socio-cognitive and behavioral variables. Although too high levels of arousal might result in counterproductive effects (Carey et al., 2013; Peters et al., 2013; Ruiter et al., 2001; Ruiter et al., 2014; Ruiter et al., 2004; Witte, 1992), it seems that too low levels of arousal should be avoided as well. Indeed, we found that less aroused participants became traffic safety supportive to a lesser extent than participants declaring they were more aroused by the program. These findings appear to be in line with the view that the relationship between stimulus arousal and message acceptance can best be represented as an inverted U-shaped curve with moderate arousal levels leading to optimal results (Janis, 1967; McGuire, 1968, 1969).

Taking together the results of these two interventions for younger drivers (i.e., post-license education and pre-license education) which are illustrated in Table 2, it seems that both traffic safety interventions have an effect on socio-cognitive (and behavioral) variables and might serve as a method to improve the traffic safety view of young people. However, effects were sometimes small and even counterproductive. In addition, effects depended upon the target groups (i.e., gender and education type), which is in line with previous studies evaluating traffic safety campaigns among young people (King et al., 2008; Rosenbloom et al., 2009; Ulleberg, 2001) and illustrates that young people are not a homogenous group. The finding that high school students already had a road safety supportive view confirms that although they are new-comers as car drivers, they are not new to the roads. They already have extensive experience in other traffic roles like pedestrians and (motor)cyclists (Mann & Lansdown, 2009; Waylen & McKenna, 2008).

**Table 2.** Effects of interventions for young people on socio-cognitive and behavioral variables

| | **Post-license: On the Road (Chapter 5)** | | **Pre-license: Traffic Informers (Chapter 6)** | |
|---|---|---|---|---|
| **Socio-cognitive and behavioral variables** | **Measurement 1 (immediately after session attendance)** | **Measurement 2 (two months after session attendance)** | **Measurement 1 (immediately after session attendance)** | **Measurement 2 (two months after session attendance)** |
| Attitude | | / | General and occupational education: Post-test >Baseline | Males: Follow-up > Baseline |
| *Positive beliefs* | | | | |
| *Negative beliefs* | | | | |
| *Risk perception* | *Drink driving: Post-test < Baseline* | | | |
| Subjective norm | | / | General and occupational education: Post-test > Baseline | Males: Follow-up > Baseline |
| *Descriptive norm* | *Speeding: Post-test > Baseline* | | | |
| *Injunctive norm* | *Drink driving: Post-test < Baseline* | | | |
| *Personal norm* | *Drink driving: Post-test < Baseline* | | | |

|  | **Post-license: On the Road (Chapter 5)** |  | **Pre-license: Traffic Informers (Chapter 6)** |  |
|---|---|---|---|---|
| **Socio-cognitive and behavioral variables (continued)** | **Measurement 1 (immediately after session attendance)** | **Measurement 2 (two months after session attendance)** | **Measurement 1 (immediately after session attendance)** | **Measurement 2 (two months after session attendance)** |
| Perceived Behavioral Control |  | / | General education:<br>Post-test > Baseline | Females:<br>Follow-up > Baseline |
| *Situational pressure* | *Speeding:*<br>*Post-test > Baseline* |  |  |  |
| *Social pressure* |  |  |  |  |
| Behavioral intention |  | / | General and occupational education:<br>Post-test > Baseline | Males:<br>Follow-up > Baseline |
| *Situational pressure* | *Speeding:*<br>*Post-test > Baseline* |  |  |  |
| *Social pressure* |  |  |  |  |
| *General* |  |  |  |  |
| Behavior | n.a. | n.a. | Occupational education:<br>Post-test > Baseline | Males:<br>Follow-up > Baseline |

n.a. = not applicable

# 2. CLINICAL AND POLICY RECOMMENDATIONS

Based on these main findings, some clinical and policy recommendations can be offered both regarding the assessment of driving behavior and the evaluation of traffic safety interventions.

