Simulator study on the effects of sign typology, distraction and time on driving

Kristof Mollu

promotor :
Prof. dr. Tom BRIJS

co-promotor :
dr. Ellen JONGEN

Masterproef voorgedragen tot het bekomen van de graad van
master in de verkeerskunde, afstudeerrichting verkeersveiligheid

ACKNOWLEDGEMENT

Five years ago, I decided to follow the academic training in Transportation Sciences at the University of Hasselt. Today I present my Master's Thesis. As my main subject I have chosen Traffic Safety and the title of my dissertation is : "Simulator study on the effects of sign typology, distraction and time on driving". By means of a traffic simulator I have examined the differences in traffic behaviour dependent on the used speed sign, time and a higher mental load.

First of all I want to express my gratitude to some people. During the preparation of this document, I was supervised by *Dr. Ellen M.M. Jongen* (co-promoter) and *Dr. Kris Brijs*. I want to thank them both for their positive feedback, constructive criticism and close cooperation. Each time I had a problem, they came up with a possible solution or they referred me to the proper literature. Whenever I mailed my co-promoter, I almost immediately received an answer.

Next, *Dirk Roox* (Institute for Mobility – IMOB) deserves special attention because he programmed the scenarios and explained the databases. I also want to mention my promoter *Prof. Dr. Tom Brijs* for his supervision and coaching.

A total of 49 persons have participated in my research and I sincerely want to express my thanks to them all. I would also like to mention my aunt *Marina Van Attenhoven* and sister *Ellen* who have helped me with my English and have corrected this paper.

Further, I want to thank all my *friends* and *family* for the moral support during this five-year training. My friends gave me the right distraction whenever it was necessary so I could start all over again with a clean slate.

Last but not least, I want to thank *Caroline Ariën* who gave me new insights in simulator research. Caroline (2010) is a colleague student with a similar thesis and we helped each other where possible.

Kristof Mollu, Kortenaken
28th of May 2010

ENGLISH SUMMARY

In general, the speed limit on open roads outside built-up areas in Belgium is defined at 90 km/h unless a speed sign indicates differently. Since 2002, more and more cities switch over to a speed limit of 70 km/h on different locations. Because this is not a general implementation, traffic signs are needed. One can do this in two (four) different ways: the traditional indication (eventually with repetition) or the zone indication (eventually with repetition). Starting from the question whether these indications are efficient, this study examined three types of speed indications and this in a situation where one was distracted or not: traditional signalization using the C43 sign to indicate the speed limit that is valid until the next intersection (without recall the speed limit after an intersection is 90 km/h), zone signalization using zone signs to indicate the begin (F4a sign) and end (F4b sign) of a zone, and zone-repetition signalization similar to zone signalization but adding a 'F4a-repetition sign' in the zone. Since not complying to the speed rules is one of the most important reasons for crashes, it was useful to see if there are any differences in reaction to the different speed indications.

To determine the effect of these three types of signalization on driving behaviour, 49 participants (data of 46 persons were useful, of which 24 men; average age 38 years) were asked to drive two research trips of 18 kilometres in a driving simulator. The experiment was conducted on the high-fidelity driving simulator of Hasselt University, which is fixed-based (no kinesthetic feedback). The simulation included vehicle dynamics, visual and auditory feedback and a performance measurement system. The visual virtual environment was presented on a large 180° field of view (resolution 1024x768).

After three warm-up trips of 6 km, the experimental scenario was presented consisting of one 18 km long trip with a secondary task and the same trip without a secondary task. Each research trip took place on a light curved road with two lanes and two bicycle tracks, consisting of three segments of 6 kilometres in which a different speed indication was used. Both the order of the two trips and the order of the three used signalizations (i.e. the three segments) within one trip were counterbalanced. In each segment, there were only two speed regimes: first there was for 1 km a limit of 90 km/h which, depending on the scenario, was transformed by the traffic sign C43 or F4a into a limit of 70 km/h (for 4750 m), after which this speed limit was cancelled out 250 m before the end of the first segment by the traffic sign C45 or F4b. In each segment there was added

on two, three, four and five kilometres an intersection where the traffic lights were at green and this in order to see whether the driver accelerated if the speed was not explicitly indicated after an intersection. In the traditional scenario the speed limit was indicated after each crossing, while this was not the case in the two zone scenarios. In the zone scenario only the beginning and the end of the zone was indicated, while in the zone-repetition scenario the F4a sign was placed again at 3500 m with at the bottom the word 'repetition'.

The secondary task – that should provide distraction – consisted of a two-choice discrimination reaction time task in which a reaction was required at four different target stimuli in the rearview mirror. In the trip where this extra task had to be carried out, there was not given a priority in the instruction between the driving task and the extra task. Before one started with the trips, a questionnaire was used to determine if one knew the different speed indications and the wrong answers were corrected. The instruction for each trip was that one must drive as one normally would do and that all traffic lights should be at green. The average speed, the standard deviation of the average speed and of the lateral position, the time and distance out of lane and the performance on the secondary task of each participant was analyzed in a repeated measures ANOVA with Sign (three levels: traditional, zone, zone-repetition), Secondary Task (two levels: with, without) and Intersection (four levels) and, eventually, Before/After the sign (two levels: 250 m before, 250 m after) as factors.

The results of the research trips confirm the compensation behaviour that was found in literature when one is distracted, namely one drove slower. Further, the time and distance outside the lane was less and one had a smaller standard deviation of the lateral position in the trips with distraction, resulting in less swerving. The latter findings are, however, the opposite of what was found in literature. The main conclusion of this study was that when time went by (or more intersections were added) there was a difference in the response to the speed indication. When the limit was indicated after each intersection by the traffic sign C43 (traditional indication), the speed remained more or less the same while there was a linear increase in the zone indication. However, the repetition sign showed to be efficient because – after the speed was increased till the repetition sign was placed – the speed decreased after the repetition sign to increase again after the next intersection (cubic trend). It should be noted that distraction had no effect on these patterns. Further, it was demonstrated – by means of a questionnaire – that drivers knew less the meaning of the sign that indicates the beginning of a zone (F4a sign) than the meaning of the traditional indication. After correction for this fact, no difference was found in the average speed in the 250 m after a speed transition between the traditional and zone signs (C43 compared to F4a and C45 compared to F4b).

Based on these results, the policy is recommended not to implement a general introduction of speed zones and it is rather advised to go to a general speed limit of 70 km/h outside built-up areas instead of the current 90 km/h limit. However, this study has pointed out that drivers are little sensitive to changes in the Highway Code and for this reason new rules should be communicated exhaustively and a study should be determine if one follows this new general speed limit.

NEDERLANDSE SAMENVATTING

In het algemeen is de snelheidslimiet buiten de bebouwde kom in België vastgesteld op 90 km/u, tenzij er een verkeersbord is geplaatst dat een andere limiet aanduidt. Sinds 2002 schakelen steeds meer gemeenten op verschillende locaties over naar een snelheidslimiet van 70 km/u en omdat het niet over een algemene regel gaat, zijn verkeersborden nodig. Men kan dit doen op twee (vier) verschillende manieren: de traditionele aanduiding (eventueel met herhaling) of de zonale aanduiding (eventueel met herhaling). Vanuit de vraag of deze aanduidingen wel efficiënt zijn, ging deze studie drie snelheidsaanduidingen na en dit in een situatie waarbij men afgeleid was of niet: de traditionele aanduiding waarbij na elk kruispunt het verkeersteken C43 wordt geplaatst, de zonale aanduiding waarbij enkel het begin (verkeersteken F4a) en einde (verkeersteken F4b) van de snelheidszone wordt aangeduid en de zone-herhaling aanduiding waarbij er een herhalingsbord wordt geplaatst in de zone. Omdat het niet naleven van de snelheidslimiet een van de belangrijkste oorzaken is van ongevallen, was het aangewezen om te onderzoeken of er verschillen zijn in reactie op de verschillende snelheidsaanduidingen.

Om na te gaan wat het effect is van deze drie aanduidingen op het verkeersgedrag, werd aan 49 deelnemers (gegevens van 46 personen bruikbaar, waarvan 24 mannen; gemiddelde leeftijd 38 jaar) gevraagd om twee onderzoeksritten van 18 kilometer uit te voeren in een rijsimulator. Het experiment werd uitgevoerd op de geavanceerde rijsimulator van de Universiteit Hasselt, een fixed-based simulator zonder kinetische feedback. De simulatie bevatte de voertuigdynamiek die via visuele en auditieve feedback werd gepresenteerd en een meetsysteem dat het rijgedrag registreerde. De visuele omgeving werd op een groot projectiescherm van 180° gepresenteerd (resolutie 1024x768).

Nadat drie opwarmingsritten van telkens 6 km werden afgelegd, vonden er twee onderzoeksritten plaats waarbij men één keer met en één keer zonder secundaire taak (dezelfde rit) een rit van 18 km reed. Elke rit vond plaats op een licht bochtige weg met twee rijstroken en aanliggende fietspaden, bestaande uit drie segmenten van 6 kilometer waarin telkens een andere snelheidsaanduiding werd gebruikt. Zowel de volgorde van de twee onderzoeksritten als de volgorde van de snelheidsaanduidingen (i.e. de drie segmenten) binnen de onderzoeksritten werden gecontrabalanceerd. In elk segment

waren er slechts twee snelheidsregimes: eerst was er gedurende 1 km een limiet van 90 km/u die afhankelijk van het scenario door het verkeersbord C43 of F4a werd omgevormd tot een limiet van 70 km/u (gedurende 4750 m), waarna deze snelheidslimiet op 250 m voor het einde van het eerste segment via het verkeersbord C45 of F4b werd opgeheven. In elk segment werd er op twee, drie, vier en vijf kilometer een kruispunt toegevoegd waarbij de verkeerslichten op groen stonden en dit om te kijken of de snelheid veranderde wanneer de limiet niet was aangegeven na een kruispunt. In het traditionele scenario werd de snelheidslimiet na ieder kruispunt aangeduid terwijl dit niet het geval was in de twee zonale scenario's. In het zonale scenario werd enkel het begin en het einde van de zone aangeduid terwijl in het scenario met herhaling ('zone-herhaling') op 3500 m het zonebord F4a opnieuw werd geplaatst met het onderbord 'herhaling'.

De secundaire taak – die voor afleiding moest zorgen – bestond uit een *two-choice discrimination reaction time task* waarbij men aan de hand van de richtingaanwijzer moest reageren op vier verschillende stimuli in de achteruitkijkspiegel. In de rit waarin deze extra taak uitgevoerd moest worden, werd er geen prioriteit opgegeven tussen de rijtaak en de extra taak. Alvorens van start te gaan met de ritten, werd via een vragenlijst nagegaan of men de verschillende snelheidsborden kende en werden foutieve antwoorden gecorrigeerd. De instructie voor elke rit was dat men moest rijden zoals men normaal zou rijden en dat alle verkeerslichten op groen zouden staan. Van elke deelnemer werd de gemiddelde snelheid, de standaardafwijking van de gemiddelde snelheid en van de laterale positie, de tijd en afstand buiten de rijstrook en de performantie op de secundaire taak geanalyseerd in een repeated measures ANOVA met Bord (drie niveaus: traditioneel, zone, zone-herhaling), Secundaire Taak (twee niveaus: met, zonder) en Kruispunt (vier niveaus) en eventueel Voor/Na het bord (twee niveaus: 250 m voor, 250 m na) als factoren.

De resultaten van deze onderzoeksritten bevestigen het in de literatuur teruggevonden compensatiegedrag dat men, wanneer men afgeleid is, trager rijdt. Verder was de tijdspanne en de afstand buiten het rijvak kleiner en had men een kleinere standaardafwijking van de laterale positie in de ritten met afleiding waardoor men minder slingerde in deze ritten. Deze laatste vaststellingen zijn echter het tegenovergestelde van wat in de literatuur werd teruggevonden. De belangrijkste conclusie van de studie was dat als de tijd toenam (of meer kruispunten werden toegevoegd) er een duidelijk verschil was in de opvolging van de snelheidsaanduiding. Wanneer de limiet na elk kruispunt werd aangeduid via het verkeersbord C43 (traditionele aanduiding), bleef de snelheid min of meer stabiel terwijl er een lineaire toename was in de zonale aanduiding. Het herhalingsbord bleek echter wel efficiënt te zijn omdat – nadat de snelheid was gestegen tot aan het herhalingsbord – de snelheid daalde na het herhalingsbord om na het volgende kruispunt opnieuw toe te nemen (kubische trend). Hierbij dient er opgemerkt te worden dat afleiding geen effect had op deze patronen. Verder werd er via een vragenlijst aangetoond dat bestuurders de betekenis van het begin zonebord F4a niet even goed kenden als de betekenis van de traditionele aanduiding. Na correctie voor dit feit was er tussen de traditionele en zonale aanduiding geen verschil in gemiddelde snelheid in de 250 m na een snelheidstransitie (C43 vergeleken met F4a en C45 vergeleken met F4b).

Op basis van deze resultaten wordt een algemene invoering van snelheidszones naar het beleid toe afgeraden en wordt er aangeraden om eerder over te gaan naar een algemene snelheidslimiet van 70 km/u buiten de bebouwde kom in plaats van de huidige 90 km/u. Hierbij moet men echter wel opmerken dat deze studie ook heeft aangetoond dat bestuurders weinig gevoelig zijn voor veranderingen in het verkeersreglement en nieuwe verkeersregels dus goed gecommuniceerd moeten worden en dat een studie moet aantonen of bestuurders deze nieuwe algemene verkeersregel wel opvolgen.

LIST OF FIGURES, TABLES AND CHARTS

Table of contents

READING GUIDE

In the first chapter – the ***introduction*** – the problem definition and the relevance of this Master's Thesis are discussed. An overview of the evolution of road safety in Belgium with a special emphasis on Flanders is given.

In the ***literature*** chapter (chapter 2, beginning at page 20) an overview of the relevant aspects that could be found in literature is given. First, the different speed indications in Belgium are listed up so the reader becomes familiar with these indications. Next, several aspects of the driving simulator are discussed. Further, the driving task is described, more specifically taking into account the hierarchal model of driving, the way of information processing, attention and divided attention. The literature section concludes with the formulation of some research questions and hypotheses.

The tasks and instruction of the simulator study and the experimental design, which consists of a discussion of the participants, the used simulator and the scenerio – with the design and variables – are discussed in the third chapter, the ***method*** (beginning at page 42).

In the ***results*** (chapter 4, beginning at page 54), an exploration of the collected data is given and the analysis for the average speed and the standard deviation of speed and lateral position is carried out for the different zones. Also, one has looked at the time and distance that a vehicle was out of lane and, finally, the performance on the secondary task is discussed.

The ***conclusion and discussion*** (chapter 5, beginning at page 86) is the most important component of this study. The research questions are solved, and these are discussed. Finally, a few shortcomings of the study are described, the implications on road safety are discussed and there are given a number of recommendations.

The ***references*** of this study can be found in chapter 6 (beginning at page 100) and the study concludes with some annexes (chapter 7, beginning at page 111).

I. Introduction

1. PROBLEM DEFINITION

The literature has shown that speed influences both the probability and the consequences of a crash (Aarts, 2004; Evans, 2004). In general, the speed limit on open roads outside built-up areas in Belgium is defined at 90 km/h, unless a speed sign indicates differently. Since 2002, the speed on many locations is reduced to 70 km/h as for safety reasons (Daniëls, Vanrie, Dreesen, & Brijs, 2010). So, traffic signs are needed because this is not a general implementation. There are three ways to indicate the limit: 'traditional signalization' using the C43 sign to indicate the speed limit that is valid until the next intersection (without repetition the speed limit after the intersection is 90 km/h), 'zone signalization' using the F4a sign to indicate the speed that is valid until it is overruled by a F4b sign, and 'zone-repetition signalization' similar to zone signalization, but adding a 'F4a-repetition sign' in (the middle of) a zone. There is also a repetition variant of the C43 sign, but this is not included in this study. Given the relation between speed and crashes mentioned above, it is important to determine if there are any differences between the different speed indications. A simulator study by Daniëls et al. (2010) showed that the speed transition between different speed segments was more effective using a traditional sign as compared to a zone sign as deceleration started earlier and occurred faster. Their study consisted only of one intersection and did not examine the repetition sign in a zone. They found higher speeds for the zone segment after the intersection than for the sign segment (Daniëls et al., 2010). So, it can be interesting to see of this effect is stronger when more intersections are added or in other terms, more time goes by. In reality a speed zone consists of several intersections, so it is important to extent the study by Daniëls et al. (2010) to more crossings. A last point of interest is the effect of distraction on the behaviour and the interaction of it with the three different indications. There can be, for example, a difference in performance to speed signs, because of the fact one was distracted or not. A study by Muttart, Fisher, Knodler & Pollatsek (2007) showed that the horizontal field of view reduces when one makes a call while driving or in other words, in case of distraction. Other research showed that drivers detected (McCarley et al., 2004) and recognized (Strayer, Drews, & Johnston, 2003) less objects while they performed a secondary task.

To summarize, a lot is known about the relation between traffic safety and speed, about speed signalization, about detection of objects and about distraction, but the interaction between these elements has never or only partially been examined. So, little is known about the effectiveness of the three speed indications and how intersections and distraction will influence the three speed indications and the difference between them. According to Nederhoed (2007) the term “problem definition” covers the phrasing of the question and of the objective. The problem definition of this Master ‘s Thesis is as follows: A simulator study will examine the effectiveness of three speed indications executed in Flanders *(subject)* because one likes to know if adding distraction and intersections (more time goes by) will influence the effectiveness *(question)* in order to select the most effective way of speed indication *(objective)*.

1.1 Relevance of the research

Traffic safety is one of the most important health problems in the world. According to the World Health Organization (WHO, 2008) crashes were the ninth cause of death in 2004 and the importance will increase in future. Crashes in Belgium – in 2004 – were responsible for 1.4% and in Flanders for 1.5% of all deaths (Belgian Federal Government, n.d.). The factor ‘human’ explains more than 90% while the factors ‘vehicle’ (approximately 15%) and ‘environment’ (approximately 35%) are less important. The sum of the percentages of the relation between human – vehicle – environment (Sabey & Taylor, 1980) is not 100% because there are a lot of interactions between these factors. Nevertheless, humans are for approximately 65% solitary responsible for a crash. According to the Flemish Department of Mobility and Public Infrastructure (2008), maladjusted speed is the most important reason of a crash. This Master‘s Thesis focuses on the relation between the environmental factors (the type of speed indication and the amount of intersections) and the human factors (response to the type of speed indication and distraction).

Over the last years, the number of fatalities per million inhabitants in Belgium is decreased (Chart 1). Since 2001 there has been a significant improvement in Belgium and the reduction of the number of fatalities in Flanders was higher than in Wallonia. This stronger decline can be attributed to a more frequent reinforcement in Flanders. In 2008, Wallonia has made a remarkable drop and the number of road victims decreased more than in Flanders.

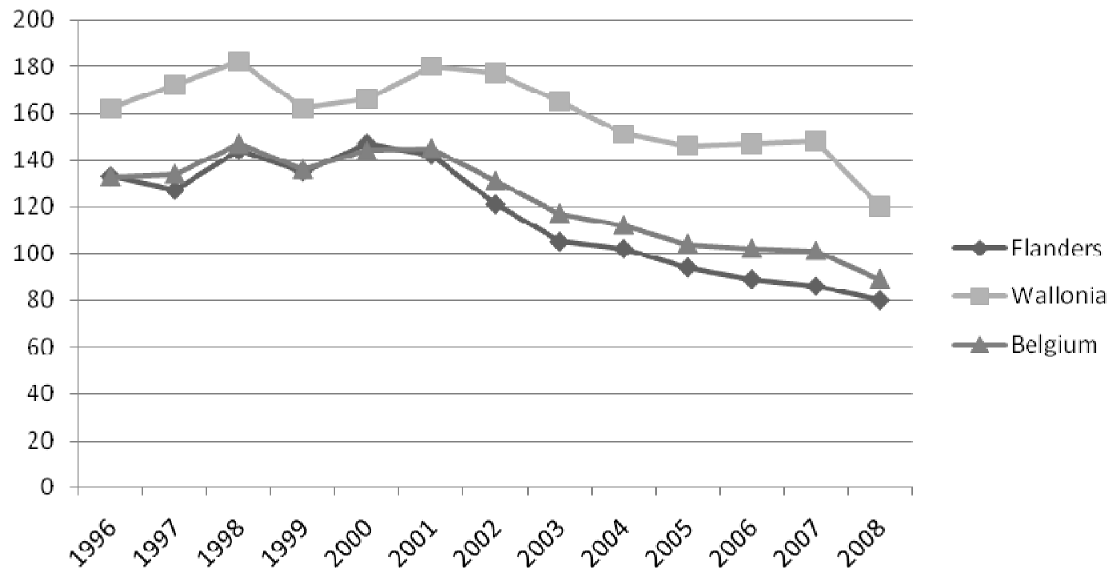


Chart 1 Evolution of the number of traffic fatalities per million inhabitants in Belgium: 1996 – 2008 (Eurostat, 2010 - own adaptations)

The Belgian number of fatal road crashes per million inhabitants still remains higher than the average of the 27 EU Member States, resulting in a 15th place in 2009 (Chart 2). However, the Western European countries perform well and two out of the five most traffic safely European countries are a neighbouring country of Belgium. So, it is remarkable that Belgium does not have a better score.