## 2.1. Assessment of driving behavior of older drivers

It is recommended to base screening programs not solely on age, since this might not be successful in lowering fatality rates of older drivers. Given that functional abilities are more important for assessing driving ability than chronological age, it is recommended that driver assessment programs include a module focusing on functional abilities. For example, a module focusing on cognitive capacity can be recommended since cognitive capacity is important for safe driving, both during non-distracted and during distracted driving. However, given the multifactorial nature of driving and the finding of the first study of this doctoral thesis (Chapter 1) that the importance of functional abilities depends on the driving measure under investigation, it will be necessary to assess several functional abilities, in contrast to assessing a single functional ability. As a result, a multi-tier system, which includes measures of functional ability in the second tier, will only be successful when the right set of functional abilities is measured. Interestingly, a recent investigation of the implementation of a three-tier system in California concluded that the system should not be adopted for state-wide implementation, since there was no reduction in the number of traffic accidents among drivers aged 70 years and older (Camp, 2013). Possibly, this reflects the lack of an instrument that adequately distinguishes between safe and unsafe drivers at this moment. Therefore, an assessment program that only includes measures of functional abilities will not be successful in discriminating safe from unsafe older drivers. Indeed, in the first study of this doctoral thesis (Chapter 1) it was concluded that functional abilities explain only a limited amount of the variance in driving ability. Although measures of functional ability are still useful in predicting driving ability of older drivers, incorporating a more context-relevant assessment (i.e., driving based) seems necessary to obtain reliable screening results. Hence, both measures of functional abilities and driving ability should be included when making decisions about driver fitness. Driving ability can be investigated with a direct test of driving ability, on the road or in a driving simulator. Given that drivers usually have problems with specific driving situations, it is important to assess specific driving measures in order to obtain a detailed enough view of driving ability.

It is recommended to eliminate driver distraction as much as possible since driver distraction had degrading effects on the majority of driving measures in participants with both lower and higher cognitive capacity. In addition, since complete elimination of driver distraction is impossible, education programs are important to increase awareness about adverse effects of driver distraction and to prevent that drivers overestimate their driving performance during distraction.

## 2.2. Development and evaluation of traffic safety interventions

In order for an intervention to be effective, it is recommended to focus on the right target group. Both ends of the driver age spectrum are a relevant target group since they have increased fatality rates. More specifically, young drivers are a relevant target group, since the first few months of independent driving pose the greatest risk of collision for novice drivers (Mayhew et al., 2003). In addition, previous research has shown that traffic safety-related attitudes evolve over time (Iversen & Rundmo, 2012) and that individuals are highly susceptible to attitude change during late adolescence and early adulthood (Krosnick & Alwin, 1989). Older drivers are also a relevant target group, since with age there is a decrease in functional abilities important for driving. However, programs targeting traffic safety views will probably have more effect in other target groups, for example, drivers with Mild Cognitive Impairment or as an alternative sanction for particular groups of traffic offenders, since it can be expected that they have more and larger deficits in (socio-cognitive determinants of) driving behavior. Originally, testimonials of (relatives of) traffic victims that are now offered for high school students were meant to serve as a 'curative' or a 'corrective' measure for clinical use in adult road user populations with elevated risk-taking levels such as occasional offenders. Previous research has indicated that testimonials could be an effective tool for the more mature offender (i.e., those with an age of 35 years or older) making an offense for the first time (Shinar & Compton, 1995). However, these testimonials will have limited effect on recidivism rates for people who drive under influence fairly often, since they have created a habit which is difficult to counter with solely one session.

In addition, it is recommended to work in structured and evidence-based manner, which is in line with the basic philosophy behind some well-known frameworks for the development of health and safety interventions such as the Intervention Mapping approach of Bartholomew et al. (2016). One needs to thoroughly investigate the true underlying needs within a specific target group before deciding on which variables to target. For example, although both cognitive working memory training and driving simulator based training might serve as a method to remediate specific deficits in older drivers, a cognitive training will have more effect in people who experience problems with cognitive abilities instead of problems with driving, while driving simulator based training will have more effect in people who have problems with driving instead of problems with cognitive abilities. Ideally, the training is tailored to the individual or a group of individuals with common characteristics, targeting those functions that are hampered. Importantly, program developers should not be overambitious in the number of objectives to be reached, but focus on a suitable amount of objectives.

Once the needs assessment has been conducted, appropriate methods and strategies should be selected based on the available theoretical and empirical scientific evidence. Unfortunately, interventions do not always select the appropriate methods and strategies to reach their objectives. For example, the post-license traffic safety intervention On the Road (chapter 5) which is in theory an insight program, still focuses too much on methods and strategies enhancing lower levels of the Goals for Driver Education matrix (i.e., knowledge). If it would focus more on methods and strategies enhancing higher levels, the intervention would be more successful in reaching the objectives.

It is recommended to evaluate the effects of interventions, since program effects are sometimes small, or even counterproductive. In addition to effect evaluations, process evaluations are also important to know why an intervention has or has not beneficial effects. Effects can depend on the background profile of participants (e.g., education) and on the way the program is offered (e.g., emotional and cognitive impact). Regarding the way the program is offered, it can be recommended to practitioners to aim at moderate arousal levels since these can be expected to result in optimal message processing.

## 3. STRENGHTS

These studies all have their strengths.

### 3.1. Older drivers

A strength of the first four studies (chapter 1, 2, 3 and 4) is that they used of a driving simulator that offers the possibility to investigate dangerous situations in a safe environment. One advantage of simulators is that they can function both as an assessment instrument and as an intervention instrument. As an assessment instrument it gives estimates of a person's driving performance. As an intervention instrument, it gives the opportunity to improve a person's driving performance. Moreover, it allows to investigate specific measures of driving ability. As a result, a more detailed view of the relation between driving ability and functional abilities and demographic variables can be identified which is necessary in order to make recommendations for driver assessment and traffic safety interventions.

In the first study (chapter 1) several types of functional abilities (i.e., cognitive abilities, motor abilities and visual abilities), instead of only one type of functional ability were considered.

In the second study (chapter 2) not only the effect of two types of driver distraction (i.e., visual distraction and cognitive distraction) were investigated, but also whether cognitive capacity moderates the effect of distraction.

In the third study (chapter 3), the differential effects of following an adaptive training, a non-adaptive training and no training were investigated. The adaptive training group can be regarded as an experimental group, while the non-adaptive training group can be regarded as an active control group. Since these groups only differ in terms of task difficulty, this provides a conservative assessment of training effects, because the influence of various unspecific factors is attenuated. The no-training control group can be regarded as a passive control group which allows to determine possible test-retest effects.

In the fourth study (chapter 4) not only the effect of driving simulator based training on specific measures of driving ability were investigated, but also the merits of driving-specific feedback.

A strength of the third and fourth study (Chapter 3 and 4), is the investigation of possible test-retest effects.

### 3.2. Younger drivers

A strength of the last two studies (Chapter 5 and 6) is the focus on both younger people who have obtained their driver's license recently as those who still need to obtain a driver's license. Other strengths of the last two studies are the use of questionnaires focusing on socio-cognitive and behavioral variables, the investigation of both immediate and extended effects and the investigation of possible questionnaire effects.

The fifth study (chapter 5) investigated not only the effect of a program on socio-cognitive and behavioral variables, but also on risk detection and risk-related knowledge.

The sixth study (chapter 6) investigated not only the effect of a program on socio-cognitive and behavioral variables, but also on the cognitive and emotional state of participants and whether this effect on the cognitive and emotional state of participants influenced the impact of the program on socio-cognitive and behavioral variables. Moreover, the amount of social desirable answering was investigated.

## 4. LIMITATIONS

Despite of these strengths, unavoidably, these studies have their limitations. The limitations are mainly related to: (1) the use of a driving simulator to investigate (effect of an intervention on) driving behavior, (2) the possibility of an underestimation of results due to several factors, and (3) the use of unrepresentative samples.

### 4.1. Use of a driving simulator

Although driving simulators have their benefits, simulators lack some of the complexity of real-world driving (e.g., interacting with other road users) and actions in a simulator have no real consequences. A key-issue is the degree to which simulated driving corresponds to real world driving and the extent to which findings in the simulator will thus correspond with on road findings. It has to be noted that although there is positive evidence for simulator validity (Aksan et al., 2016; Casutt, Martin, et al., 2014; Fisher et al., 2011; Lee et al., 2003), there is only evidence for relative validity, not for absolute validity. This means that the direction of change of a simulated driving measure is in the same direction as a corresponding driving measure in the real world, but does not produce the same numerical change. As a consequence, investigation of driving in real-world conditions would cause comparable changes in driving measures that were investigated in a simulator, however, the amount of changes in the real-world can be different than what is observed in the simulator (Fisher et al., 2011).