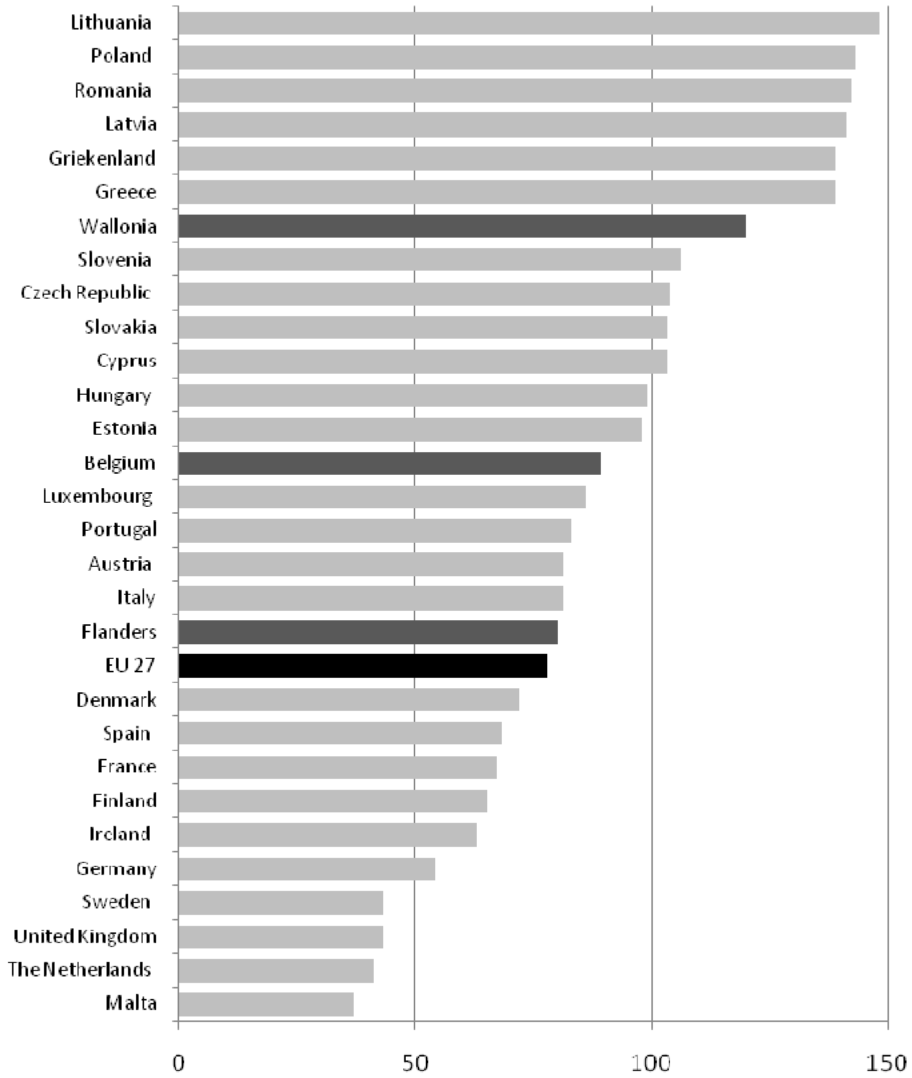


Chart 2 Comparison of the number of fatal road accidents per million inhabitants in Europe in 2009 (CARE, 2009; Eurostat, 2010 - own adaptations)

II. Literature

1. INTRODUCTION

In this section an overview is given of the relevant aspects that could be found in literature. First, the different speed indications in Belgium are listed up so the reader becomes familiar with these indications. Next, several aspects of the driving simulator are discussed. Then the driving task is described, more specifically taking into account the hierarchal model of driving, the way of information processing, attention and divided attention. This literature section concludes with the formulation of some research questions and hypotheses.

2. SIGNALIZATION OF SPEED

Since the earth is heterogeneous and individuals want to develop themselves at all levels, people move from A to B. Hereby, transport is not a purpose in itself but is a derived demand (Jourquin, 2008). People and vehicles are moving with a certain speed and usually one wants to travel as fast as possible because a movement in itself does not have a utility.

Since the mid 90's, the following definition is used for an optimal speed of a road: *"The design of a speed of a road is equal to the highest possible speed that is safe and can be comfortably held in relation to other road users when the traffic intensity is low"* (ETSC, 1995). Hereby, the speed limit can never be higher (or lower) than the function of the road, otherwise the credibility of the road will be lost. Vlassenroot, Vandenberghe & De Mol (2008) suggested that it is important to have a consistent road design on a longer road segment in non-urban areas. This means that speed zones should explain themselves and little signalization is needed. Table 1 gives an overview of the Belgian speed classifications.

Table 1 Belgian speed classifications (FOD Mobiliteit en Vervoer, n.d.)

Infrastructure	*Private cars*	*Busses*	*Trucks*
Motorway	120 km/h	90 km/h	90 km/h (+7,5 tons)
Road 2x2 (separated)	120 km/h	90 km/h	90 km/h (+7,5 tons)
Outside built-up area	90 km/h	75 km/h	60 km/h
Inside built-up area	50 km/h	50 km/h	50 km/h
Residential area	20 km/h	20 km/h	20 km/h

Because the area in Flanders is very different and there is much ribbon development, it is not simple to define homogeneous areas. Therefore, in locations outside the built-up area – where the speed limit is lower than the generally prevailing speed of 90 km/h – one places traffic signs which indicate the maximum speed. There are two different ways to indicate the speed. A first indication is via the C43 road sign. This sign is placed on the right side of the road and shows the prevailing speed until the next intersection. If the traditional sign is placed on a long road segment, it can be repeated with at the bottom the word "repetition" ("herhaling" in Dutch). By the Royal Decree of January 29th 2007, the Highway Code registers that road authorities have the possibility to define speed zones. These zones have the advantage that the road operator no longer has to place a sign after each intersection. From the zone sign (F4a) to the end zone sign (F4b) it is forbidden to drive at a higher speed than the zone speed. The zone sign is placed at the right of each access of the speed zone. The road operator can place an adhesive logo or recognition sign of the traffic sign C43 at lighting and traffic poles within the zone that recalls zone speed to mind. Since one can assume that drivers not bother with changes in the Highway Code (Lajunen, Hakkarainen, & Summala, 1996) and the zone signs are relatively recent, it can be expected that drivers who got their license before 2007, are less familiar with these signs. The regulations that are applied to the zone, can be repeated by a sign similar to the sign placed at the beginning of the zone, completed with the word "repetition". Figure 1 illustrates the two possible speed signs with possibly a repetition.

Traditional indication: C43 | *Traditional indication with repetition: C43* | *Zone indication: F4a/F4b* | *Zone indication with repetition: F4a/F4b*

Figure 1 Belgian speed signs

<u>Summary signalization of speed:</u>

In this study the type of speed sign was very important because one examined three different types: traditional, zone and zone-repetition. The traditional sign C43 is valid until an intersection while the zone sign F4a is valid until it is explicitly overruled by a F4b sign, and both signs can by accompanied by a repetition sign. The study by Daniëls et al. (2010) has examined the difference between the zone sign (higher transition speed from 90 to 70 km/h and higher mean speeds after the intersection) and the traditional sign, but has not examined the effect of a repetition sign and the transition from 70 to 90 km/h. Also, there was only one intersection in each condition. Therefore, this Master's Thesis is important because one examined the direct effect of the three speed signs – traditional, zone and zone-repetition – and this at a speed transition from a higher to a lower limit and vice versa and also a more practical outcome, namely the effect of sign in time (or intersections).

3. Driving simulator

A scientific study at the TU Delft (Kuipers, Wieringa, Winter, & Boschloo, 2005) showed that the behaviour of drivers on the road is similar to the behaviour in a driving simulator. Evans (2004) observed however that simulators measure the driving performance of what a driver *can* do, while safety is determined by the driving behaviour or, in other terms, what a driver *chooses* to do. According to Kaptein, Theeuwes & Horst (1996), driving simulators can also be used for the evaluation of the vehicle design and for scientific research with respect to driving behaviour. An important advantage of simulations is driving in a virtual environment. Since experiments are conducted in a virtual environment and the simulation can be influenced, only hypothetical accidents can happen and the experiment can be kept under control. This way, confounding factors can be controlled and one can control the characteristics of the participants. After the experiment, one can ask additional questions to the participant – whose characteristics can be collected – which can be relevant to the study. Finally, the driving performance can be registered and evaluated in much more detail.

A distinction between 'fixed based' and 'moving based' simulators can be made (Evans, 2004; Shinar, 2007). In a *fixed based* simulator, only the landscape on the screen moves and the driver and the vehicle are stationary. Vibrations, acceleration and braking (abruptly) will not be felt and will therefore have no influence on the driving behaviour. This can be regarded as a shortcoming because the driver does not get direct feedback from his behaviour and the adaptation is larger in comparison to reality. These additional cues are offered in a *moving based* simulator so the difference with reality is smaller. According to Shinar (2007), a moving based simulator can be a thousand times more expensive than non-moving simulator and the pros and cons should always be taken in consideration.

The resolution of the screen is often a critical point in a simulator study because the projection has a much lower quality than the image in the car. A study at the TU Delft (Kuipers et al., 2005) showed that not the sharpness of the image but the angle of it is of primary importance, so an angle of 180 degrees or more is recommended. The same research showed that there are no significant differences between a moving and a fixed simulator while other results (McLane & Wierwille, 1975) showed that adding kinesthetic information affects the validity positively. The validity of a driving simulator refers to the degree in which the recorded behaviour corresponds to the behaviour that under similar circumstances would occur in reality. Kaptein et al. (1996) argued that as long as the (most important) aspects of research match in both environments, the results are valid. Furthermore, they made a distinction between 'absolute and relative validity' and between 'internal and external validity'. When one investigates, for example, the effectiveness of a speed effect, the study is *absolutely valid* if the absolute magnitude of the speed impact in the simulator is comparable to the absolute magnitude in reality. The driving simulator is however *relatively valid* if the direction or relative magnitude of the effect is similar. Törnros (1998) observed that relative validity is necessary for a simulator as a research tool, but absolute validity is not required. If it is important to know the magnitude of the speed reduction, one uses the first validity while the second is used when one wants to classify measures. *Internal validity* refers to the recognition of a possibly clear relationship between a manipulation (e.g. placing a new speed indication) and an intended effect (e.g. speed reduction). If the desired effect is achieved and apart from the manipulation, there are no alternative explanations for the change in behaviour, then the study is internally valid. *External validity* refers to the degree in which the obtained results, within a specific set of participants, in a specific environment and during a specific time period, can be generalized to other people, environments and time periods. It is, for example, important to be able to generalize the results of the speed indication at a specific road segment to other road types. Besides these four major categories of validity, there are some other forms such as 'face validity' or 'physical validity' (how realistic is the simulator to the participants), 'statistical conclusion validity' (how statistically reliable are the results) and 'construct validity' (is there measured what is intended) (Kaptein et al., 1996).

<ins>Summary driving simulator:</ins>
Driving simulators are a useful tool to examine traffic behaviour on a safe and relatively efficient way because one can control some factors. Nevertheless there are some concerns about the different types of validity, one can give a large confidence in the results.

4. DRIVING TASK

4.1 Hierarchical model

Evans (2004) described the driving task as a 'closed-loop compensatory feedback control process' which means that the driver generates controlled input (through the steering wheel, brakes and accelerator pedal), receives feedback by monitoring the effects of the input and responds by generating additional input. Furthermore, the driving task is a complex task that takes place at different levels. Several authors cited the hierarchical model of Michon (1985) that consists of three levels: strategic, tactical and operational.

If the behavioural levels of Rasmussen (1986) are linked to Michon (1985), one gets Figure 2. The *strategic level* corresponds to the knowledge based behaviour and concerns the preparation of the trip. Here, decisions are taken such as: Does one make a trip? Where does one make a trip to? Which route is used? Which means of transport? When does one leave? One thinks thoroughly about this kind of decisions, so one is aware of any decision. When acts are repeated frequently, however, the decisions become a habit. In the *tactical level* (also called manoeuvring level or guidance level), decisions are taken within a few seconds and one falls back on rules ('*if* this happens, *then* I respond like this'). The typical manoeuvres here are: catching up, insert and turn. The tasks at this level are semi automatic and a derivative of the strategic level by which they are influenced by motivational and situational variables. At the *operational level* (also called control level), decisions are automatically taken in a fraction of a second as a response to a stimulus. Examples of fully automated decisions are: shift gear and keeping track (Ranney, 1994; Weller, Schlag, Gatti, Jorna, & Van den Leur, 2006).

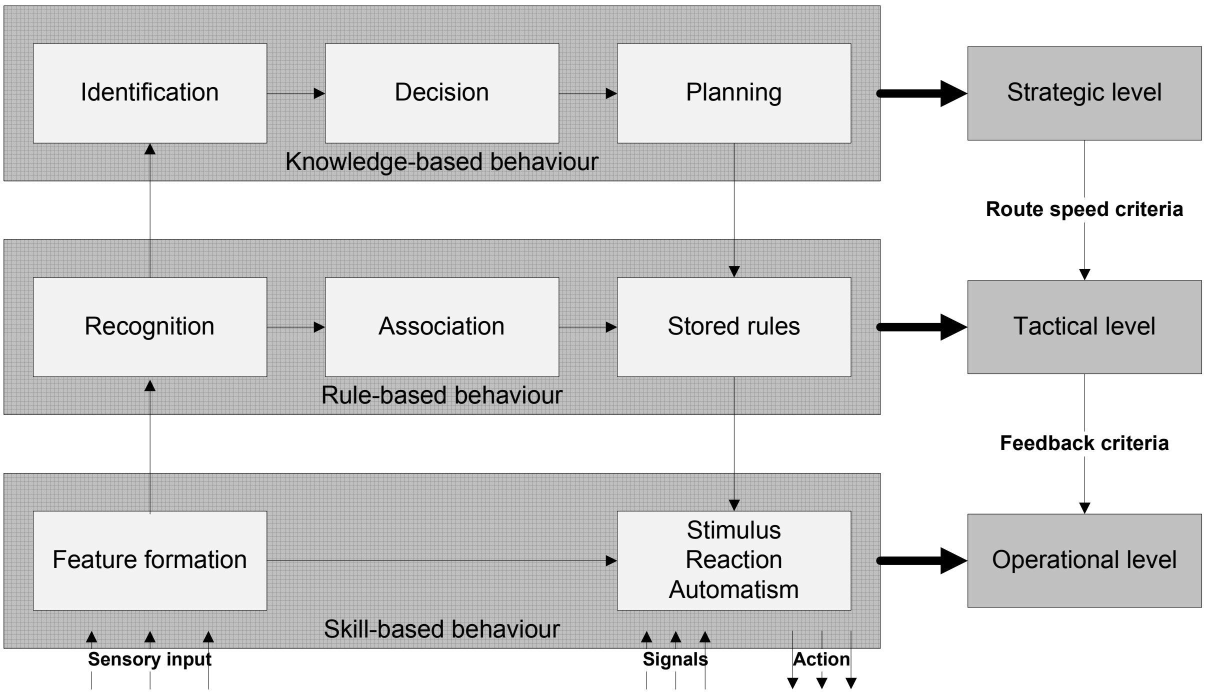


Figure 2 Combination of the performance levels of Rasmussen (left) and the hierarchical model of Michon (right) (Weller et al., 2006)

4.2 Information processing

Shinar (2007) cited several authors (a.o. D. Kline et al., 1992; Sojourner & Antin, 1990; Wood & Troutbeck, 1992) that state that 90% of the required information for the driving task is visual by nature, but he described at the same time another study (Sivak, 1996) that shows that there is no scientific evidence for this. The only conclusion that can be drawn from this, is that a large part of the information is visual, which is confirmed by Evans (2004). Figure 2 shows that the input is sensory. The information a driver receives during the driving task should be processed to result in a certain output. This data flow is directly proportional to the speed: the faster one drives, the more information needs to be processed (Shinar, 2007). According to Weller et al. (2006), data processing consists of (1) selecting relevant information, (2) processing this information and (3) the final action. Rumar (1985; described in Weller et al., 2006) has drawn up a cognitive model of data processing (Figure 3). When a driver drives, he gets some experience that entails a certain expectation. The more a new situation corresponds to a previous one, the stronger the expectation will be. This expectation helps the driver to pay attention to places where it is assumed that information can be found (= top-down process). Misleading information caused by erroneous expectations leads to bad decisions and not to an appropriate behaviour. This is described by Rumar as *cognitive filtering*. Whether or not a stimulus attracts attention, depends on the properties of the stimulus (= bottom-up process). Furthermore, environmental stimuli will also lead the attention. Moving stimuli are faster and more easily detected by the peripheral attention than stationary objects – such as traffic signs – with low contrasts. This shortcoming is called the *perceptual filtering*. When attention is focused on important objects, it may happen that these objects are not seen because they are physically obscured by other objects (= *physical filtering*).

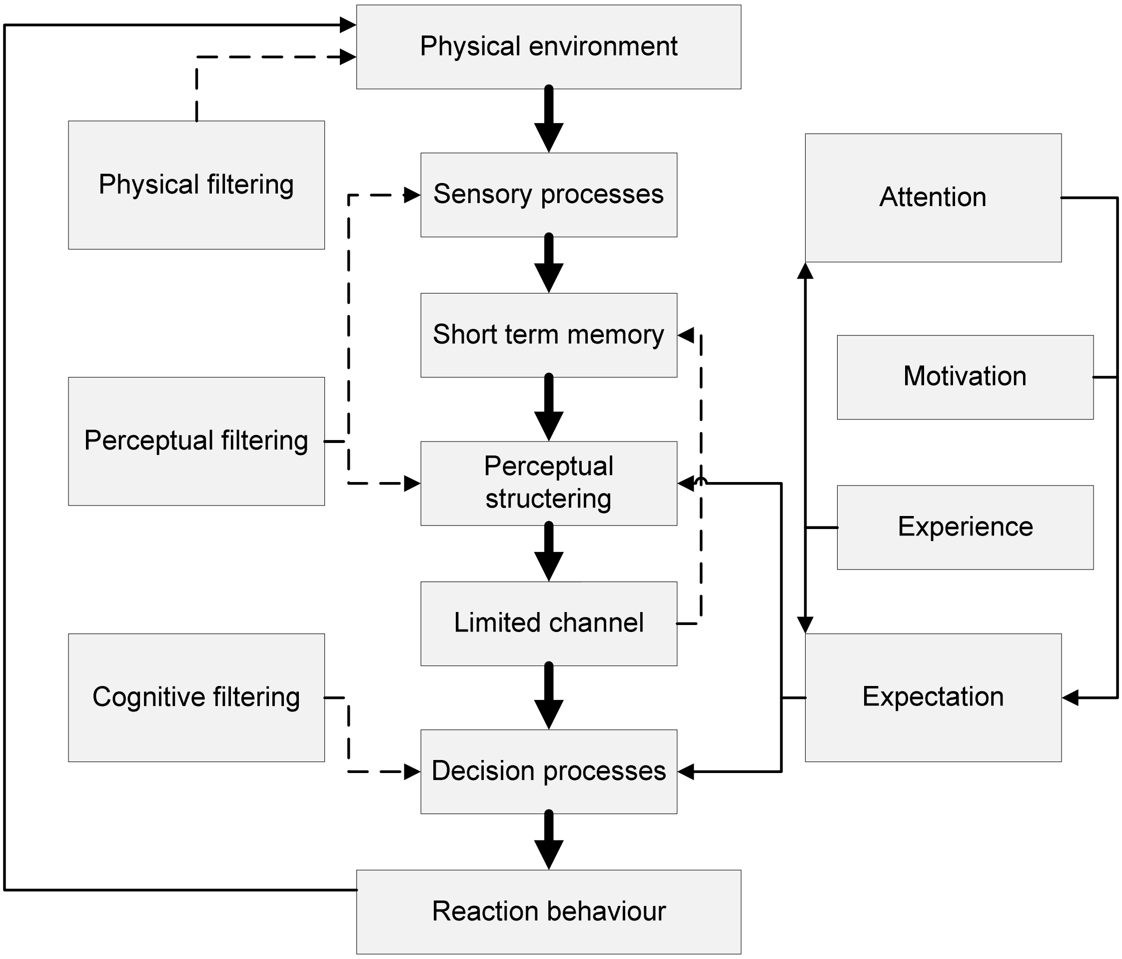


Figure 3 The cognitive model of Rumar (Weller et al., 2006)

The input of a driver mostly depends on the traffic situation, but it may also be part of the system itself. When a driver experiences, for example, that he is getting tired, the processing of the input will be influenced by this. Usually, the information is part of the environment: current speed limit, the condition of the road surface, the road environment, etc. The output is the behaviour of the road user or the change in the environment. Since the output is also compared with the change in environment, Vanrie & Willems (2006) stated that the information achieved by traffic participants is dynamic by nature. Own behaviour ensures that the information is never the same.

According to the task-capability interface model of Fuller (2005), one has a few *demands,* or stated in another way, objective requirements, that are needed to drive a car. These demands are dependent on the vehicle, speed, environment, etc. On the other hand, there are the personal *capabilities* of a driver such as experience. One has control over the car when the capabilities are greater than the demands, but this control disappears when the capabilities are not enough in order to compete with the demands. The latter can result in a lucky escape or in a collision. For this reason, drivers try to keep their task demands still below the capabilities and adjust their speed when they perform an additional task. The mental workload describes this relation between the (quantitative) demand for resources imposed by a task and the capability to supply those resources by the operator (Wickens, 2002). When drivers need to perform several tasks, one must give priority between different tasks. Tasks that serve the driving task directly (e.g. reading a map to go to the destination) will receive a higher priority from drivers than tasks that are less important to the driving task (e.g. making calculations in car). One assumes that tasks that serve goals high in the hierarchy will be considered more important than lower goals, and that tasks not directly related to the driving task are neglected more often in high-demand situations (Cnossen, Meijman, & Rothengatter, 2004). As known, the most important way to reduce task demands, so that it is compatible with capabilities, is to reduce the speed because lower speeds allow more time for information processing.

4.2.1 Visual perception

There is a distinction between foveal and peripheral vision. Only 5 degrees of the visual field is projected on the *fovea* and is seen sharply. The other part of the visual field (approximately 175 degrees for young people) remains vague and is called the *peripheral visual field* (Shinar, 2007). If one should not move the eyes, a large part of the visual field would not be seen sharply. It is therefore important to drivers that they scan the environment so they get a sharp visualization. Vanrie & Willems (2006) argued that a fixation in the central part of the retina (i.e. the fovea) does not necessarily lead to a conscious recognition because attention must be paid to an object.

Road signs are placed mostly at predictable locations (at the right side of the road and often after intersections) what makes the visual search easier. Young, inexperienced drivers more often look in the vicinity of the nose of the vehicle and more to the right than experienced drivers (Evans, 2004). The interpretation is that inexperienced drivers need more attention to keep their vehicle in the proper position on the road.

4.3 Attention

Individuals are faced with limited resources so these must be spread across different stimuli. This allocation takes place by the principle of 'attention' (Weller et al., 2006). Attention is not the same as workload (Wickens, 2002) because it is the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. If one does not pay attention to stimuli, the information can not be processed. The attention to an object can be given voluntarily (= top-down) or involuntarily by the properties of the stimuli (= bottom-up). An important addition to this distinction is the difference between 'object conspicuity' and 'search conspicuity' (Martens, 2000). *Object conspicuity* refers to the capacity of the object to pull the attention of the driver without really searching for the object, while *search conspicuity* refers to the ability to be found if the driver really was looking for it. Speed signs should therefore have a high object conspicuity because drivers must be aware of the current limit. Conspicuity, that means literally remarkableness, is a complex phenomenon. The term is used in different ways and its meaning depends on several aspects: contrast between environment and object, line of vision, size of the object, etc. It is important to note that the mood of the driver, the expectations about the object and the behaviour of the observer also play an important role. Näätänen & Summula (1976; described in Martens, 2000) argued that the motivation of the driver is the reason why certain traffic signs are noticed or not. So, the idea behind is that the physical characteristics of traffic signs do not play such a large role as originally was assumed. If one uses flashing or dynamic signs, then the idea is not valid. Charlton (2006) indicated in his report that about 75% of the speed signs were detected and recognized. Lajunen et al. (1996) attributed this high percentage to motivation and learning factors because ignoring a speed limit is often accompanied by a penalty. But it is assumed that drivers who habitually exceed speed limits do no consider their safety endangered by their speeding behaviour (Michon et al., 1985). So, safety conditions are not so an important factor in speed choice as was thought. Other factors, such as pleasure to speed and time savings, do predict actual speed choice much more accurately.

First of all, it is necessary that one can observe and read a traffic sign to understand it. Situation awareness refers to the perception of the elements in the environment within a volume of time and space, the understanding of the meaning and the projection of the status in the near future (cited from Weller et al., 2006). In other words, it means that drivers know what happens. The study by Martens (2000) described a few methods to check to what degree the information of traffic signs is perceived. Two of these methods are used in this study: observation of the driving behaviour and verbal reporting after driving (section III 2.3.1 at page 47).

4.4 Divided attention

4.4.1 Distraction

Most of the time when driving, attention is divided between the driving task and other tasks. People are very efficient in ignoring irrelevant stimuli to focus on one source of information (= selective attention) but according to Shinar (2007) it is more difficult to draw attention to several sources (= divided attention). Ranney (1994) concluded that a high selective attention leads to a low accident rate. Shinar (2007) cited several studies that say that 20 to 80% of the crashes are caused by inattention and delayed recognition due to distraction. This wide range is ascribed to a difference in definition of distraction. If inattention is equal to diversion (= distraction) then there is a high percentage but the percentage gets lower when distraction is limited to external sources that attract attention.

Distraction is the attention given to a non-driving related activity and it leads typically to a deterioration of driving performance (ISO, 2004; cited in Shinar, 2007). In literature there are three types of distraction that all lead to a delayed recognition and an imminent crash (Treat et al., 1979; cited in Shinar, 2007): (1) internal distraction by objects or events in the vehicle such as children and the radio, (2) external distraction by objects or events outside the vehicle such as billboards and traffic signs and (3) inattention that is internal to the driver such as daydreaming. The main conclusion Shinar (2007) made, is that no driver during the entire trip pays only attention to the driving task so everyone is distracted. The most frequent non-driving task related activities are (observed data) (Shinar, 2007): radio settings (91% of the drivers), talking to passengers (77%) and eating or drinking (71%). Thus, it is a fact that distraction is an important part of the driving task. Drivers can be involuntarily subjected to it but they can also ask for it.

According to the theory of 'Multiple Resources' – that is related to attention and workload – there will be an interference between different tasks and this has an impact on the performance on both tasks. According to Wickens (1976) and Young & Stanton (2002), the timeshare between two tasks is more efficient when there are two separate structures (= ‘cross-modal timesharing’) than when a common structure (= ‘intra-modal timesharing’) is used. A later paper by Wickens (2002) gave an example of the structural distinction: visual processing of the eyes and auditory processing of the ears. The dual task performance will be worse when two visual tasks have to be shared in comparison to a visual and an auditory or vice versa. Parkes & Coleman (1990) provided a more specific example in traffic: the driver is more successful in driving and understanding audile instructions than while the same set of instructions is read from a display. This is because the eyes and ears use a different resource structure. Based on these studies, it can be concluded that performance is worse when two visual tasks are shared.

Shinar (2007) described several studies using the cell phone while driving. These studies showed that the visual search pattern, the peripheral vision, the frequency of sidelong glances and the frequency of glances at the instrument panel are reduced. Another finding was the higher reaction time of drivers when they use a cell phone (Muttart et al., 2007).

Several studies – both field and simulator studies – showed inconsistent results about the effect of distraction on driving speed. Lansdown, Brook-Carter & Kersloot (2004) noted a significant speed reduction of 8% when a secondary task was performed in the simulator while there was no effect on lateral position. The secondary task was a discrimination task, requiring subjects to discriminate even and uneven numbers or vowels and consonants by pressing one of four buttons. The instruction was to respond as quickly as possible without reducing the safety of the primary task. The authors concluded that drivers reduced their driving speed to compensate for the increased workload and women did this more than men. Shinar (2007) cited several studies that confirmed this compensatory reaction both in simulator studies as in observational studies. The observational study by Liu & Lee (2006) showed a speed decrease of 5.8% (average speed of 67.00 km/h instead of 71.10 km/h) when subjects were distracted by making mathematical calculations via telephone while driving. Jordan & Johnson (1993) showed that the time to complete a route increased when drivers had to operate the radio. This implies that driving speed was lower. The basic assumption is that driving is a self-paced task and an additional task demand will lead to an increased workload and a subsequent decrease in speed (Fuller, 2005). According to Fuller (2005), drivers do not seek risk homeostasis but rather seek task difficulty homeostasis and this is mainly achieved through an adaptation in speed. A lower driving speed does not necessarily mean that one compensated because of safety or task reasons. It is for instance possible that one reduced the speed because one did not pay attention to the current limit.

The study by Daniëls et al. (2010) showed in the 90 km/h segment a lower speed when there was distraction (86.40 km/h without distraction and 83.10 km/h with distraction) but showed at the same time a higher average speed in the 70 km/h segment (70.50 km/h without distraction and 74.30 km/h with distraction). This speed pattern refers, according to Daniëls et al. (2010), to the fact that drivers rely on their own and preferred speed when there is an increased mental load (cf. Recarte & Nunes, 2002). However, these data showed that the driving performance deteriorates when there was distraction because there was a higher deviation of the 90 km/h and the 70 km/h limit. Also, a slower reaction occurred in the transition from 90 to 70 km/h when one was distracted. Research showed that drivers can be so distracted by extra tasks that driving performance is affected. Pohlman and Traenkle (1994) showed that drivers deviated more from their lane when they drove a complex visual task. Cnossen, Meijman & Rothengatter (2004) stated that depending on the used secondary task, the results are different.

An exception to the speed reduction due to distraction is the observational study by Recarte & Nunes (2002) showing that the speed – when an imposed speed has to be maintained – was higher in case of a higher mental load than under a low load (respectively 102.2 km/h and 99.5 km/h) and there was no significant difference in the free speed condition (high: 110.7 km/h; low: 111.3 km/h). In the trips on a real highway, with a restricted speed, drivers were told to drive in the range of 90 to 100 km/h while there was no restriction in the free speed choice trip. The secondary tasks were several mental tasks such as listening to an audio message and comment this, mental calculation tasks, spatial orientation tasks, etc.

4.4.2 Overview of secondary tasks in a driving simulator

Secondary tasks can be divided as follows:

- Detection task in which the participant must detect and respond to each stimulus.
- Discrimination task in which the participant must determine which button must be used (discrete choice) or in which the participant must determine if he has to respond or not on a target stimulus (go and no-go task).

- Working memory task in which the participant constantly has to make an appeal to his working memory.

Table 2 gives an overview of some visual secondary or easy to transform auditory tasks with a reference to a paper that used this task. The detection tasks are not included in this table because the secondary task should load the driver so much that the capacity level is exceeded and there is an influence on driving performance while this is not the case with the simple detection tasks. So, the detection tasks are not strong enough to implement in this Master's Thesis.

Table 2 Overview of secondary tasks

	Task	*References*
Discrete choice task	**Symbol test**	Meex (2009). Simulatoronderzoek omleidingsignalisatie. Hasselt.
		Devos et al. (2007). Predictors of fitness to drive in people with Parkinson disease. *Neurology*, 69(14), 1434-1441.
Go & no-go task	**Arrows Task**	Engström, Johansson, & Östlund (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F*, 8(2), 97-120.
Working memory task	**PASAT (Paced Serial Addition Task)**	Additional road markings as an indication of speed limits: Results of a field experiment and a driving simulator study. *Accident Analysis & Prevention*, *40*(3), 953-960.
	CMT (Continuous Memory Task)	Verwey & Veltman (1996). Detecting short periods of elevated workload: A comparison of nine workload assessment techniques. *Journal of Experimental Psychology: Applied*, 2(3), 270-285.
	L-counting task	Verwey & Veltman (1996). Detecting short periods of elevated workload: A comparison of nine workload assessment techniques. *Journal of Experimental Psychology: Applied*, 2(3), 270-285.

a. Discrimination tasks

- **Discrete choice task**

In the study of Meex (2009) and Devos et al. (2007) different symbols appeared in the mirrors. When a triangle appeared in the right (left) mirror, one had to blink to the right (left); when a horn appeared in the middle of the screen, one had to give a honk. Devos et al. (2007) presented these symbols 28 times in a 15 kilometres ride so the stimulus appeared every 535 metres on the screen. If there was no response within 5 seconds, it was considered as 'missed'. Besides the number of missed stimuli, the reaction time and the number of wrong responses were analyzed. The results showed that 14% of stimuli were missed, 7% was wrong and the median of the response time was 2.22 seconds.

- **Go & no-go task**

The Arrows Task used by Engström, Johansson, Östlund (2005) was a visual go & no-go task. For 5 seconds, a matrix with 16 arrows (4x4) in different directions was presented and if an arrow pointed up, the driver had to push a button. After 5 seconds, a new matrix appeared. The level of difficulty of this task can be adjusted by increasing the number of arrows (more difficult) or decreasing it (easier).

b. <u>Working memory task</u>

The PASAT-task is usually presented auditory but a visual variant is also possible (like a n-back task that influences the working memory), although this has not been found so far in literature. Daniëls et al. (2010) had used this secondary task in the auditory variant to examine the influence of the mental load on the primary driving task. A series of numbers between 1 and 10 was given, in a fixed frequency of 2 or 3 seconds, and the participant answered each time aloud with the sum of the presented number and the previous one. In their study, the performance on the secondary task was not explicitly measured.

The Continuous Memory Task, that was used in the study by Verwey & Veltman (1996), involved – while driving in a real vehicle – listening to certain words and counting the target letters (A, B, C) in the stream of words. This caused a continuous load on the working memory. The task can possibly be transformed to a visual task, in which the letters appear on the screen and one has to respond on the target stimuli. The L-counting task is a similar task (described by Verwey & Veltman, 1996). On the left side of the car, a device was placed on the dashboard with four LED's that lighted up every 2 seconds. The driver had to count the number of times that the letter "L" appeared. By doing this, the working memory was continuously loaded. In the analysis of the results not only the impact on the primary task was considered, but also performance of the secondary task (number correct, number false, number missed and number correct refused).

4.4.3 Selection of the secondary task

The previous section gave a brief overview of the secondary tasks. This Master�In Thesis is an extension of the study by Daniëls et al. (2010), making it desirable to use the same secondary task (PASAT). However, there were some concerns. Daniëls et al. (2010) used an auditory PASAT while, as described earlier, an intra-modal timeshare is more difficult. A second reason why PASAT was not used, is the auditory response that is more difficult to register. At last, there was not found a visual variant of PASAT in literature. Therefore, in this Master‘s Thesis, a visual distraction was added to the experiment that consisted mainly of visual discrimination processes. By doing this, the distraction was the greatest. There was opted for an existing visual discrimination task that loaded working memory. This task was similar to Devos et al. (2007) and Meex (2009) but there was an adjustment to increase the degree of difficulty. The stimuli that they had used, provided an indication of the action that the participant had to undertake (triangle left meant blink to the left). By presenting the stimuli in the rearview mirror, giving no indication of the response and varying both the object and the colour of the object, the task was intended to become more difficult, so the driver had to put in greater efforts. The implementation of the secondary task is discussed in section III 2.4 .

The reaction time to these stimuli was logged, as well as the number of correct, incorrect and missed responses (no reaction within 3 seconds). According to Näätänen & Summala (1976; cited in Evans, 2004) the reaction time is influenced at first by the number of stimuli (Hick-Hyman law) and the possible responses, and secondly by the expectation. The Hick-Hyman law says that the reaction time in a task is linearly linked with the amount of information (A. Johnson & Proctor, 2004). The reaction time will increase with a constant amount every time the number of possible stimuli increases. It was therefore important that the order of possible responses was randomly distributed over the total number of presented stimuli and that the interval between the stimuli – in other words, the longitudinal position – was as much as possible random. Furthermore, an equal number of stimuli per category were presented.

<u>Summary driving task:</u>

Most of the driving task is visual by nature and as speed goes up, the amount of information increases. Once the relevant information is selected, and is processed there is a final action. Drivers must be aware of the current limit, so the speed sign must attract the attention of the driver which means there is a high object conspicuity. Also, the mood of the driver plays an important role in detecting signs. As known, drivers try to keep their task demand below their capabilities and for this reason, many studies showed a lower speed when one is distracted. Given the fact that driving is a self-paced task, an additional task demand will lead to an increased workload and a subsequent decreased speed. As proven in accident data, inattention and delayed recognition due to distraction can explain a lot of accidents. For this reason, a lot of attention is given to the examination of the effect of distraction, and in particular the effect of using a cell phone while driving. To implement this in a simulator study, there are several secondary tasks possible that influences the workload. Most of the studies stated that one drove slower (and there was a difference standard deviation of lateral position) when one is distracted because one compensated the workload (lowering the speed) and one fell back on a preferred speed in case of distraction, but non of the studies had examined the interaction of distraction with three types of speed signs and with four intersection. The study by Daniëls et al. (2010) – that only consisted of a traditional and a zone sign without repetition – had only found a lower speed when one is distracted and there was no interaction of distraction with the type of sign in the 70 km/h segment, neither there was an interaction between sign and intersection.

5. RESEARCH QUESTIONS AND HYPOTHESES

In this chapter, the research questions are presented and hypotheses are formulated where possible.

Compared to the similar study by Daniëls et al. (2010) there is an added value because they considered only the C43 and F4a sign and included only one intersection. The effect of the repetition sign and the speed transition from 70 to 90 km/h by a C45 or F4b sign were not considered.

In this Master's Thesis there are three important factors:

- The type of speed indication, including three possible types:
    - traditional (C43 and C45)
    - zone-repetition (F4a, F4a-repetition sign, F4b)
    - zone (F4a and F4b)
- Time, implemented by four intersections
- Distraction, implemented by the inclusion of a secondary task in part of the experiment

From these three factors, a number of research questions can be derived. Regarding the **main effects**, these are the following:

A *Is there an effect of the speed sign on mean speed?*

When this is true, there is a direct difference of mean speed between the situation before and after a speed sign. Daniëls et al. (2010) examined only if there was an effect of a transition form 90 to 70 km/h (there was found one), but this Master's Thesis will also examine if there is an effect of the repetition sign and the transition from 70 to 90 km/h. It is expected that for each sign, there will be a difference in speed between before and after.

B *Is there a direct effect of the type of speed sign on mean speed?*

This means that one will examine if there is a difference in mean speed for each sign and this averaged over before and after. However this question is less relevant, it can reveal if one reacts better to one of the signs. Since the traditional signs are more commonly used, and given the results by Daniels et al. (2010) for the transition from 90 to 70 km/h, it can be hypothesized that one reacts better to these signs at the transition points.

C *Is there an effect of time – or in other words, an effect of the order of intersections – on mean speed?*

As time goes by, is there a difference in mean speed? It is hypothesized that one drives faster as time goes by.

D *Is there an effect of distraction on the mean speed and on the standard deviation of lateral position?*

Most of the studies demonstrated lower speeds in case of distraction because one tries to compensate the necessary workload (Daniëls et al., 2010; Jordan & G. Johnson, 1993; Lansdown et al., 2004; Liu & Y. Lee, 2006; Shinar, 2007), so it is expected that this Master's Thesis will reveal the same conclusion. A study by Pohlman & Traenkle (1994) showed that the standard deviation of lateral position is larger when on is distracted.

In addition to the main effects, the following **2-way interaction effects** will be examined:

E *Is there, at the (potential) repetition sign, a difference in mean speed between before and after and does this depend on the scenario? & Is there a difference in mean speed in the situation of 250 m after the transition points and does this depend on the type of speed sign?*

This means that one will examine if there is a difference between before and after at the (potential) repetition sign and if this depends on the scenario because there was only placed a repetition sign in the repetition scenario. Secondly, one will examine if there is a difference in mean speed after two speed transitions (from 90 to 70 km/h and from 70 to 90 km/h) and if this depends on the type of sign (C43 compared to F4a and C45 compared to F4b). The study by Daniëls et al. (2010) showed that the classic C43 sign was more effective than the speed zone sign F4a at the transition point from 90 to 70 km/h because decelerating started earlier and was faster. Here, in addition the transition from 70 to 90 km/h will be examined. Since the traditional signs are more commonly used, and given the results by Daniels et al. (2010) for the transition from 90 to 70 km/h, it can be hypothesized that one reacts better to these signs at the transition points.