Moreover, people can experience symptoms of simulator sickness which are comparable to symptoms of car sickness. Symptoms include oculomotor disturbance (e.g., fatigue, headache, eyestrain, difficulty in focusing, blurred vision), disorientation (e.g., dizziness, vertigo), and nausea (e.g., increased salivation, sweating, stomach awareness; Mullen et al. (2010)). Due to simulator sickness not all drivers can be tested or trained with a driving simulator (Fisher et al., 2011). This is especially the case for older drivers since the risk of sickness increases with age (Mullen et al., 2010; Teasdale et al., 2009). In the present studies (chapter 1, 2, 3, and 4) there was a drop-out between 20% and 30% due to simulator sickness which is comparable to other studies investigating older drivers in a driving simulator.

### 4.2. Possibility of underestimation of results

Possibly, there is an underestimation of results in all studies due to several factors (e.g., sample size, inclusion criterion, baseline scores, self-selection bias).

Regarding the studies with older drivers (chapter 1-4), the sample size of each group was relatively small. As a consequence, the chance to detect significant results is smaller. In addition, an MMSE of 25 was used as an inclusion criterion in these studies. However, MMSE scores vary by age and years of education. Median scores are higher for people with a young age and people with several years of education, while median scores are lower for people with an advanced age and people with no or limited years of education. As a consequence, the threshold of 25 could have been too high for older people with no or limited years of education. Hence, these people were possibly incorrectly excluded from the studies. In addition, many older drivers are unfamiliar with computer technology and the use of driving simulators may be intimidating and impede their performance.

Regarding the traffic safety interventions, small positive intervention effects are maybe what we could have expected, since the margin available for the program to have an effect on participants' traffic safety supportive view was limited beforehand. For example for older drivers (Chapter 3 and 4), there could have been an underestimation of the program's true effectiveness, since although cognitive plasticity can be assumed in old age, it is more constrained compared to that of younger people (Lange & Süß, 2015). Compared to intervention studies with younger people, training studies with older people have typically reported smaller effects (Lange & Süß, 2015; von Bastian & Oberauer, 2014).
Also for younger drivers, there could have been an underestimation of the program's true effectiveness (chapter 5 and 6), since prior to session attendance, they were already quite traffic safety supportive, which might have created a ceiling effect.

Regarding all studies (chapter 1-6), the possibility of a self-selection bias has to be kept in mind. Especially those drivers that think of themselves as good drivers could be more willing to volunteer to participate in a study investigating (socio-cognitive and behavioral variables of) safe driving.

### 4.3. Unrepresentative samples

Regarding the studies with older drivers (chapter 1-4) and the studies with younger drivers (chapter 5-6), the investigated samples are not representative for the whole population of older and younger drivers due to the adopted inclusion criteria (e.g., MMSE score of 25 or higher), and to the possibility of a self-selection bias.

## 5. FUTURE RESEARCH SUGGESTIONS

Based on the present studies, some suggestions for future research can be offered.

### 5.1. Assessment of driving behavior

Related to the use of a driving simulator to assess driving behaviour, future research should replicate the studies described in chapter 1-4 during real-world driving in order to investigate the practical relevance of the results. Further investigation of simulator sickness and ways to prevent it are important, especially since driving simulators may be part of assessment and training programs.

Related to the study investigating effects of driver distraction (chapter 2), future studies should investigate the effect of in-vehicle instruments that can lead to distraction. Taken into account the progress in Advanced Driver Assistance Systems, especially the possible detrimental effects of these systems should be investigated. Although these systems are developed to assist the driver in the driving task in order to minimize the number of errors and to avoid unsafe behavioral choices as much as possible (Davidse, 2006), they can also distract the driver during driving.

### 5.2. Evaluation of traffic safety interventions

Related to the methods and strategies used in an intervention, future research should investigate the effects of other interventions than investigated in this doctoral thesis. For example, in this doctoral thesis, a context-general cognitive training was investigated. Since previous research found promising effects of a context-specific cognitive training in the context of drinking and eating behavior (Houben & Jansen, 2011;

Houben, Nederkoorn, Wiers, & Jansen, 2011; Jones & Field, 2013), the benefits of this kind of cognitive training should be investigated.
In addition, in this doctoral thesis only the effect of a training targeting one cognitive ability was investigated. Given the finding that different cognitive abilities are differently related to different driving measures, the effects of a multifactorial cognitive training (i.e., a training that includes tasks addressing a variety of cognitive abilities as used by Schmiedek et al. (2010)) should be investigated. Related to this issue, not only a multifactorial training targeting cognitive abilities should be investigated but also a training targeting visual and motor abilities since they are also important for driving. Although this would again be an indirect way for training driving ability, previous research found promising effects of a motor training on driving ability (Marmeleira et al., 2009). In addition, this doctoral thesis investigated the effects of cognitive training and driving simulator based training separately. Given the finding that functional abilities alone insufficiently predicts driving ability, the effect of a multifactorial training targeting both functional abilities and driving should be investigated. At last, in this doctoral thesis (chapter 3-6) the evaluation studies have been carried out at the intervention overall level. In order to know which components (do not) work, future research should adopt a component-specific approach.