F ***Is there a variation of mean speed in time and does this variation depend on the used type of speed sign*?**

It is hypothesized that zone signs, because they are not always repeated after each intersection and thus remain in force until explicitly overruled, result in an increased speed in time. Intuitively, it sounds logical that if there is no explicit indication of the current speed, one drives faster. This intuition was confirmed by Daniëls et al. (2010) showing that the speed appeared to be lower when the velocity regime was explicitly determined by the traditional sign in comparison with the zone, however they did not consider the repetition sign. It can be assumed that if there is a repetition sign in the zone, this effect is less (not studied so far). From the fact that there is no systematic recall of the speed regime, it is hypothesized that the speed after each intersection will increase in the zone scenario. In the study by Daniëls et al. (2010) – where only one intersection was added – a higher average speed (15.8% accelerated over 80 km/h while only 1.6% accelerated in the traditional case) in the section after the intersection in the zone segment was found. In Figure 4 four intersections and the expected impact on speed are shown. In the traditional indication, it is hypothesized that the speed increases until an intersection is reached and decreases afterwards because the speed is explicitly indicated. In the zone indication with repetition, the repetition sign is placed after the second intersection so the speed drops again after this intersection and then increases again (cubic trend). If no repetition sign is placed, the speed increases after each intersection (linear trend).

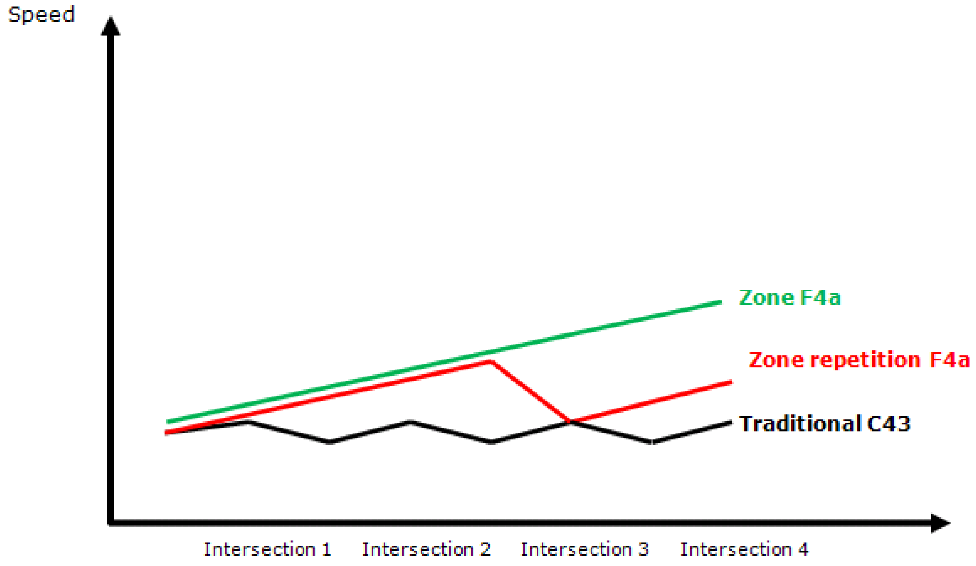


Figure 4 Hypothesis: speed sign and intersections

G *Is there an effect of distraction on mean speed and does this depend on time?*

Up till now, there is not found a study that looked for this interaction. It was hypothesized that one drives faster as time goes by, but with distraction one drives slower.

H *Is there a variation of mean speed depending on the type of speed sign and does this variation depend on distraction?*

It is hypothesized that one drives slower in the traditional conditions compared to the zone-repetition and zone condition, but with distraction one drives also slower.

Finally, there is one **3-way interaction effect**:

I ***<u>Does the mean speed over time depend on the type of speed sign and if so, does this variation depend on distraction?</u>***

It is possible that if one is distracted, the differences between signs – as time goes by – are larger because the workload became higher and one forgets the speed regime earlier. When this should be true, the curves for distraction that can be added on Figure 4, are less symmetrical when time goes by. On the other hand, it is possible that since distraction leads to lower speeds, the increase of speed in the zone-repetition and zone condition can be diminished by distraction.

The two most import questions that will be the main subject of this Master's Thesis are (repeated form above):

<u>Question F:</u> *Is there a variation of mean speed in time and does this variation depend on the used type of speed sign?*

<u>Question I:</u> *Does the mean speed over time depend on the type of speed sign and if so, does this variation depend on distraction?*

III. Method

1. INTRODUCTION

The research questions can be answered with the aid of the driving simulator of the University of Hasselt. Simulations are becoming important in transportation studies because it is a useful tool to determine the impact of measures and their development and implementation. One wants to imitate reality in simulations so real information can be obtained without implementing measures in reality (Longley, Goodchild, Maguire, & Rhind, 2005).

2. EXPERIMENTAL DESIGN

2.1 Participants

Below, an illustration is given to go from a theoretical population to a sample, and finally to a useful response (Baarda & Goede, 2001):

- Theoretical population or universe: all drivers around the world.
- (Operational) population: all Flemish drivers having a car driving license for at least three years and a maximal age of 65 years (anno 2009).
- Sample: employees of Hasselt University, friends, acquaintances and family.
- (Initially) response: the part of the population that will participate.
- Final response: the part of the sample that participated and produced useful data.

A similar study by Daniëls et al. (2010) was based on 30 participants, of which only 3 women. The initially response of this Master's Thesis was 49 persons, but one person was removed because his data was not correct and two other persons were an outlier (section IV 2. Exploring the data) so the final response was 46 persons (24 men; 22 women). The age ranged between 22 and 63 years, with an average of 38.3 years. All drivers had a car driving license for at least 3 years (on average 18.7 years) and nobody knew in advance the aim of the study. The average number of kilometres a year was 21 146 km.

2.2 Driving simulator

The experiment was conducted on the high-fidelity driving simulator (STISIM M400; Systems Technology Incorporated) of the University of Hasselt. It was a fixed-based (drivers did not get kinesthetic feedback) driving simulator with a force-feedback steering wheel, brake pedal and accelerator. The simulation included vehicle dynamics, visual and auditory feedback and a performance measurement system. It was a 'mid-level' simulator because good visualization techniques, a large projection screen and a fairly realistic driver's cab were used. The 'mock-up' consisted of the driver's seat, steering wheel, dashboard, gears and pedals so it was necessary to project the mirrors on the screen (Figure 5). The visual virtual environment was projected by three projectors on a large 180° field of view (resolution 1024 x 768). According to Kuipers, Wieringa, Winter & Boschloo (2005) this angle is sufficient. The coating on the projection screen was thermoplastic so the projected images were not reflected to the other side of the curved screen. When drivers participate in a simulator study, there is a probability of becoming ill ('simulator sickness'). Symptoms of this disease are lightheaded or feelings of sickness because there are disrupted expectations and there is a limited depth perception. Young or inexperienced drivers are less sensitive to it, so these symptoms occur less frequently in case of young or inexperienced persons (Kappé & Emmerik, 2005). An explanation for this is that novice drivers do not know how a car should respond in steering and braking input and it is very difficult to simulate this.

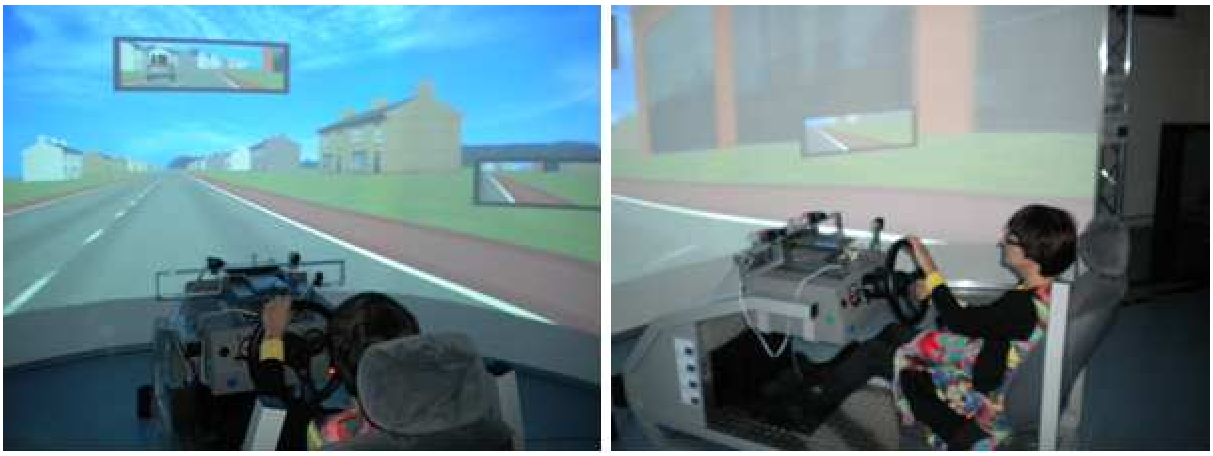


Figure 5 Mock-up simulator

2.3 Scenario[1]

Three scenarios were created, each had a length of 6 kilometres. These three scenarios had each a different speed indication: traditional speed signs, zone speed signs with a repetition sign and finally zone speed signs without repetition. In each, there were only

[1] A detailed description of the scenario can be found in Annex 1: Scenario at page 112 and also an overview of the used traffic signs in Annex 2: Used traffic signs at page 115

two speed regimes – 90 km/h and 70 km/h – that took place in the same order. The following sequence, which applied to each scenario, can be interpreted as follows (in segments of 250 m): first 1000 m driven at 90 km/h, then 4750 m at 70 km/h and finally 250 m at 90 km/h.

90	90	90	90	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	90

If one followed the sequence above, it took approximately five minutes to go through a scenario. The three scenarios were joined into a single trip of 18 kilometres, and to take order and learning effects into account, the segments of speed indications were counterbalanced. This resulted in six (three factorial) possible rankings[2]. Further, the trip was driven once under a low mental load and once under a high load (indicated with $^+$). Half of the participants drove first the trip under a low mental load and next a trip under a high mental load while the other half took the opposite order. This counterbalancing took place to minimize learning effects and boredom (Field, 2005), because participants can be experienced in their second trip and react differently or they can be bored. The order of the three segments for each participant was the same for the trip covered under low and high mental load, so this was a restriction in the counterbalancing[3]. To avoid bias in the performance of the primary driving task there were no differences in the zones of interest. In the so-called filler pieces (i.e. the zones that are not analyzed) small differences were allowed. Through each scenario, the road type was a secondary road type III (two lanes, each a width of 3.25 m), buildings and two cycle tracks. The intensity was determined based on a comparison road (Mollu, 2008). There were intersections added to discover whether there was an effect on speed because the hypothesis was that one would perform weaker to zone signs if one crossed an intersection. One possible reason for this is that one expects that the current speed limit will be indicated again after each intersection. However, this was not the case in the zone indication (with and without repetition). The distance between each intersection in the 70 km/h segment was

[2] An overview of the six different sequences can be found in Annex 3: Overview of the scenario order at page 115

[3] An overview of the trips can be found in Annex 4: Trip order by participant at page 116

determined at 1000 m, according to the preference distance in 'the Manual Secondary Roads'[4] (Engels, Devriendt, & Lauwers, 2003). Each intersection had a traffic control signal where the light was at green. One reason for this design is the fact that it was not the intention that participants would brake at intersections for safety reasons because they doubted if they had priority or not. When this would be the case, then there would be a bias in the results because one braked for priority reasons and not for speeding reasons. Given the traffic lights at intersections, it was also less conceivable that one missed an intersection. The study by Daniëls et al. (2010) – in which a section of 7 kilometres is made – included only one intersection. This Master's Thesis is an extension to it because the number of intersections is increased. It is expected that the difference between the traditional situation – where the speed is indicated after each intersection – and the zone indication will increase as time increases. Therefore, four crossings were added within the 4750 m long segment of 70 km/h.

Thirty metres after the start, the current speed (90 km/h) was indicated in each of the three trips by a C43 sign. In the traditional scenario, the introduction of a 70 km/h speed segment was identified by the traffic sign C43, and after each intersection the traffic sign C43 was repeated. In this traditional configuration, the sign C45 was placed after 5750 m to pointing out that the previous speed limit expired and one could drive the normal speed of 90 km/h. The underlying idea of this C45 sign was that it was not explicitly indicated that one must drive 90 km/h, but the standard rate (= 90 km/h) is valid. In this way, there was no noise with the zone scenarios. A lower limit than 90 km/h in the zone-repetition scenario was indicated by the traffic sign F4a and this was overruled by the traffic sign F4b when one leaved the area. After 3500 m a repetition sign was placed in this scenario. A last scenario, the zone scenario, was based on the previous one, but it differed in the fact that the repetition sign at 3500 m was removed.

Figure 6 indicates a segment of 6 kilometres (in sub segments of 250 m). The blue colour denotes 90 km/h and the orange colour 70 km/h. On the first line, one drives in a traditional scenario, the second line indicates a zone with repetition and the last line is a

---

[4] This manual was produced in 2003 by Tritely NV and Iris consulting (on behalf of the Ministry of the Flemish Community), but has never got an official status

zone. The vertical axes are the four intersections (to the left or right). Additionally, the figure shows the analysis zones (vertical shading represents an intersection analysis, the horizontal shading a traffic sign analysis and a draughtboard pattern indicates a control zone). The control zone will be used to determine whether or not there are differences between the conditions in areas where there are no differences expected (for more information, section III 2.3.2).

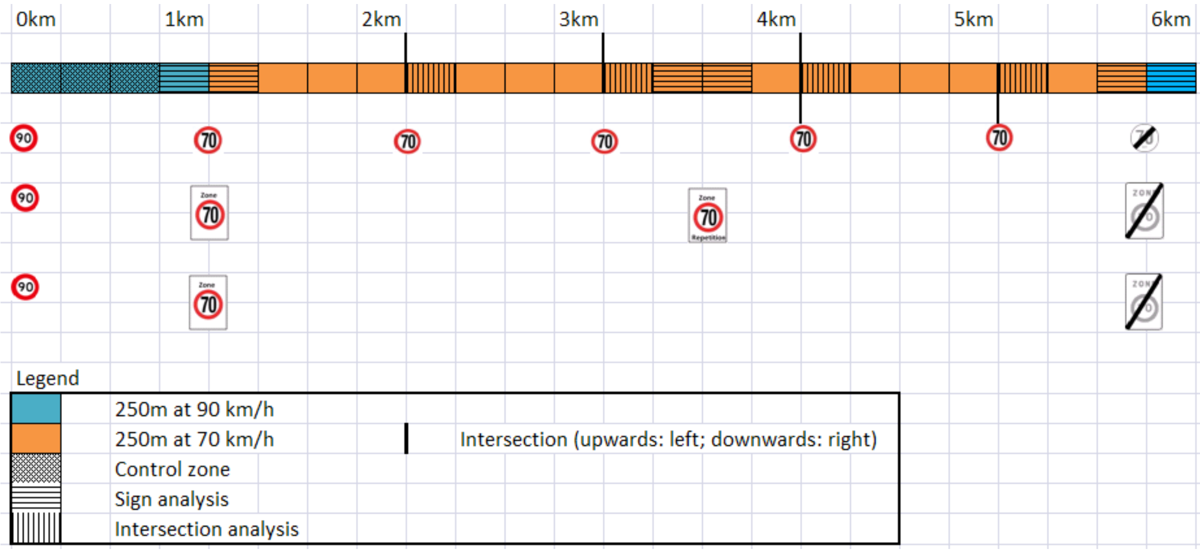


Figure 6 Scenarios: placement of the signs and intersections; zones of interest and filler pieces

2.3.1 Procedure

After the participant entered the waiting room he was asked to read a questionnaire with information about the study (section VII Annex 5. at page 117). To save time in the examination room, the questionnaire contained an informed consent form, a list of personal questions and a number of questions related to traffic rules. After the participant filled in this list, he went to the examination room where the researcher started a PowerPoint. The questionnaire on the Highway Code was corrected to clear the errors. The purpose of these questions was to detect whether the participant knew the meaning of the different speed signs and to explain the wrong answers. In this way, differences in driving performance were not caused by not knowing the traffic rules. After this, the participant took place in the car seat and adjusted it to sit comfortably. It was explained where the horn, the direction indicator, the speedometer, the revolution counter, the gearbox and the mirrors are located. Before one started the first trip, the following instructions were given:

- Please behave as you would normally behave.
- At crossings the traffic lights are always at green.

After that, a division was made between those who first carried out the trip without secondary task and persons who first carried out the trip with secondary task. Both groups drove a warming up trip of 6 kilometres – this is by analogy with other studies (a.o. Devos et al., 2007) – to get used to the simulator. It was the intention that, during this trip, one drove as normally as possible and one stopped, changed gear, moved the wheel and used the direction indicator a few times. Subsequently, the first group drove a first research trip of 18 kilometres (without secondary task). When this was completed, the secondary task was explained. This included responding to four different symbols. The participant exercised this task a few times before he performed this for real. He started with an easy warming up where 20 symbols were presented in a PowerPoint (randomly chosen) and where the test person auditory said "down" or "up" and simultaneously used the direction indicator. The first symbols appeared with a time interval of 5 seconds, and finally an interval of 3 seconds. When the participant had a score of 12/20 or less, the exercise was interrupted and a memory aid was learned to remember the relationship. The exercise was repeated until a score of 14/20 was reached. After this easy warming up period, the driver drove a trip of 6 kilometres on a straight road, with no other road users, with no speed restrictions because the simulator was – in this trip – limited to 70 km/h and with no gear shifts. The driver only reacted 44 times to the symbols. When a score of 31/44 or more was reached, he could proceed to the next warming up trip. In this last warming up trip, he performed the driving task (switch gear, other road users, speed restrictions, etc.) together with the secondary task. When one had a score of 31/44 or more, the actual research trip could be performed. This included a 18 kilometres long trip with 132 symbols. The researcher told the participant that he must perform the driving task and the secondary task, but no priority was given between both tasks. The group who performed first the trip with secondary task drove after this research trip, the trip with only the driving task. Each warming up trip was by analogy with other studies (a.o. Bella, 2005; van der Horst & de Ridder, 2007; Lansdown, 2002; Y. Lee, J. Lee, & Boyle, 2007) that relied on a warming up period of 10 to 15 minutes in which, on the one hand, the general operation of the simulator was trained and, on the other hand, the secondary task.

At the end of all trips, the de-briefing took place to examine Situation Awareness, and to see if one knew the purpose of the study. In this discussion moment one asked what kind of road signs the participants had encountered and what the colour of the repetition sign was.

Table 3 Procedure participants

Step	***Act***			***Time (minutes)***
1	Read and fill in informed consent form + personal questions + traffic rules (without researcher)			10
2	Check traffic rules + briefing about the course of trips			5
3	Introduction to the simulator + instruction			5
	Trip: without and with secondary task		***Trip: with and without secondary task***	
4	Warming up trip to get used to the simulator	5	Warming up trip to get used to the simulator	5
5	Research trip: driving task	15	Warming up secondary task: auditory	5
6	Warming up secondary task: auditory	5	Warming up trip secondary task: limited speed	5
7	Warming up trip secondary task: limited speed	5	Warming up trip secondary task: driving & secondary task	5
8	Warming up trip secondary task: driving & secondary task	5	Research trip: driving & secondary task	15
9	Research trip: driving & secondary task	15	Research trip: driving task	15
10	De-briefing	5	De-briefing	5
TOTAL				**75**

2.3.2 Design and variables

The experiment consisted of four different analyses with each a different design (also Figure 6 at page 47). The conditions, that are listed up below, were tested in two different trips. Each participant drove once a trip – with three different speed indications and four intersections – under a low mental effort and once under a high mental effort. The participants were subjected to a *within design* (= 'repeated measures design'), which means that the independent variables within each participant were manipulated and the independent variables are these variables that were manipulated. As a result, the noise is kept under control, so the differences in performance were due to systematic variation (Field, 2005). Systematic variation refers to the variation that is the result of the manipulation while non-systematic variation refers to the variation in spite of the fact that there is no manipulation. This last variation is small in a repeated measures design (Field, 2005) because it is unlikely that the same person behaves differently in the two trips as a result of a not manipulated variable (if there is randomizing and counterbalancing).

a. Control zone: (0 m – 750 m)

This analysis took place to see if there were differences where no differences were expected. The control zone analysis goes from 0 m to 750 m (this area was in each segment of 6 km the same). There were two independent variables, namely the type of speed Sign (with three levels: traditional, zone-repetition and zone) and Secondary Task (with two levels: low and high), so, there were six (3x2) experimental conditions for this analysis.

b. Sign analysis: (250 m before versus 250 m after each sign at 1000 m, 3500 m and 5750 m)

In each segment of 6 km, the first interesting sign – that indicated the transition from 90 to 70 km/h – was placed at 1000 m (C43 in traditional scenario and F4a in the other two scenarios). The second sign – the repetition sign – was placed at 3500 m (only in the zone-repetition scenario) while the last sign – transition from 70 to 90 km/h – was placed in every scenario at 5750 m (C45 in traditional scenario and F4b in the other two scenarios). This analysis compared the behaviour of 250 m before the sign with 250 m after the sign. By doing this, there were three independent variables, namely the type of speed Sign (with three levels), Secondary Task (with two levels) and a variable named 'Before/After' (with two levels: 250 m before the sign and 250 m after the sign). So, there were three independent analyses – one for each sign – with each twelve (3x2x2) experimental conditions.

c. <u>Intersection analysis:</u> (250 m after each intersection at 2 km, 3 km, 4 km and 5 km)

In each segment there were four intersections and the behaviour of 250 m after each intersection was analyzed. This analysis consisted of three independent variables, namely the type of speed Sign (with three levels), Secondary Task (with two levels) and the order of Intersections (i.e. a time referred variable with four levels: intersection one, intersection two, intersection three and intersection four). There were three different speed indications, two mental load situations and four intersections, so there were twenty-four experimental conditions (3x2x4). This analysis had an added value in comparison to the study by Daniëls et al. (2010) because they analyzed only the effect of one intersection while in this Master's Thesis there were four intersections.

d. <u>Speed segment of 70 km/h analysis:</u> (1000 m – 5750 m)

One kilometre after the start, the speed limit dropped form 90 to 70 km/h and this for 4750 metres (till 5750 m). Like in the control zone, there were two independent variables (Sign with three levels and Secondary Task with two levels), so there were six experimental conditions (3x2).

There were some dependent or explanatory variables that were examined. Noy (1987) stated that secondary tasks influenced the primary task performance and other studies have confirmed this (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Haigney & Westerman, 2001; Recarte & Nunes, 2002; Daniëls et al., 2010). To find out if the speed indication, the mental effort and the intersections had an impact, the following parameters were logged, and this 60 times per second:

- Longitudinal control
    - Speed: average and standard deviation
- Lateral control
    - Lateral deviation relative to the centre line: standard deviation
    - Percentage of time/distance out of the lane

The mean speed was analyzed because a study by Daniëls et al. (2010) showed that the rate of reduction in the traditional approach was more explicit, and the reduction process started earlier. A possible reason for this can be the greater familiarity with the traditional speed signs and Kappé & Emmerik (2005) stated that the average speed is a way to analyze speed enforcement. The standard deviation of speed served as a measure of stability or as a measure of speed control (Daniëls et al., 2010; Reed & Green, 1999). According to Reed & Green (1999) and Liu & Lee (2006) the standard deviation of lateral position served as a measure of driving precision (smaller standard deviation indicates a greater precision). Kappé & Emmerik (2005) stated that the standard deviation of lateral position is one of the possibilities to analyze steering behaviour. It was important that only the data was included where the car drove on his own lane, because one analyzed the standard deviation of lateral position. As defined, the width of a lane is 3.25 m and values above indicated that the middle of the car was outside the right edge of the lane. Values below zero indicated that the middle of the car had crossed the center line. To take this into account, only the lateral position between 0 and 3.25 was considered. According to Lansdown (2002) and Young & Stanton (2002) the percentage of time out of lane serves as a measure of vehicle control. Lane exceedence was defined as when the nearest edge of the vehicle – thus not the middle of the car – intruded outside of the nearest side of the lane and this percentage could be found back in the logged data files. In addition to the parameters above, the distance, time and current speed limit were registered. With regard to the secondary task, the response time and the number of correct, incorrect and missed were recorded. The reaction time was defined as the temporal interval between the presentation of the visual stimuli and the onset of the detected response by the simulator.

Table 4 Overview of the parameters

Primary driving task	***Secondary task***	***General***
Longitudinal speed	Reaction time	Travelled time
Lateral deviation to the centre line	Number correct	Travelled distance
	Number incorrect	Current speed limit
% of time/distance out of the lane	Number missed (no reaction within 3 s)	

2.4 Tasks and instruction

The primary task in this study was the driving task. Participants were asked to act as they act in reality, and this was by analogy with other studies (a.o. Godley, Triggs, & Fildes, 2002; Daniëls et al., 2010). In addition to the driving task, a secondary task was introduced. In the instruction it was not specified which of the two tasks should receive priority. This means that one was told that there was a second task, without further specifying which task has priority (by analogy with Daniëls et al., 2010). In section II 4.4.2 an overview of the various secondary tasks is given. Here, a two-choice discrimination reaction time task was chosen to be used. In the task, a reaction was required at four different target stimuli by which the combination of colour and shape determined the reaction. Figure 7 shows the four stimuli with the expected response for group A: yellow diamond (YD), red diamond (RD), yellow square (YS) and red square (RS). The flashing down or up was counterbalanced between the participants. This means that for one group (A) YD and RS meant flashing downwards and RD and YS meant upwards, while the opposite was true for group B. Both the diamond as the square had the same size (i.e. each with a width of 5 cm) and were projected in the middle of the rearview mirror. By doing this, the geometry of the figures was the same.

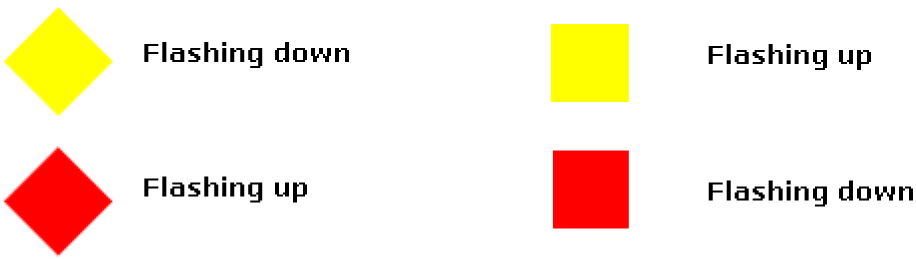


Figure 7 Stimuli for group A

The order of the four stimuli of Figure 7 was determined by using a random number generator at a random distance through the trip. The stimuli in the 90 km/h segments were presented every 75 to 125 metres while in the 70 km/h segment this was every 58 to 97 metres. Given the purpose of this Master's Thesis – a study on the type of speed signs – it was important that the speed signs could be detected. That is why 55 metres before and 10 metres after the speed signs there were no stimuli presented. Given this restriction, it was very difficult to use a random number generator to determine the interval distance, so the researcher had determined the interval distance himself, taking the restrictions into account. The maximum duration that a stimulus was projected in the rearview mirror was 3 seconds. Annex 6. gives an overview of the randomization of the 132 stimuli.

IV. Results

1. ANALYSIS

Analysis of variance (ANOVA) was used to investigate the effects of the independent variables on driver performance measures. ANOVA's were corrected for deviations from sphericity (Greenhouse-Geisser epsilon correction). The corrected F-values and probability values and the uncorrected degrees of freedom are reported. All effects discussed in the following sections were statistically significant with type I error probability less than or equal to .05, or marginal significant with an error probability less than or equal to .10, unless noted otherwise. The significance level of 5% means that with this probability a true null hypothesis may, mistakenly, be rejected (Field, 2005). The different parameters were averaged for sections of 50 metres and the analysis took place for 250 metres segments. The number of observations in each section of 50 metres varied with speed. The measurements were averaged for each participant and section of 50 metres.

Some analyses were made for completeness and are little or not connected with the research questions, but as much as possible only the relevant analyses were done. For example, the control zone would not serve to answer any research question, but it was interesting to verify the logged data. If there were carried out multiple divisions of the interaction effects, the first that is discussed is the most relevant. It should however be noted that not all the divisions have been carried out that could be done. It was for example possible the split up the 3-way interactions in three ways, but most of the time it was only done in one or two ways. The most important analyses, that serve to answer the research questions, are repeated in section V 1. Conclusion parameters – research questions at page 87.

2. EXPLORING THE DATA

Before the data could be analyzed, it was important to check if there were outliers in it. An outlier is a score very different from the rest of the data and results in biased conclusions (Field, 2005). By making several boxplots for the different analyses, person 33 and 22 (women) were considered as an outlier. These persons had more than other persons some extreme values (at least three times the interquartile range) or outliers (between 1.5 and 3 times the interquartile range) so they were removed out of the data. So, there were 46 valid participants considered. Person 33 was very different from all the other persons in the analysis of average speed. Person 22 was removed because of the dissimilar behaviour in the analysis of the standard deviation of speed and in smaller extent the standard deviation of the lateral position. The remaining persons behaved 'normal' in most of the interesting zones (section VII. Annex 7. at page 128). None of the persons suffered from simulator sickness and this finding can be used as a measure for physical validity (Godley et al., 2002). So, there was a good physical correspondence of the simulator's components, layout and dynamics with its real world counterpart.

Table 5 Descriptives for 46 participants

	Age	***Genus***	***Years car license***	***Kilometres a year***	***Eye correction***
N Valid	46	46	46	46	46
Mean	38.26	47.8% women	18.72	21 146.11	47.8% with correction
SE of mean	1.94	/	1.88	1 714.21	/
Median	34.00	/	14.00	20 000	/
Std. Deviation	13.16	/	12.74	11 626.37	/
Skewness	.58	/	.59	.79	/
Minimum	22	/	3	3000	/
Maximum	63	/	44	50 000	/

The average age of the remaining 46 participants was 38.26 years and the positive value of skewness indicated a pile-up of age on the left of the distribution, meaning skewed data. This pattern could also be found in Chart 3 where one could see that age was non-normal and this was significant according to the Kolmogorov-Smirnov test ($D(46) = .19$, $p < .0005$).

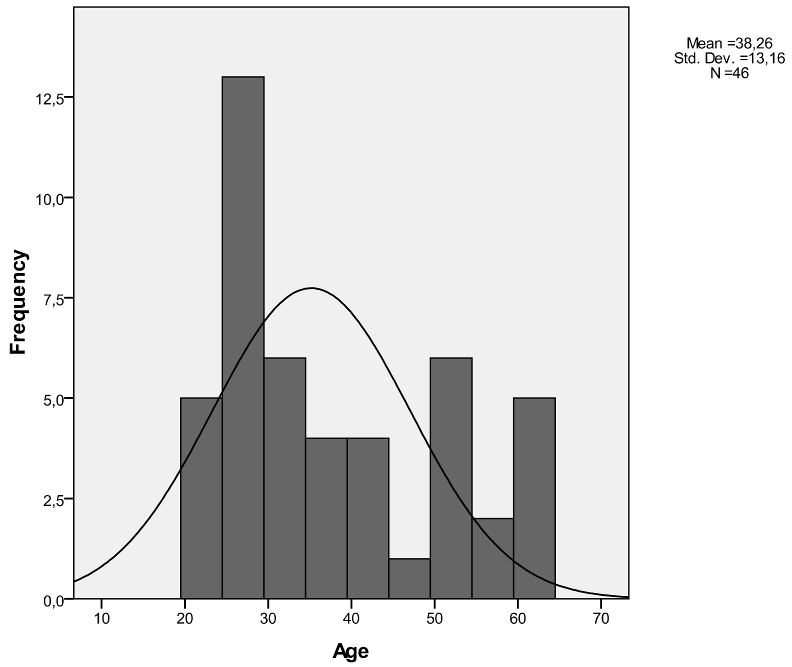


Chart 3 Histogram of age

There are two common ways of describing driving experiences: the number of years of having a car driving license and the number of driven kilometres a year. Given the fact that a lot of people do not drive a lot, it is wise to use the second proxy for experience. In Flanders, the average number of kilometres a year, with a person car, is 16 338 km (Moons, 2009) while the participants of this study drove on average 21 146 km a year. Almost half of the participants wore glasses or lenses during the study. It is important that if someone had a disturbed vision, this was corrected during the trips so one could see everything on the projection screen.

3. CONTROL ZONE

The first 750 metres of each scenario was the same, so one expected no differences between the three scenarios. The only difference that was possible, was one between the trips with and without a secondary task because all the rest was the same in this control zone (section III 2.3.2 for more information).

3.1 Mean speed

There was only a main effect of Secondary Task ($F(1, 45) = 30.00$, $p < .0005$, $\eta_p^2 = .40$), indicating that one drove slower with secondary task ($SE = .98$) compared to the situation without (*SE* = .90). There was no significant effect of Sign ($F(2, 90) = .47$, $p = .62$, $\eta_p^2 = .01$; traditional: $M = 83.12$ km/h; zone-repetition: $M = 83.46$ km/h; zone: $M = 83.97$ km/h) and no interaction effect of Sign x Secondary Task ($F(2, 90) = 1.56$, $p = .22$, $\eta_p^2 = .03$).

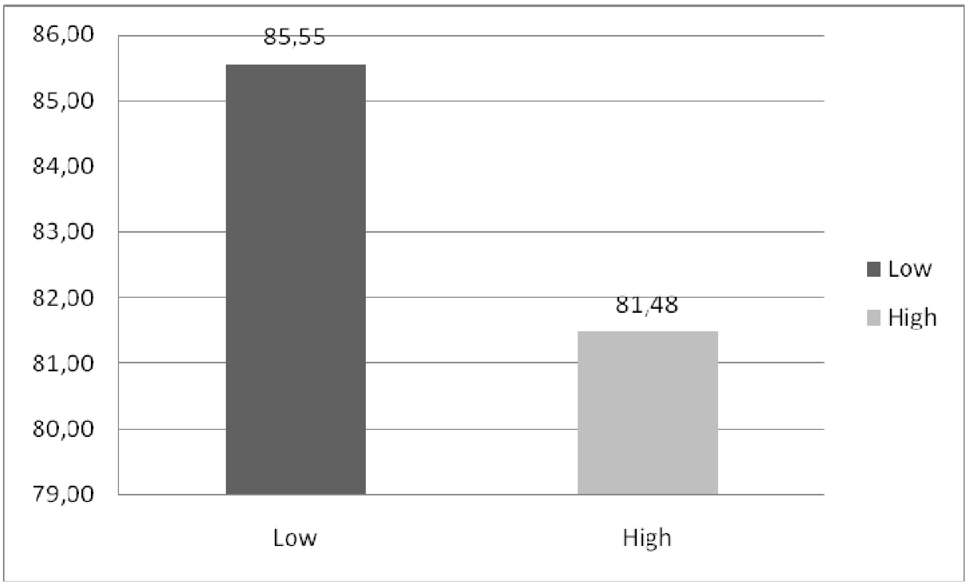


Chart 4 Mean speed in control zone: average over signs

3.2 Standard deviation of speed

There was no significant main effect of Sign $F(2, 90) = .31$, $p = .71$, $\eta_p^2 = .01$), while there was a main effect of Secondary Task ($F(1, 45) = 5.17$, $p = .03$, $\eta_p^2 = .10$) and an interaction effect of Sign x Secondary Task ($F(2, 90) = 7.15$, $p = .00$, $\eta_p^2 = .14$).

Separate tests for each level of Secondary Task showed that (Chart 5):

- *Without a Secondary Task*, there is an effect of Sign ($F(2, 90) = 3.59$, $p = .04$, $\eta_p^2 = .07$), indicating that the standard deviation of speed for the zone condition differed from traditional ($t(45) = 2.61$, $p = .01$) and from repetition ($t(45) = 1.93$, $p = .06$; marginal) while there was no difference between traditional and repetition ($t(45) = .18$, $p = .86$).
- *With Secondary Task*, there was an effect of Sign ($F(2, 90) = 4.60$, $p = .01$, $\eta_p^2 = .09$), indicating that the standard deviation of speed for the zone condition differed from traditional ($t(45) = 2.22$, $p = .03$) and from repetition ($t(45) = 2.67$, $p = .01$) while there was no difference between traditional and repetition ($t(45) = .90$, $p = .37$).

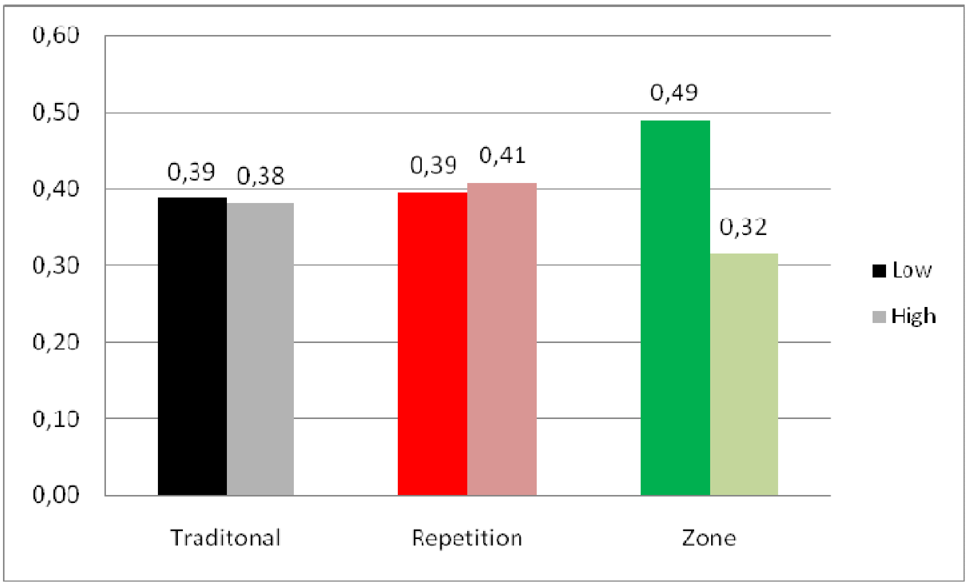


Chart 5 Standard deviation of speed in control zone

Separate tests at each type of Sign (same averages as Chart 5) showed that there was only a significant difference in standard deviation for the zone sign ($t(45) = 4.21$, $p < .0005$) and there were no differences for the other two signs (traditional: $t(45) = .17$, $p = .86$; repetition: $t(45) = .31$, $p = .76$).

3.3 Standard deviation of lateral position

There were no main effects of Sign ($F(2, 90) = .36$, $p = .68$, $\eta_p^2 = .01$) and Secondary Task ($F(1, 45) = .01$, $p = .92$, $\eta_p^2 < .0005$), indicating that the standard deviation of lateral position was similar for the situation with ($M = .05$ m, $SE = .00$) and without ($M = .05$ m, $SE = .00$) secondary task. Finally, there was no interaction effect of Sign x Secondary Task ($F(2, 90) = .34$, $p = .70$, $\eta_p^2 = .01$).

4. Speed transition from 90 to 70 km/h

At 1000 metres there was placed a traffic sign that indicated a lower speed than the general speed limit of 90 km/h, namely a 70 km/h limit (section III 2.3.2 for more information).

4.1 Mean speed

Chart 6 gives the general speed pattern at the transition point at 1000 metres. As one can see, the curves with a higher mental load were lower than the others. This pattern shows that one drove slower when one had to perform a secondary task. Next, on can see that the rate of reduction in the situation without mental effort was the same for the three situations while with an effort there seemed to be a difference (the speed reduction seemed to be stronger in the two zone indications) and the speed at the transition point itself was, with a secondary task, different (traditional: *M* = 78.09 km/h; repetition: *M* = 74.89 km/h; *M* = 75.26 km/h).

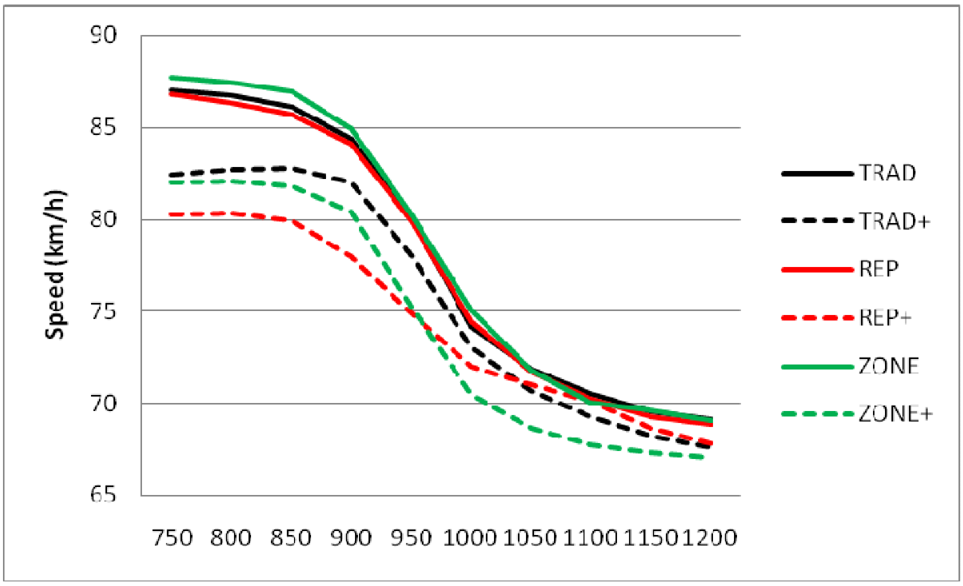


Chart 6 Average speed at transition 90 – 70 km/h: general pattern

There was no main effect of Sign ($F(2, 90) = .72$, $p = .49$, $\eta_p^2 = .02$) and no interaction of Sign x Secondary Task ($F(2, 90) = 1.35$, $p = .26$, $\eta_p^2 = .03$).