Related to the sustainability of effects, future research should examine long-term effects of an intervention, since this doctoral thesis only examined immediate effects (chapter 3-6) or effects up to two months after session attendance (chapter 5-6). Previous research with older drivers found effects of cognitive training for several months (Borella et al., 2013; Li et al., 2008) and effects of driving simulator based training for some years (Devos et al., 2010; Romoser, 2012). Previous research with high school students found effects of an educational program consisting of testimonials of traffic victims for several months (King et al., 2008). In addition, future studies should explore how many sessions are needed and whether booster sessions are necessary to obtain longer-term effects.

Although this doctoral thesis investigated both young and older drivers, none of the studies included both age groups in the same study. This does not mean that the studies are not beneficial in other than the investigated age groups. Indeed, the detrimental effects of distraction and the role of cognitive capacity has already been demonstrated in younger drivers (Ross et al., 2014), just like the promising effects of driving simulator based training consisting of four sessions of six to eight minutes on measures of driving ability of younger drivers like lateral control, steering and visual search (van Leeuwen, Happee, & de Winter, 2015; Wang, Zhang, & Salvendy, 2010). Also, the effect of an educational program on older drivers socio-cognitive and behavioral variables has been investigated (Tuokko et al., 2014). However, the effect of cognitive working memory training on driving ability of younger drivers has not been investigated yet. Since previous studies indicated the relation between working memory and driving ability of younger drivers (Mäntylä et al., 2009; Ross et al., 2014), transfer effects of cognitive working memory training to some driving measures of younger drivers can be expected. However, since this training indirectly tries to affect driving ability, especially effects on cognitive ability are expected, with rather limited effects on driving ability.

# FINAL CONCLUSIONS

This doctoral thesis focused on both ends of the driver age spectrum. Underlying mechanisms of driving behavior of older drivers were investigated and traffic safety interventions (targeting these underlying mechanisms) for both older and younger drivers were evaluated.

Based on the studies assessing measures of driving behavior of older drivers when driving under neutral circumstances, it can be concluded that when making decisions about driver fitness, it is not sufficient to base this solely on age. Although functional abilities seem to be more important predictors of driving behavior, it is also not sufficient to only pay attention to a single functional ability (e.g., cognitive ability). Instead, several functional abilities and specific measures of driving ability should be assessed.

Based on the studies assessing measures of driving behavior of older drivers when driving under distracting circumstances, it can be concluded that older drivers experienced detrimental effects of driver distraction and nevertheless estimated their performance during driving with distracting quite high. Especially older drivers with decreased cognitive capacity experienced detrimental effects of distraction. Therefore, it is important to eliminate driver distraction as much as possible and to offer educational programs so that people can improve in self-estimation.

From the studies investigating effects of traffic safety interventions for older drivers, it can be concluded that cognitive training has beneficial effects on the cognitive function being training, with adaptive training leading to larger benefits compared to non-adaptive training. Importantly, although cognitive abilities are important for safe driving, cognitive training seems to have limited effects on measures of driving ability. Driving simulator based training seems to have more and larger effects on measures of driving ability of older drivers. The finding that older people can improve by training is in support of the lifelong learning approach. Therefore, in case drivers have limited problems with functional abilities or driving ability, it can be decided to restrict their driving (e.g., daytime only) or recommend them to follow driver education or training. However, in case drivers have excessive problems with functional abilities or driving ability, driving cessation would be more appropriate. In that case, it is important to assist drivers in this process, since driving cessation can have a negative impact on people’s quality of life.

From the studies investigating effects of traffic safety interventions for younger drivers, it can be concluded that although these programs can have beneficial effects on the road safety view of young drivers who recently acquired a driver's license and those who still need to obtain a driver's license, effects depended on the characteristics of the target group (e.g., gender, education). In addition, these programs can also have counterproductive effects like a decreased risk perception of drink driving after program attendance.

The studies evaluating the effects of traffic safety interventions for both older and younger drivers demonstrated the importance of evaluation. Ideally, the intervention is tailored to the individual or a group of individuals with common characteristics, tackling especially those aspects that are needed the most. As a consequence, a needs assessment is necessary. In order to do this, specific measures are necessary to obtain a detailed enough view. Once the needs assessment is conducted, it is necessary to pay attention to the methods and strategies selected to address the objectives.

The findings of this doctoral thesis lead to more insights that are useful for the development of driver assessment procedures to distinguish safe drivers from unsafe drivers and for the development of traffic safety interventions to create safe drivers and to keep them safe drivers for as long as possible. As a result, the findings indirectly help to reach the goal to decrease the number of road fatalities.

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Ariane Cuenen graduated in Economics-Mathematics at the Sacred Heart Institute in Lanaken in 2007. Afterwards, she started her studies in Psychology at Maastricht University (the Netherlands). Ariane obtained her bachelor degree in Cognitive psychology in 2010, and subsequently her master degree in Health and social psychology in 2012. Together with her master degree, she obtained her base-registration psychodiagnostics.

In February 2012, Ariane started her PhD at the Transportation Research Institute-Hasselt University in Diepenbeek under the supervision of Prof.dr. Tom Brijs (promoter), dr. Ellen M.M. Jongen and Prof.dr. Kris Brijs (co-promoters). She was employed in the research group Traffic Safety and was enrolled in several educational activities of the bachelor-master program in Transportation Sciences at Hasselt University.

## Journal publications

Ready for submission

- **Cuenen, A.**, Jongen, E.M.M., Brijs, T., Brijs, K., Van Vlierden, K., & Wets, G. (ready for submission). The effect of driving simulator based training on specific measures of driving ability of older drivers. *Human factors.*

Accepted for publication

- **Cuenen, A.**, Jongen, E.M.M., Brijs, T., Brijs, K., Houben, K., & Wets, G. (accepted for publication). Effect of a working memory training on aspects of cognitive ability and driving ability of older drivers: Merits of an adaptive training over a non-adaptive training. *Transportation Research part F*

2016

- **Cuenen, A.**, Brijs, K., Brijs, T., Van Vlierden, K., Daniels, S., & Wets, G. (2016). Effect evaluation of a road safety education program based on victim testimonials in high schools in Belgium. *Accident Analysis and Prevention 94,* 18-27.
- **Cuenen, A.**, Jongen, E.M.M., Brijs, T., Brijs, K., Lutin, M., Van Vlierden, K., & Wets, G. (2016). The relations between specific measures of simulated driving ability and functional ability: New insights for assessment and training programs of older drivers. *Transportation Research part F* 39, 65-78.

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## Conference publications/presentations

2016

- Urlings, Judith, H.J.; Jongen, Ellen, M.M.; **Cuenen, Ariane**; & Brijs, Tom (2016). Het beoordelen van de rijgeschiktheid bij ouderen met een cognitieve beperking. Belgische vereniging voor gerontologie en geriatrie. 39ste winter meeting 2016, Blankenberge, Belgium, 26-27 February 2016.
- **Cuenen, Ariane**; & Boets, Sofie (2016). Gebruik van checklist "rijvaardigheid ouderen". Grootschalige campagne voor 65+ autobestuurders. Paper presented at the Flemish traffic safety conference, Antwerp, Belgium, 22 March 2016.
- Boets, Sofie; & **Cuenen, Ariane** (2016). Gebruik van checklist "rijvaardigheid ouderen". Grootschalige campagne voor 65+ autobestuurders. Paper presented at the National traffic safety conference, 's Hertogenbosch, the Netherlands, 21 April 2016.

2015

- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Brijs, Kris; Houben, K.; & Wets, Geert (2015). Training working memory in older drivers: The effect on cognitive ability and driving performance. Poster presented at the International Convention of Psychological Science, Amsterdam, the Netherlands, 12-14 March 2015.
- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Brijs, Kris; Houben, K.; & Wets, Geert (2015). Training working memory of older drivers: The effect on working memory and simulated driving performance. Paper in Proceedings of the eight international driving symposium on human factors in driver assessment, training and vehicle design, Lake Tahoe, United States, 22-25 June 2015.
- Urlings, Judith; Jongen, Ellen; **Cuenen, Ariane**; Brijs, Tom; Lutin, M.; & Wets, G. (2015). Predicting fitness to drive in elderly drivers with cognitive impairments. Paper presented at the Human Factors and User experience in everyday life, medicine and Work, Groningen, The Netherlands, 14-16 October 2015.
- Babaee, Seddigheh; Hermans, Elke; Shen, Yongjun; Toloo, M.; Brijs, Tom; Wets, Geert; & **Cuenen, Ariane** (2015). Safety Evaluation of Older Drivers Based on Psychological, Physical and Driving Performance. Paper in Proceedings of the Road safety and Simulation International Conference, Orlando, Florida, 6-8 October 2015.