There was a main effect of Secondary Task ($F(1, 45) = 24.49$, $p < .0005$, $\eta_p^2 = .35$) and Before/After ($F(1, 45) = 391.38$, $p < .0005$, $\eta_p^2 = .90$), and interaction effects of Sign × Before/After ($F(2, 90) = 3.34$, $p = .04$, $\eta_p^2 = .07$) and Secondary Task × Before/After ($F(1, 45) = 25.45$, $p < .0005$, $\eta_p^2 = .36$). Finally, there was a significant 3-way interaction effect of Sign × Secondary Task × Before/After ($F(2, 90) = 3.07$, $p = .05$, $\eta_p^2 = .06$) that will be examined further now.

Separate tests for each level of Secondary Task showed that:

- *Without a Secondary Task*, there only was a main effect of Before/After ($F(1, 45) = 346.64$, $p < .0005$, $\eta_p^2 = .89$) indicating that speed was lower after (*M* = 71.02 km/h, *SE* = .74) the speed transition than before (*M* = 84.95 km/h, *SE* =

.89). There was no main effect of Sign (F(2, 90) = .20, p = .81, η_p^2 = .00) and no interaction of Sign × Before/After (F(2, 90) = .28, p = .75, η_p^2 = .01).

- *With Secondary Task*, there was no main effect of Sign (F(2, 90) = 1.67, p = .20, η_p^2 = .04), a main effect of Before/After (F(2, 90) = 290.15, $p < .0005$, η_p^2 = .87), and an interaction of Sign × Before/After (F(2, 90) = 5.47, p = .01, η_p^2 = .11).
    - Separate tests for each type of Sign showed that (Chart 7):
        - For the *traditional Sign,* the mean speed was higher before (SE = 1.16) than after (SE = .95) the transition (t(45) = 7.25, $p < .0005$).
        - For the *zone-repetition Sign,* the mean speed was higher before (SE = 1.27) than after (SE = .93) the transition (t(45) = 5.83, $p < .0005$).
        - For the *zone Sign,* the mean speed was higher before (SE = 1.18) than after (SE = .84) the transition (t(45) = 8.30, $p < .0005$).

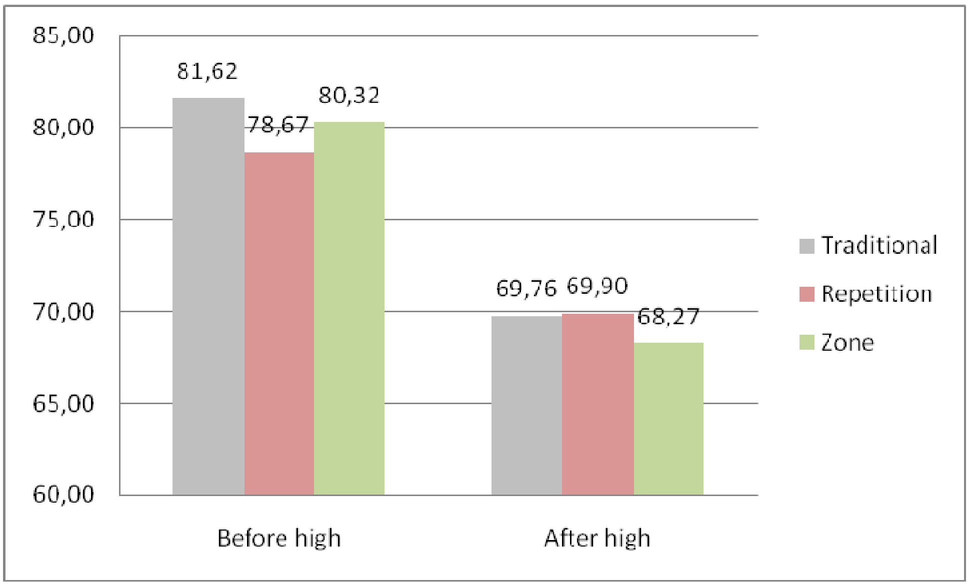


Chart 7 Average speed at transition 90 – 70 km/h for a high mental load (250 m before and after)

- Separate tests for Before/After showed that (same averages as Chart 7):
    - In the 250 m *Before*, there was a marginal main effect of Sign (F(2, 90) = 3.00, p = .06, η_p^2 = .06) but only the speed between the traditional and the repetition scenario (SE = 1.27) differed

significantly ($t(45) = 2.18$, $p = .04$) while there was no difference between zone ($SE = 1.18$) and traditional ($t(45) = 1.20$, $p = .24$) and between zone and repetition ($t(45) = 1.41$, $p = .17$).

- In the 250 metres *After* the speed transition there was no significant effect of Sign ($F(2, 90) = 2.25$, $p = .11$, $\eta_p^2 = .05$).

Separate tests at each type of Sign showed that (Chart 8):

- For the *traditional Sign*, there was a main effect of Secondary Task ($F(1, 45) = 6.00$, $p = .02$, $\eta_p^2 = .12$) and of Before/After ($F(1, 45) = 196.52$, $p < .0005$, $\eta_p^2 = .81$), and an interaction of Secondary Task x Before/After ($F(1, 45) = 3.91$, $p = .05$, $\eta_p^2 = .08$).
    - Separate tests for each level of Secondary Task showed that *without a Secondary Task* one drove faster before ($SE = 1.06$) than after ($SE = .95$) the transition ($t(45) = 13.15$, $p < .0005$) and *with Secondary Task* one drove faster before ($SE = 1.16$) than after ($SE = .96$) the transition ($t(45) = 11.51$, $p < .0005$).

- For the *zone-repetition Sign*, there was a main effect of Secondary Task ($F(1, 45) = 16.42$, $p < .0005$, $\eta_p^2 = .28$) and of Before/After ($F(1, 45) = 248.63$, $p < .0005$, $\eta_p^2 = .85$), and an interaction of Secondary Task x Before/After ($F(1, 45) = 28.30$, $p < .0005$, $\eta_p^2 = .39$).
    - Separate tests for each level of Secondary Task showed that *without a Secondary Task* one drove faster before ($SE = .92$) than after ($SE = .93$) the transition ($t(45) = 16.12$, $p < .0005$) and *with Secondary Task* one drove faster before ($SE = 1.27$) than after ($SE = .91$) the transition ($t(45) = 10.37$, $p < .0005$).

- For the *zone*, there was a main effect of Secondary Task ($F(1, 45) = 19.45$, $p < .0005$, $\eta_p^2 = .30$) and of Before/After ($F(1, 45) = 344.26$, $p < .0005$, $\eta_p^2 = .88$), and an interaction of Secondary Task x Before/After ($F(1, 45) = 5.52$, $p = .02$, $\eta_p^2 = .11$).
    - Separate tests for each level of Secondary Task showed that *without a Secondary Task* one drove faster before ($SE = 1.24$) than after ($SE = .84$) the transition ($t(45) = 16.09$, $p < .0005$) and *with Secondary Task* one

drove faster before (*SE* = 1.18) than after (*SE* = .85) the transition ($t(45) = 14.50$, $p < .0005$).

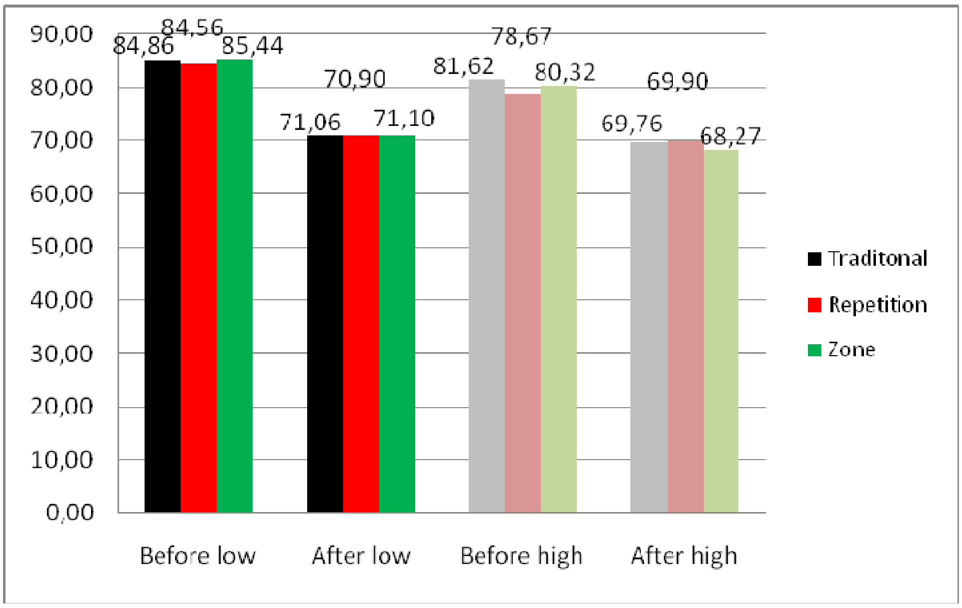


Chart 8 Average speed at transition 90 – 70 km/h (250 m before and after)

4.2 Standard deviation of speed

There were no main effects of Sign ($F(2, 90) = 2.01$, $p = .15$, $\eta_p^2 = .04$), Secondary Task ($F(1, 45) = 2.52$, $p = .12$, $\eta_p^2 = .05$), Before/After ($F(1, 45) = .22$, $p = .64$, $\eta_p^2 = .01$), and no interaction effects of Sign x Before/After ($F(2, 90) = .28$, $p = .71$, $\eta_p^2 = .01$), Sign x Secondary Task ($F(2, 90) = .60$, $p = .55$, $\eta_p^2 = .01$), Secondary task x Before/After ($F(1, 45) = 2.45$, $p = .13$, $\eta_p^2 = .05$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .13$, $p = .83$, $\eta_p^2 < 0.0005$).

4.3 Standard deviation of lateral position

There were no main effects of Sign ($F(2, 90) = .87$, $p = .42$, $\eta_p^2 = .02$), and no interaction effects of Sign x Before/After ($F(2, 90) = .54$, $p = .55$, $\eta_p^2 = .01$), Secondary Task x Before/After ($F(1, 45) = .32$, $p = .58$, $\eta_p^2 = .01$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .53$, $p = .59$, $\eta_p^2 = .01$).

The standard deviation of lateral position was larger after (*M* = .05 m, *SE* = .00) the speed transition than before (*M* = .04 m, *SE* = .00; $F(1, 45) = 39.15$, $p < .0005$, η_p^2 =

.47). There was a significant main effect of Secondary Task ($F(1, 45) = 5.58$, $p = .02$, $\eta_p^2 = .11$) and an interaction of Secondary Task x Sign ($F(2, 90) = 3.61$, $p = .03$, $\eta_p^2 = .07$).

Separate tests at each type of Sign showed that (Chart 9):

- For the *traditional Sign*, there was no effect of Secondary Task ($t(45) = 1.05$, $p = .30$).
- For the *zone-repetition Sign*, there was no effect of Secondary Task ($t(45) = .68$, $p = .50$).
- For the *zone Sign*, there was an effect of Secondary Task ($t(45) = 3.07$, $p < .0005$).

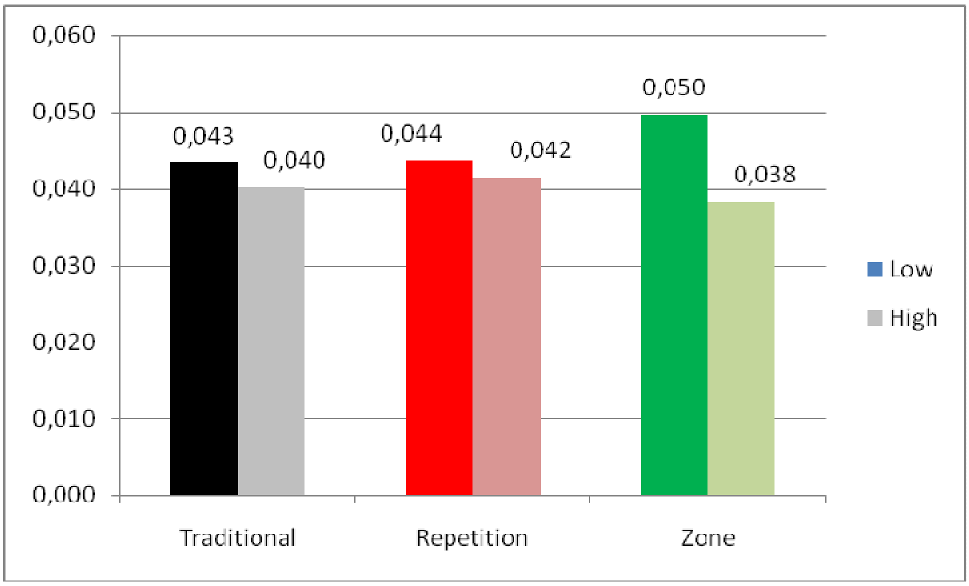


Chart 9 Standard deviation of lateral position at speed transition 90 – 70 km/h: average over before and after

5. REPETITION SIGN

In the zone-repetition scenario a repetition sign at 3500 metres was placed to remind the driver to the speed limit of 70 km/h, this sign was not placed in the other two scenarios (section III 2.3.2 for more information).

5.1 Mean speed

As one could see at Chart 10, the speed dropped at 3500 metres when a repetition sign was placed.

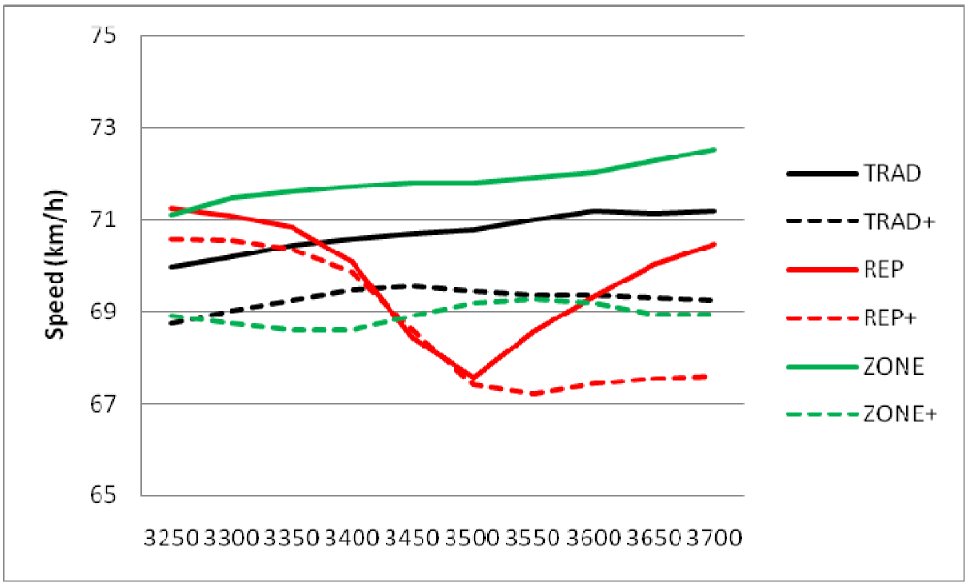


Chart 10 Average speed at repetition sign: general pattern

There was no main effect of Before/After ($F(2, 90) = 1.92$, $p = .17$, $\eta_p^2 = .04$), no interaction effect of Secondary Task x Before/After ($F(1, 45) = 2.74$, $p = .11$, $\eta_p^2 = .06$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .61$, $p = .54$, $\eta_p^2 = .01$). The main effects of Secondary Task ($F(1, 45) = 13.66$, $p = .00$, $\eta_p^2 = .23$) and Sign ($F(2, 90) = 2.56$, $p = .09$, $\eta_p^2 = .05$) were (marginal) significant.

There was a significant interaction effect of Sign x Before/After ($F(2, 90) = 9.63$, $p = .00$, $\eta_p^2 = .18$).

- Separate tests at each type of Sign showed that (Chart 11):
  - For the *traditional Sign,* there was no difference between the mean speed before ($SE = .64$) and after ($SE = .73$; $t(45) = 1.31$, $p = .20$).
  - For the *zone-repetition Sign,* one drove before ($SE = .72$) the sign faster than after the sign ($SE = .51$; $t(45) = 3.10$, $p < .0005$).
  - For the *zone Sign,* there was no difference between the mean speed before ($SE = .68$) and after ($SE = .68$; $t(45) = 1.63$, $p = .11$).

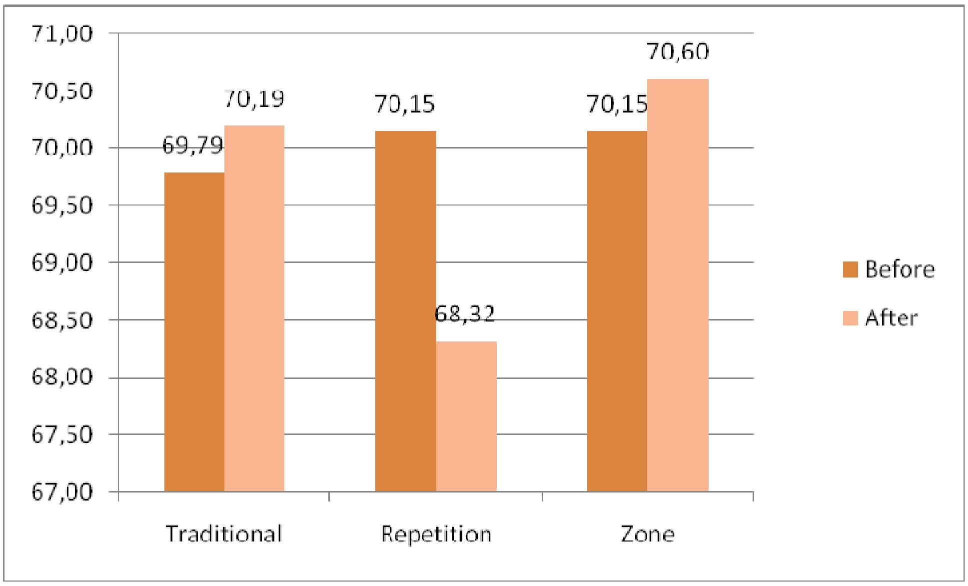


Chart 11 Average speed at repetition sign (250 m): average over mental load

There was a second significant interaction effect of Secondary Task x Sign ($F(2, 90) = 3.08$, $p = .05$, $\eta_p^2 = .06$).

- Separate tests for each level of Secondary Task showed that (Chart 12):
  - *Without a Secondary Task*, there was an effect of Sign ($F(2, 90) = 4.96$, $p = .01$, $\eta_p^2 = .10$), indicating that the speed was lowest for repetition ($SE = .67$) and this differed from zone ($SE = .67$; $t(45) = 3.39$, $p < .0005$) while there was no difference with traditional ($SE = .76$; $t(45) = 1.33$, $p = .19$). The speed for the traditional case was marginal different from zone ($t(45) = 1.73$, $p = .09$).
  - *With Secondary Task*, there was no effect of Sign $F(2, 90) = .41$, $p = .66$, $\eta_p^2 = .01$).

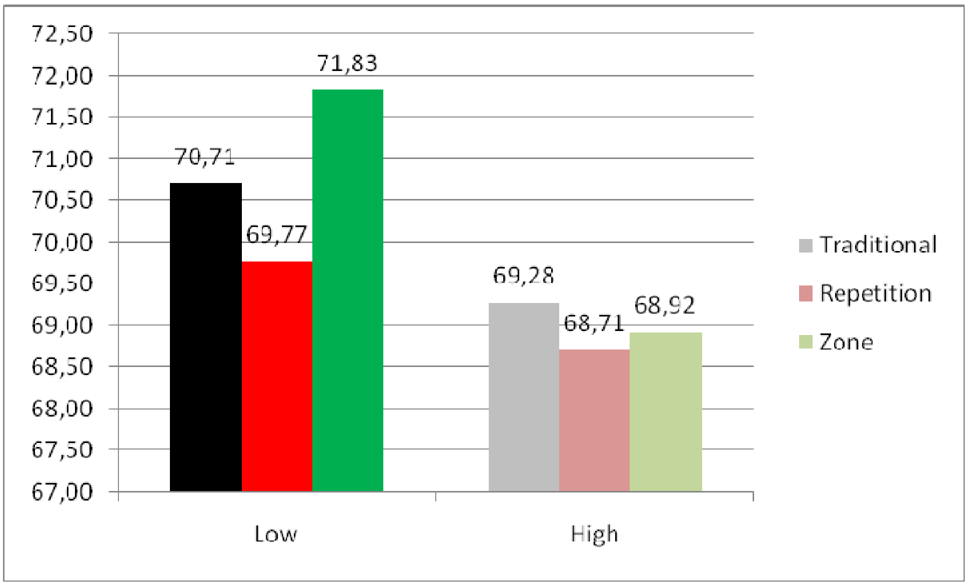


Chart 12 Average speed at repetition sign (250 m): average over before/after

- Separate tests at each type of Sign showed that (same averages as Chart 12):
  - For the *traditional Sign*, one drove with Secondary Task slower than without ($t(45) = 2.05$, $p = .05$).
  - For the *zone-repetition Sign*, there was no effect of Secondary Task ($t(45) = 1.62$, $p = .11$).
  - For the *zone Sign*, one drove with Secondary Task slower than without ($t(45) = 4.49$, $p < .0005$).