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- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Brijs, Kris; Ruiter, Rob; Guerrieri, Ramona; & Wets, Geert (2014). Training van impulscontrole bij oudere bestuurders: effecten op impulscontrole en rijvaardigheid. Paper presented at the Flemish traffic safety conference, Oostende, Belgium, 13 May 2014.
- **Cuenen, Ariane**; Brijs, Kris; Brijs, Tom; Van Vlierden, Karin, & Daniels, Stijn (2014). Getuigen onderweg: Effectevaluatie van een verkeerseducatief programma in de 3e graad secundair onderwijs. Paper presented at the Flemish traffic safety conference, Oostende, Belgium, 13 May 2014.
- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Brijs, Kris; Ruiter Rob; Guerrieri, R.; & Wets, Geert (2014). Training inhibitory control in older drivers: the effect on inhibitory control and simulated driving ability. Paper presented at the 2014 International Annual Meeting Human Factors and Ergonomics Society, Illinois, USA, 27-31 October 2014.
- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Brijs, Kris; Ruiter, Rob; Guerrieri, R.; & Wets, Geert (2014). Training inhibitory control in older drivers: the effect on inhibitory control and simulated driving ability. Paper presented at the Applied Human Factors and Ergonomics, Krakow, Poland, 13-23 July 2014.
- **Cuenen, Ariane**; Brijs, Kris; Brijs, Tom; Van Vlierden, Karin; Daniels, Stijn; & Wets, Geert (2014). Traffic informers: effect evaluation of a 3rd grade secondary school-based education program. Paper presented at the International congress of applied psychology, Paris, France, 8-13 July 2014.
- **Cuenen, Ariane**; Jongen, Ellen; Brijs, Tom; Ruiter, Rob; Guerrieri, R.; & Wets, Geert (2014). Training inhibitory control in older drivers: the effect on inhibitory control and simulated driving ability. Paper presented at the Aging and Safe Mobility conference, Bergisch-Gladbach, Germany, 27-28 November 2014.

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- **Cuenen, Ariane**; Jongen, Ellen, Brijs, Tom, Brijs, Kris, van Breukelen, G., Lutin, M., Van Vlierden, Karin, & Wets, Geert (2013). Rijvaardigheid van ouderen voorspellen. Paper presented at the Flemish traffic safety conference, Antwerp, Belgium, 16 May 2013.
- Ceulemans, Wesley, **Cuenen, Ariane**, Brijs, Kris, Brijs, Tom, & Wets, Geert (2013). Visual performance of elderly drivers and the relation with cognitive abilities: An eye tracking study. Paper presented at the International Congress: Mobility and Traffic safety in an Ageing Society, Vienna - Austria, 19-20 June 2013.
- **Cuenen, Ariane**, Jongen, Ellen M.M., Brijs, Tom, Brijs, Kris, Lutin, Mark, Van Vlierden, Karin, & Wets, Geert (2013). The effect of visual and cognitive distraction on the driving performance of older drivers - A driving simulator study. Paper presented at the 3rd International Conference on Driver Distraction and Inattention, Gothenburg, Sweden, 4-6 September 2013.

2012

- Jongen, Ellen, Brijs, Tom, Brijs, Kris, Lutin, Mark, **Cuenen, Ariane**, Van Vlierden, Karin, & Wets, Geert (2012). Beyond summarized measures: Predictability of specific measures of simulated driving by specific physical and psychological measures in older drivers. Paper presented at the International Conference on Aging, Mobility and Quality of Life, Michigan, USA, 24-26 June 2012.
- **Cuenen, Ariane**, Jongen, Ellen M.M., Brijs, Tom, Brijs, Kris, Lutin, Mark, Van Vlierden, Karin, & Wets, Geert (2012). Beyond summarized measures: Predictability of specific measures of simulated driving by specific physical and psychological measures in older drivers. Paper presented at the 25th International Co-operation on Theories and Concepts in Traffic Safety Workshop, Diepenbeek, Belgium, 8-9 November 2012.