5.2 Standard deviation of speed

There were no main effects of Secondary Task ($F(1, 45) = .88$, $p = .35$, $\eta_p^2 = .02$) and Before/After ($F(1, 45) = .51$, $p = .48$, $\eta_p^2 = .01$), and no interaction effects of Secondary Task x Sign ($F(2, 90) = 2.19$, = .12, $\eta_p^2 = .05$), Sign x Before/After ($F(2, 90) = 1.07$, $p = .33$, $\eta_p^2 = .02$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .05$, $p = .94$, $\eta_p^2 = .00$).

There was a main effect of Sign ($F(2, 90) = 8.53$, $p < .0005$, $\eta_p^2 = .16$), indicating that the standard deviation of speed for the zone-repetition sign ($SE = .05$) differed from traditional ($SE = .03$; $t(45) = 2.93$, $p = .01$) and zone ($SE = .02$; $t(45) = 3.28$, $p = .00$), while there was no difference between zone ($t(45) = .17$, $p = .89$) and traditional (Chart 13).

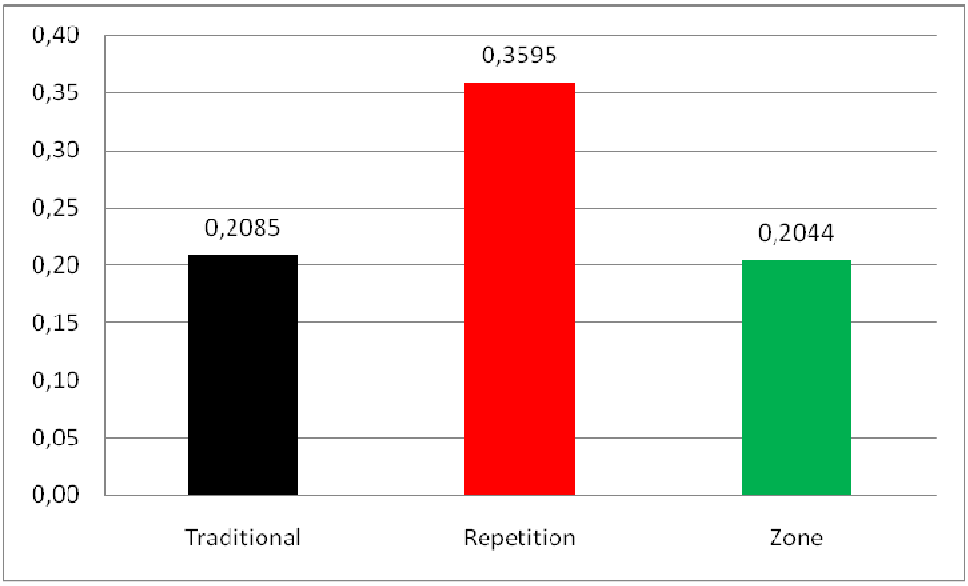


Chart 13 Standard deviation of speed at repetition sign: average over before/after and mental load

There was only one marginal interaction effect of Secondary Task x Before/After ($F(1, 45) = 3.77$, $p = .06$, $\eta_p^2 = .08$).

Separate tests for each level of Secondary Task showed that (Chart 14):

- *Without a Secondary Task*, there was no effect of Before/After ($t(45) = .74$, $p = .46$).
- *With Secondary Task,* there was an effect of Before/After $t(45) = 2.01$, $p = .05$), indicating that the deviation before was larger than after.

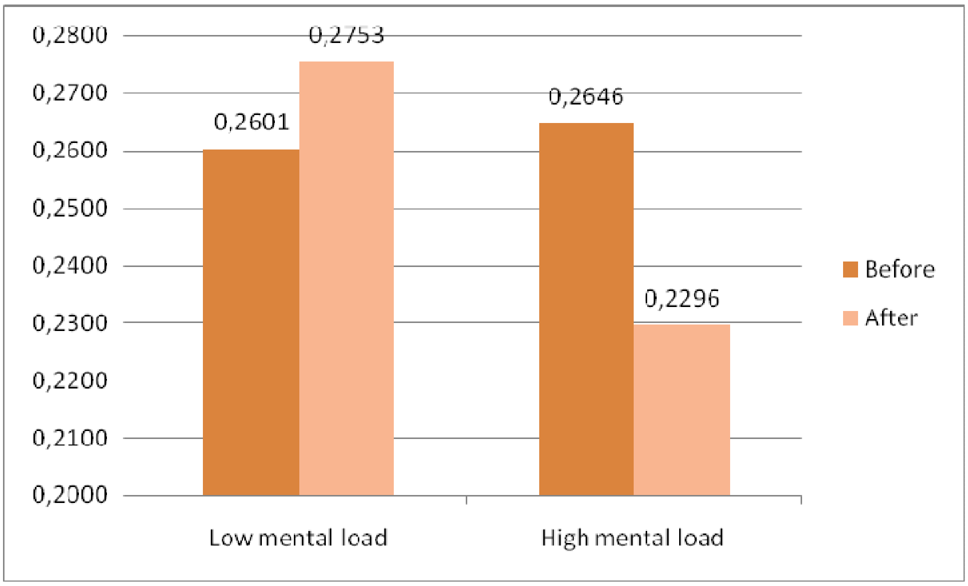


Chart 14 Standard deviation of speed at repetition sign: average over sign

Separate tests for Before/After showed that (same averages as Chart 14):

- In the 250 m *Before*, there was no effect of Secondary Task ($t(45) = .20$, $p = .84$).
- In the 250 m *After*, there was no effect of Secondary Task ($t(45) = 1.61$, $p = .11$).

5.3 Standard deviation of lateral position

There was no main effect of Before/After ($F(1, 45) = .59$, $p = .45$, $\eta_p^2 = .01$), and no interaction effects of Secondary Task x Sign ($F(2, 90) = .30$, $p = .74$, $\eta_p^2 = .01$), Sign x Before/After ($F(2, 90) = 1.41$, $p = .25$, $\eta_p^2 = .03$), Secondary Task x Before/After ($F(1, 45) = .48$, $p = .49$, $\eta_p^2 = .01$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .67$, $p = .51$, $\eta_p^2 = .02$).

There was a main effect of Secondary Task ($F(1, 45) = 5.59$, $p = .02$, $\eta_p^2 = .11$), indicating that the standard deviation of lateral position was smaller with a Secondary Task (Chart 15).

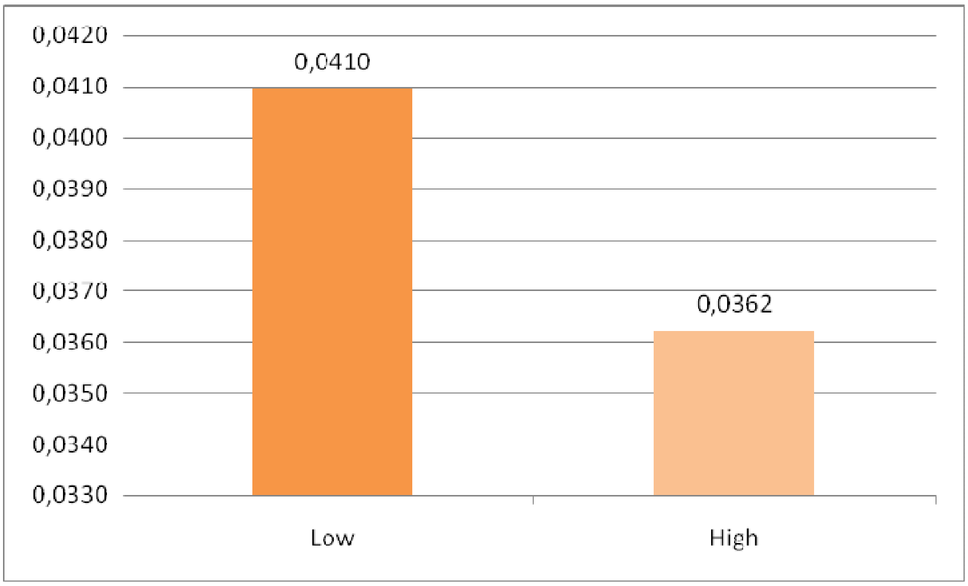


Chart 15 Standard deviation of lateral position at repetition sign: average over sign and before and after

Finally, there was another main effect of Sign ($F(2, 90) = 7.46$, $p < .0005$, $\eta_p^2 = .14$), but there was only a difference between repetition and traditional ($t(45) = 3.99$, $p < .0005$) and between repetition and zone ($t(45) = 2.48$, p = .02) and there was no difference ($t(45) = 1.41$, $p = .16$) between zone and traditional (Chart 16).

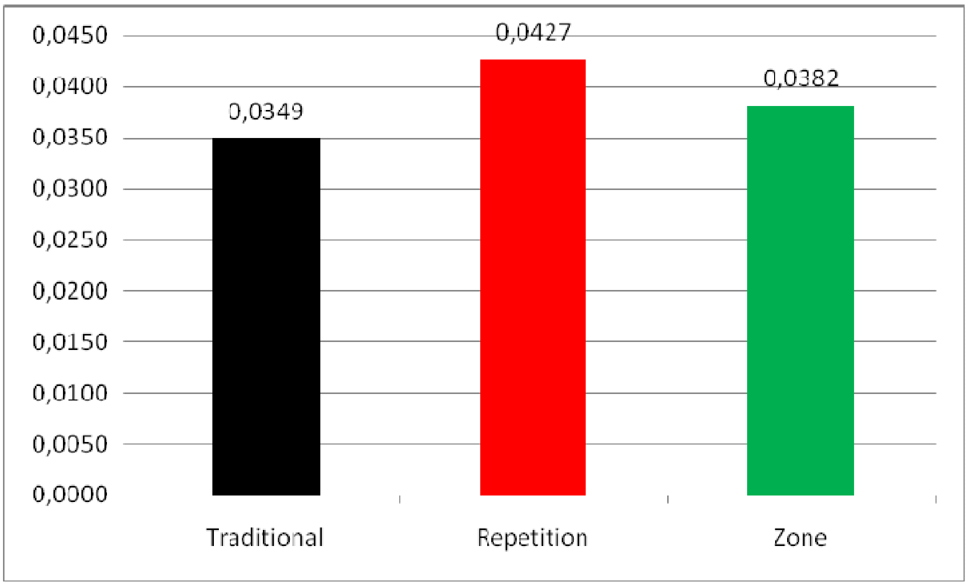


Chart 16 Standard deviation of lateral position at repetition sign: average over before/after and mental load

6. Speed transition from 70 to 90 km/h

At 5750 metres a traffic sign that indicated – indirectly – the normal speed limit of 90 km/h was placed (section III 2.3.2 for more information).

6.1 Mean speed

Chart 17 gives the general speed pattern of the speed transition at 5750 metres.

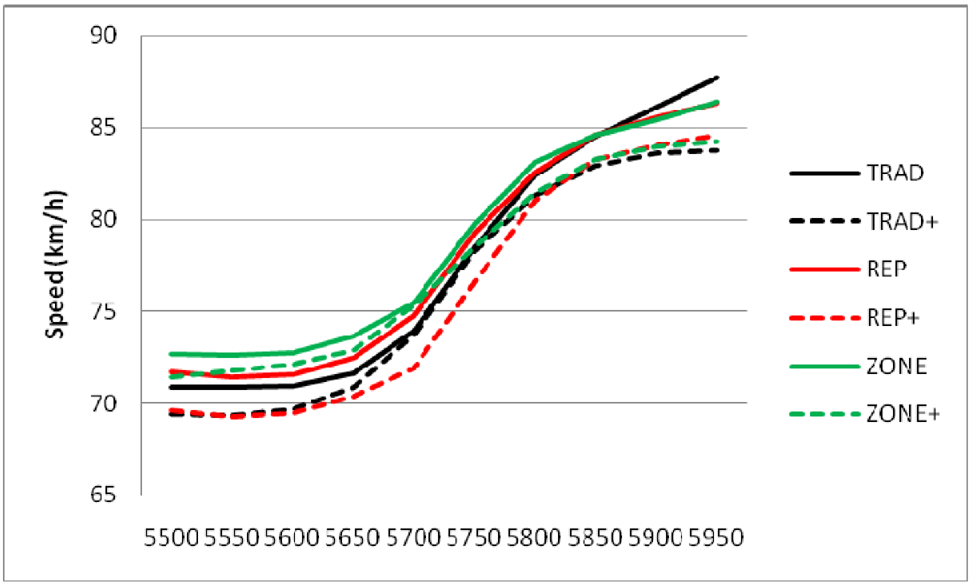


Chart 17 Average speed at transition 70-90 km/h: general pattern

There was no main effect of Sign ($F(2, 90) = 1.93$, $p = .16$, $\eta_p^2 = .04$), no interaction effects of Secondary Task x Sign ($F(2, 90) = .46$, $p = .63$, $\eta_p^2 = .01$), Secondary Task x Before/After ($F(1, 45) = .32$, $p = .58$, $\eta_p^2 = .01$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .82$, $p = .44$, $\eta_p^2 = .02$).

The main effect of Before/After was significant ($F(2, 90) = 412.77$, $p < .0005$, $\eta_p^2 = .90$), while the main effect of Secondary Task was only marginal significant ($F(1, 45) = 3.90$, $p = .06$, $\eta_p^2 = .06$). This means that one drove – averaged over Sign and Before/After – slower with a Secondary Task (M = 76.60 km/h, SE = .80) than without (M = 78.15 km/h, SE = .81). The interaction of Sign x Before/After was significant ($F(2, 90) = 3.28$, $p = .05$, $\eta_p^2 = .07$).

Separate tests for each type of Sign showed that (Chart 18):

- For the *traditional Sign,* the mean speed was lower before (*SE* = .64) the transition than after (*SE* = .80) the transition ($t(45) = 17.11$, $p < .0005$).
- For the *zone-repetition Sign,* the mean speed was lower before (*SE* = .85) the transition than after (*SE* = 1.03) the transition ($t(45) = 18.16$, $p < .0005$).
- For the *zone Sign,* the mean speed was lower before (*SE* = .81) the transition than after (*SE* = .97) the transition ($t(45) = 13.27$, $p < .0005$).

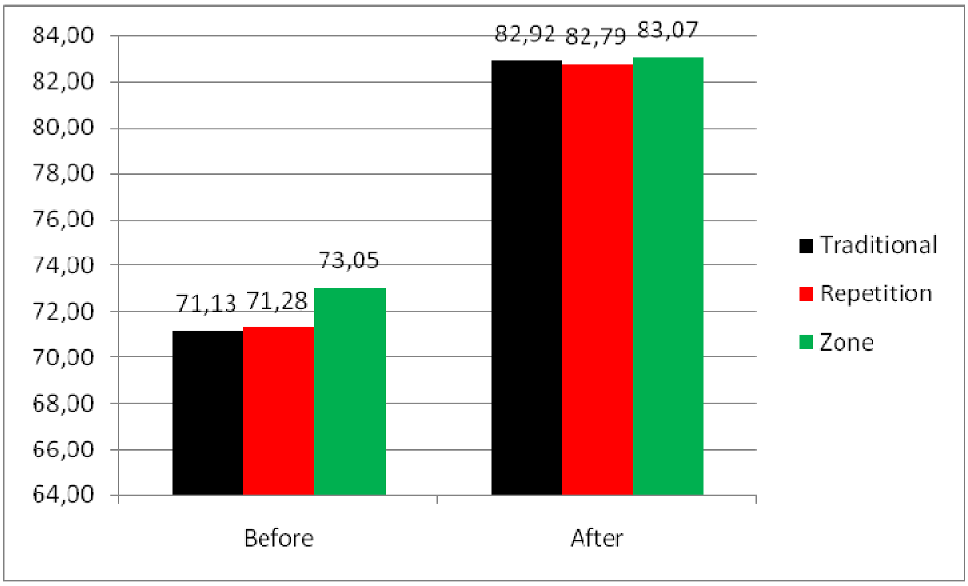


Chart 18 Average speed at transition 70 – 90 km/h (250 m before and after): average over mental load

Separate tests for Before/After showed that (same averages as Chart 18):

- In the 250 m *Before*, there was a main effect of Sign ($F(2, 90) = .72$, $p = .01$, $\eta_p^2 = .10$). One drove fastest in the zone scenario and this was significant higher than traditional ($t(45) = 2.63$, $p = .01$) and zone-repetition ($t(45) = 2.32$, $p = .03$) while there was no difference in speed between traditional and zone-repetition ($t(45) = .25$, $p = .81$).
- In the 250 metres *After* the speed transition, there was no significant effect of Sign ($F(2, 90) = .07$, $p = .91$, $\eta_p^2 < .0005$).

6.2 Standard deviation of speed

There were no main effects of Secondary Task ($F(1, 45) = .26$, $p = .61$, $\eta_p^2 = .01$), Sign ($F(2, 90) = .29$, $p = .74$, $\eta_p^2 = .01$), and no interaction effects of Sign x Before/After

($F(2, 90) = .93$, $p = .40$, $\eta_p^2 = .02$), Secondary Task x Before/After $F(1, 45) = 1.03$, $p = .32$, $\eta_p^2 < .0005$).

There was a significant main effect of Before/After ($F(1, 45) = 26.28$, $p < .0005$, $\eta_p^2 = .02$), and an interaction of Secondary Task x Sign ($F(2, 90) = 3.13$, $p = .05$, $\eta_p^2 = .07$), and finally a 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = 3.56$, $p = .03$, $\eta_p^2 = .07$).

Separate tests for each level of Secondary Task showed that:

- *Without a Secondary Task*, there was a main effect of Before/After ($F(1, 45) = 23.62$, $p < .0005$, $\eta_p^2 = .34$), a marginal main effect of Sign ($F(2, 90) = 5.58$, $p = .09$, $\eta_p^2 = .05$), and a marginal interaction of Sign x Before/After ($F(2, 90) = 2.35$, $p = .10$, $\eta_p^2 = .05$).
    - o Separate tests for Before/After (Chart 19) showed that in the 250 m *Before*, there was no effect of Sign $F(2, 90) = .02$, $p = .98$, $\eta_p^2 < .0005$) and in the 250 *After*, there was an effect of Sign ($F(2, 90) = 3.71$, $p = .03$, $\eta_p^2 = .08$). There was a significant difference between traditional ($SE = .07$) and repetition ($SE = .07$; $t(45) = 2.27$, $p = .03$) and between traditional and zone ($SE = .05$; $t(45) = 2.10$, $p = .04$) while there was no difference between the repetition and zone scenario ($t(45) = .66$, $p = .51$).

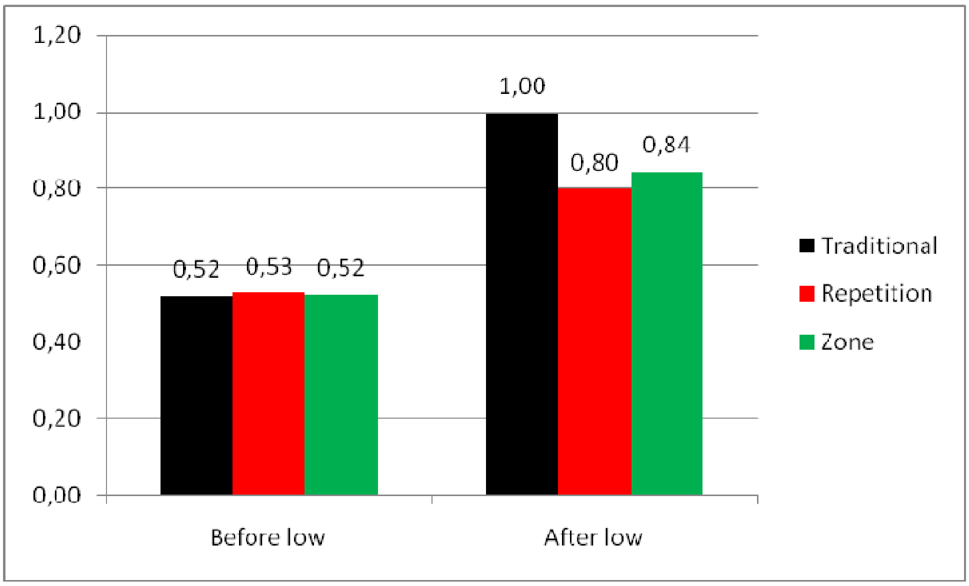


Chart 19 Standard deviation of speed at transition 70 – 90 km/h for a low mental load

- *With Secondary Task*, there was no main effect of Sign ($F(2, 90) = .62$, $p = .54$, $\eta_p^2 = .01$), and no interaction of Sign x Before/After ($F(2, 90) = 1.96$, $p = .15$, $\eta_p^2 = .04$). The deviation op speed before the transition was smaller ($M = .54$ km/h, $SE = .04$) than after ($M = .82$ km/h, $SE = .06$; $F(1, 45) = 14.39$, $p < .0005$, $\eta_p^2 = .24$).