## Other publications/presentations

- **Cuenen, Ariane**, Jongen, Ellen, M.M., Brijs, Tom, Brijs, Kris, & Daniels, Stijn (2016). Driving simulator based and cognitive training with the goal to keep older drivers safe drivers for as long as possible. http://www.steunpuntverkeersveiligheid.be/en/node/631
- Brijs, Kris, Van Vlierden, Karin, **Cuenen, Ariane**, Ross, Veerle, Urlings, Judith, Jongen, Ellen, Declercq, Katrien, Brijs, Tom, & Wets, Geert (2016). Towards a reformed driver training: Study on the effectiveness of models and components.
- **Cuenen, Ariane,** Urlings, Judith, Jongen, Ellen, Neven, An, & Brijs, Tom (2016). Rijvaardigheid van senioren. April nummer Actueel van de Vlaamse ouderenraad.
- **Cuenen Ariane.** Rijvaardigheid van senioren. *Themadag: Mobiliteit, seniorproof? Vlaamse Stichting Verkeerskunde*. Focusthema: met de auto. Mechelen (Belgium). 4 May 2015.
- **Cuenen, Ariane**, Brijs, Kris, Brijs, Tom, Van Vlierden, Karin, Daniels, Stijn, & Wets, Geert (2013). Traffic informers: effect evaluation of a traffic-related education program in the 3rd grade of secondary school. http://www.steunpuntmowverkeersveiligheid.be/nl/node/527

## Projects

- Jessa Hospital, IMOB (UHasselt) (2010-2012). Limburg Sterk Merk. Driving ability of older drivers.
- Steunpunt Verkeersveiligheid, 3$^{e}$ generatie (2012-2015). WP4: Ontwikkeling van verkeersveiligheidsmaatregelen.
- Steunpunt Verkeersveiligheid, 3$^{e}$ generatie (2012-2015). WP5: Ranking en evaluatie van maatregelen.
- Jessa hospital, BVBA Dr. Lutin, IMOB (UHasselt), Enter (2014-2017). CareVille Moving Care. A multidisciplinary approach of evaluation and support of safe mobility of seniors.
- BIVV, IMOB (UHasselt). Checklist 65+ driver, check your driving ability. http://www.senior-test.be

## Scholarships and grants

A-CIPA Young Researcher Prize with the support of la Fondation Maison des Sciences de l'Homme, €500,- for the study 'Effect evaluation of a 3rd grade secondary school-based education program' presented at the 28th International Congress of Applied Psychology.

## Teaching activities

Bachelor of Transportation Sciences

- Course Traffic psychology (2012-2013, 2013-2014, 2014-2015, 2015-2016)
- Course Traffic research 2 (2012-2013, 2013-2014, 2014-2015, 2015-2016)
- Course Integrated Project:
    - Michelle Geenen: Invloed van dementie op het rijgedrag van ouderen (2012-2013)
    - Han Xia and Nodira Yusupova: Improving the Driving Ability through Driving Simulator Based Training (2013-2014)
    - Danh Phan Chau and Pablo Luján García: Living without a driver’s license (2013-2014)
    - Giel Vanzeer: Effect van werkgeheugentraining bij senioren (2014-2015)

Master of Transportation Sciences

- Course Traffic and Travel Behavior (2012-2013, 2013-2014, 2014-2015, 2015-2016)
- Course Case study:
    - Dana Deliever: Evaluating the effectiveness of an educative insight program (2011-2012)
- Course Academic research skills:
    - Steffen Briers: Older drivers and cognition (2012-2013)
    - Brecht Pelssers: Rijmanieren van oudere bestuurders: effect van training (2013-2014)
- Course Internship:
    - Thi Thuy An Vo: Improving driving ability through a driving simulator based training (2013-2014)
- Course master thesis:
    - Dana Deliever (2012-2013): *Evaluating the effectiveness of the educative insight program ‘Getuigen onderweg’*
    - Steffen Briers (2013-2014): *The effect of a working memory training on cognitive ability and driving ability of older drivers*
    - Veronika Rudnenko (2014-2015): *Effect of Social Pressure on Driving Ability of Older Drivers*
    - Brecht Pelssers (2014-2015): *Het effect van een cognitieve training op de cognitieve vaardigheden en rijvaardigheden van ouderen*