Separate tests at each type of Sign showed that:

- For the *traditional Sign,* there were main effects of Before/After ($F(2, 90) = 24.32$, $p < .0005$, $\eta_p^2 = .35$) and Secondary Task $F(1, 45) = 3.59$, $p = .07$, $\eta_p^2 = .07$), and an interaction of Before/After x Secondary Task ($F(1, 45) = 5.08$, $p = .03$, $\eta_p^2 = .10$).
    - Separate tests for each level of Secondary Task showed that *without a Secondary Task* (same averages as Chart 19), the standard deviation before was smaller than after ($t(45) = 4.80$, $p < .0005$), just like the situation *with Secondary Task* (before: $M = .53$ km/h, $SE = .05$; after: $M = .78$ km/h, $SE = .06$; $t(45) = 3.06$ km/h, $SE = .00$).
- For the *zone-repetition Sign,* there was no effect of Secondary Task ($F(1, 45) = .97$, $p = .33$, $\eta_p^2 = .02$) and no interaction of Before/After x Secondary Task ($F(1, 45) = .68$, $p = .41$, $\eta_p^2 = .02$). Before the transition ($M = .53$ km/h, $SE = .04$) the standard deviation was smaller than after ($M = .85$ km/h, $SE = .06$; $F(1, 45) = 17.73$, $p < .0005$, $\eta_p^2 = .28$).
- For the *zone Sign,* there was no effect of Secondary Task ($F(1, 45) = .01$, $p = .94$, $\eta_p^2 <.0005$) and no interaction of Before/After x Secondary Task ($F(1, 45) = 1.09$, $p = .30$, $\eta_p^2 = .02$). Before the transition ($M = .55$ km/h, $SE = .04$) the standard deviation was smaller than after ($M = .82$ km/h, $SE = .05$; $F(1, 45) = 15.73$, $p < .0005$, $\eta_p^2 = .26$).

6.3 Standard deviation of lateral position

There were no main effects of Secondary Task ($F(1, 45) = .15$, $p = .71$, $\eta_p^2 < .0005$), Sign ($F(2, 90) = .28$, $p = .74$, $\eta_p^2 = .01$), and no interaction effects of Secondary Task x Sign ($F(2, 90) = .14$, $p = .86$, $\eta_p^2 = .00$), Sign x Before/After ($F(2, 90) = .66$, $p = .51$, $\eta_p^2 = .01$), Secondary Task x Before/After ($F(1, 45) = 1.01$, $p = .32$, $\eta_p^2 = .02$), and no 3-way interaction effect of Sign x Secondary Task x Before/After ($F(2, 90) = .82$, $p = .44$, $\eta_p^2 = .02$).

There was only a main effect of Before/After ($F(1, 45) = 19.90$, $p < .0005$, $\eta_p^2 = .31$), indicating that the standard deviation of lateral position was lower before the speed transition than after (Chart 20).

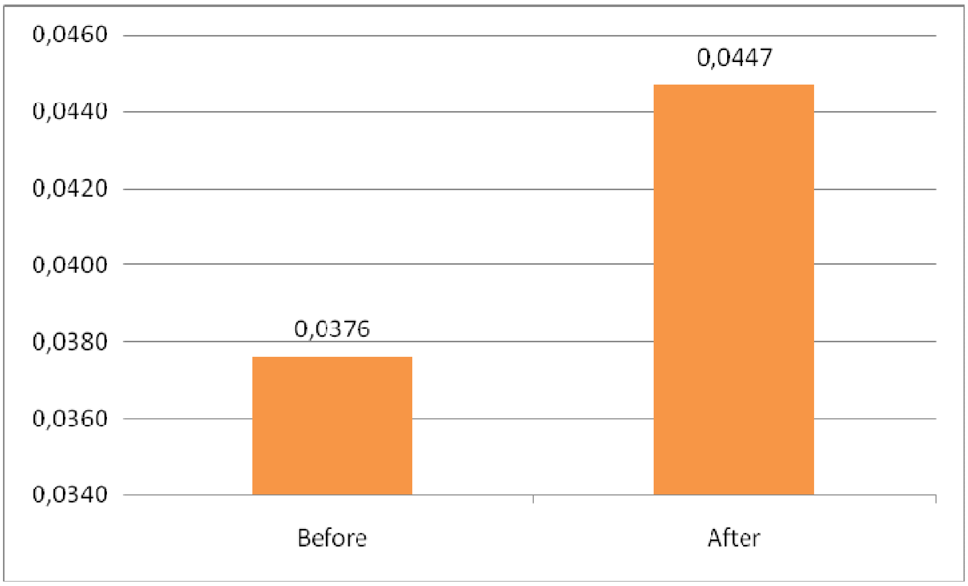


Chart 20 Standard deviation of lateral position at transition 70 – 90 km/h: average over sign and mental load

7. INTERSECTION

There were four intersections (at two, three, four and five kilometres) with traffic lights at green in each scenario and the 250 metres after each crossing was analyzed (section III 2.3.2 for more information).

7.1 Mean speed

There were no interaction effects of Secondary Task x Sign ($F(2, 90) = .13$, $p = .87$, $\eta_p^2 < .0005$), Secondary Task x Intersection ($F(3, 135) = 2.12$, $p = .12$, $\eta_p^2 = .05$), and no 3-way interaction effect of Sign x Secondary Task x Intersection ($F(6, 270) = .74$, $p = .57$, $\eta_p^2 = .02$).

The main effects of Sign ($F(2, 90) = 4.93$, $p = .01$, $\eta_p^2 = .10$), Intersection ($F(3, 135) = 14.32$, $p < .0005$, $\eta_p^2 = .24$) and Secondary Task ($F(1, 45) = 27.16$, $p < .0005$, $\eta_p^2 = .38$) were significant. The last main effect indicated that (Chart 21) one drove faster after the intersections without a Secondary Task (*SE* = .61) compared to the situation with Secondary Task (*SE* = .57).

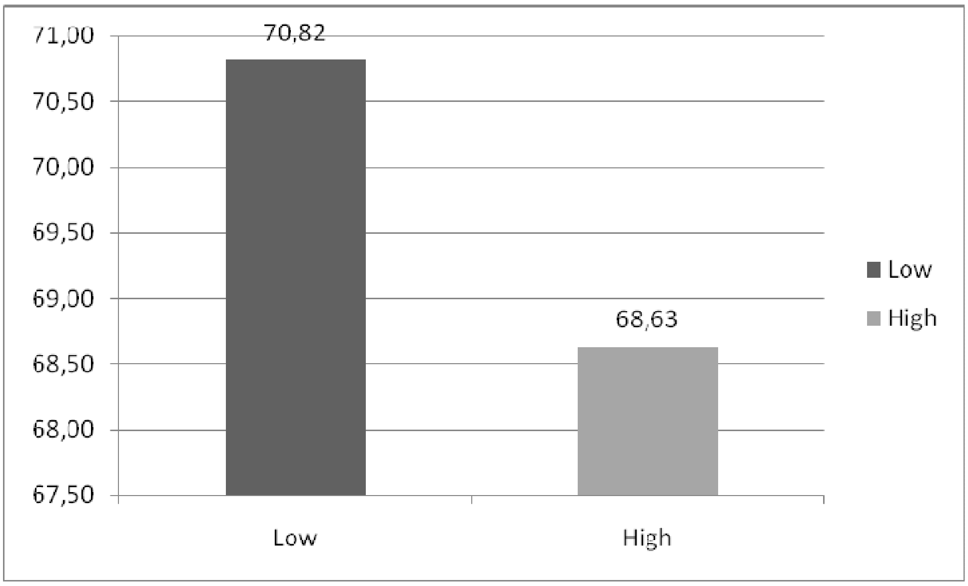


Chart 21 Speed at intersections (250 m after): average over sign and four intersections

Finally, there was an interaction effect of Sign x Intersection ($F(6, 270) = 5.09$, $p < .0005$, $\eta_p^2 = .10$).

Separate tests at each level of Sign showed that (Chart 22 or same averages as Chart 23):

- For the *traditional Sign,* there was a main effect of Intersection ($F(3, 135) = 9.98$, $p < .0005$, $\eta_p^2 = .18$) and this was quadratic ($F(1, 45) = 14.57$, $p < .0005$, $\eta_p^2 = .25$) and linear ($F(1, 45) = 5.00$, $p = .03$, $\eta_p^2 = .10$). Intersection four (*M* = 70.02 km/h, *SE* = .54) differed from the other three intersections (Intersection one: *M* = 68.99 km/h, *SE* =.60; $t(45) = 2.54$, $p = .02$; Intersection two: *M* = 68.40 km/h, *SE* = .47; $t(45) = 3.84$, $p < .0005$; Intersection three: *M* = 68.39 km/h, *SE* = .60; $t(45) = 4.22$, $p < .0005$).
- For the *zone-repetition Sign,* there was a main effect of Intersection ($F(3, 135) = 14.39$, $p < .0005$, $\eta_p^2 = .24$) and this was cubic ($F(1, 45) = 20.81$, $p < .0005$, $\eta_p^2 = .32$) which means that there were two changes in the direction of the trend. Furthermore, there was also a quadratic effect ($F(1, 45) = 22.66$, $p < .0005$, $\eta_p^2 = .34$). Intersection three (*M* = 67.91 km/h, *SE* = .62) differed from the other

three intersections (Intersection one: *M* = 71.10 km/h, *SE* = .73; *t*(45) = 6.07, *p* < .0005; Intersection two: *M* = 70.56 km/h, *SE* = .81; *t*(45) = 4.20, *p* < .0005; Intersection four: *M* = 70.91 km/h, *SE* = .66; *t*(45) = 8.01, *p* < .0005).

- For the *zone Sign,* there was a main effect of Intersection (*F*(3, 135) = 4.16, *p* = .01, η_p^2 = .09) and this was linear (*F*(1, 45) = 76.97, *p* = .01, η_p^2 = .14). The speed after Intersection four (*M* = 71.37 km/h, *SE* = .75) was highest and differed from the other three (Intersection one: *M* = 69.59 km/h, *SE* = .67; *t*(45) = 2.51, *p* = .02; Intersection two: *M* = 69.52 km/h, *SE* = .76; *t*(45) = 2.69, *p* = .01; Intersection three: *M* = 69.97 km/h, *SE* = .75; *t*(45) = 2.28, *p* = .03).

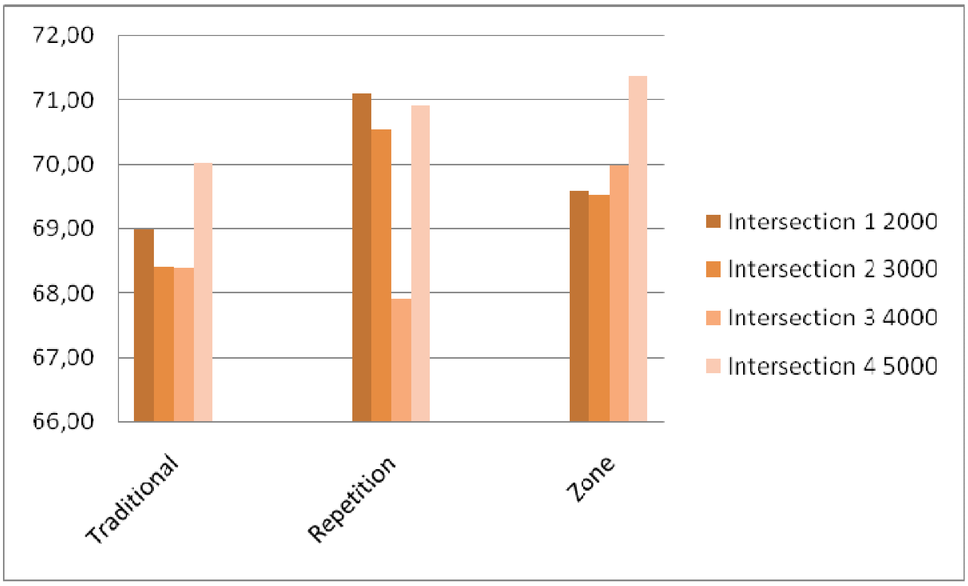


Chart 22 Speed at four intersections (250 m after): average over mental load (a)

Separate tests for each Intersection showed that (Chart 23):

- For *Intersection one*, there was a main effect of Sign (*F*(2, 90) = 6.34, *p* < .0005, η_p^2 = .12), indicating that the speed for the traditional scenario (*SE* = .60) was lower (*t*(45) = 3.81, *p* < .0005) than for zone-repetition (*SE* = .73) while this was not significant (*t*(45) = 1.16, *p* = .25) compared to zone (*SE* = .67), and there was a difference between zone-repetition and zone (*t*(45) = 2.07, *p* = .04).
- For *Intersection two*, there was a main effect of Sign (*F*(2, 90) = 4.99, *p* = .01, η_p^2 = .10), indicating that there was a difference between traditional (*SE* = .47) and zone-repetition (*SE* = .81; *t*(45) = 2.93, *p* < .0005) and a marginally difference between traditional and zone (*SE* = .76; *t*(45) = 1.74, *p* = .09), while

there was no difference between zone-repetition and zone ($t(45) = 1.56$, $p = .13$).

- For *Intersection three*, there was a main effect of Sign ($F(2, 90) = 8.19$, $p < .0005$, $\eta_p^2 = .15$), indicating that on drove slowest in zone-repetition ($SE = .62$) compared to zone ($SE = .75$; $t(45) = 3.88$, $p < .0005$), while there was no difference between zone-repetition and traditional ($SE = .60$; $t(45) = 1.06$, $p = .30$) and between traditional and zone ($t(45) = 2.61$, $p = .12$).
- For *Intersection four*, there was no main effect of Sign ($F(2, 90) = 2.02$, $p = .15$, $\eta_p^2 = .04$), indicating that there was no difference between the scenarios.

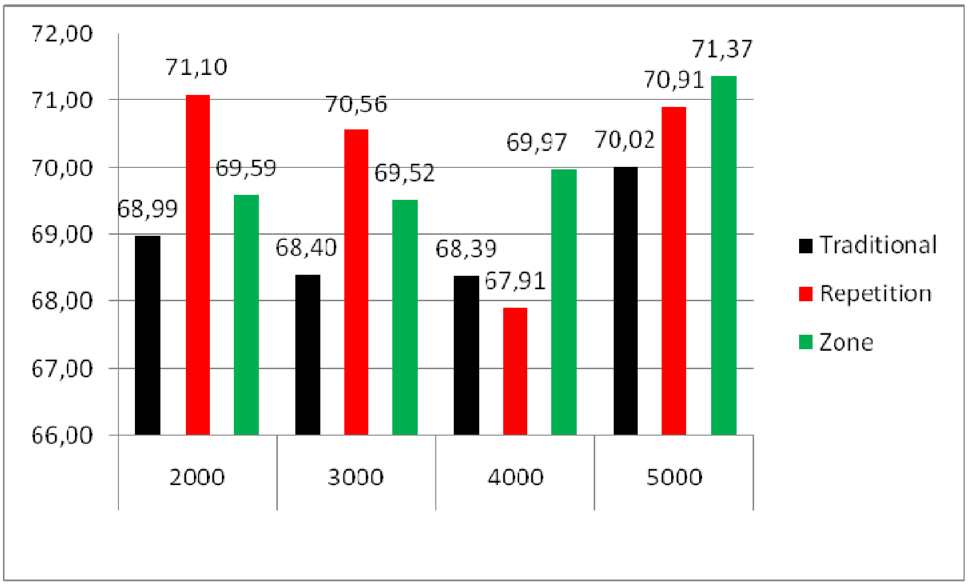


Chart 23 Speed at four intersections (250 m after): average over mental load (b)

7.2 Standard deviation of speed

There was only a significant main effect of Intersection ($F(3,135) = 5.27$, $p = .00$, $\eta_p^2 = .11$), indicating that depending on the intersection, there was in the 250 m after it a different standard deviation of speed (Chart 24). The fourth Intersection ($SE = .02$) differed from the other three (Intersection one: $SE = .02$; $t(45) = 3.88$, $p < .0005$; Intersection two: $SE = .03$; $t(45) = 2.19$, $p = .03$; Intersection three: $SE = .02$; $t(45) = 2.88$, $p = .01$).

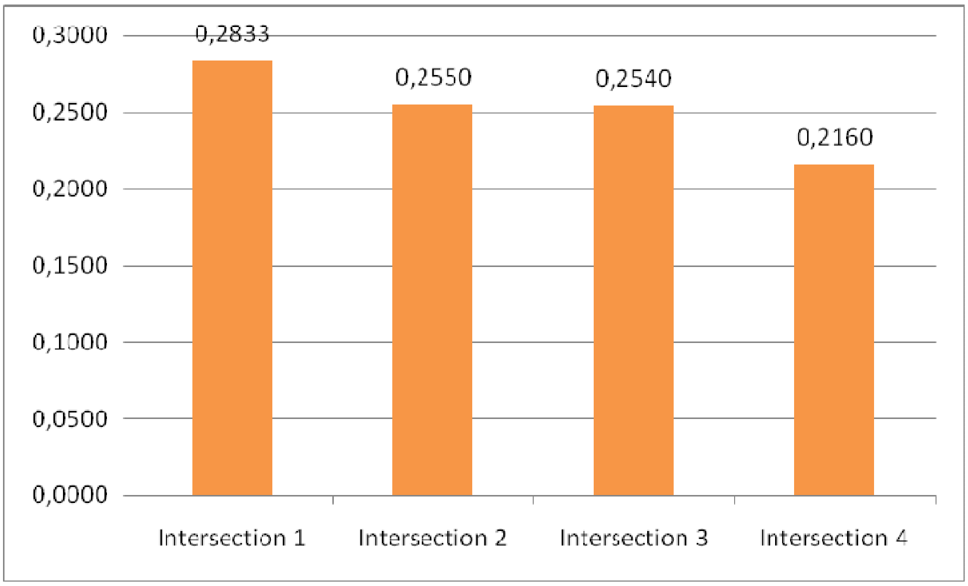


Chart 24 Standard deviation of speed at four intersections (250 m after): average over mental load and sign

There were no main effects of Secondary Task ($F(1,45) = .58$, $p = .45$, $\eta_p^2 = .01$) and Sign ($F(2, 90) = 1.63$, $p = .20$, $\eta_p^2 = .04$), and no interaction effects of Secondary task x Sign ($F(2, 90) = .00$, $p = 1.00$, $\eta_p^2 < .0005$), Secondary Task x Intersection ($F(3, 135) = .39$, $p = .75$, $\eta_p^2 = .01$), Sign x Intersection ($F(6, 270) = 1.17$, $p = .33$, $\eta_p^2 = .03$), and no 3-way interaction effect of Secondary Task x Sign x Intersection ($F(6, 270) = 1.13$, $p = .35$, $\eta_p^2 = .03$).

7.3 Standard deviation of lateral position

There was only a main effect of Secondary Task ($F(1, 45) = 10.63$, $p = .00$, $\eta_p^2 = .19$), indicating that one drove more precisely with Secondary Task than without (Chart 25). There were no main effects of Sign ($F(2, 90) = 1.29$, $p = .28$, $\eta_p^2 = .03$), Intersection ($F(3, 135) = .36$, $p = .74$, $\eta_p^2 = .01$), and no interaction effects of Secondary Task x Sign ($F(2, 90) = .18$, $p = .83$, $\eta_p^2 = .00$), Sign x Intersection ($F(6, 270) = .74$, $p = .60$, $\eta_p^2 = .01$), Secondary Task x Intersection ($F(3, 135) = .21$, $p = .88$, $\eta_p^2 = .02$), and no 3-way interaction effect of Sign x Secondary Task x Intersection ($F(6, 270) = .85$, $p = .52$, $\eta_p^2 = .02$).

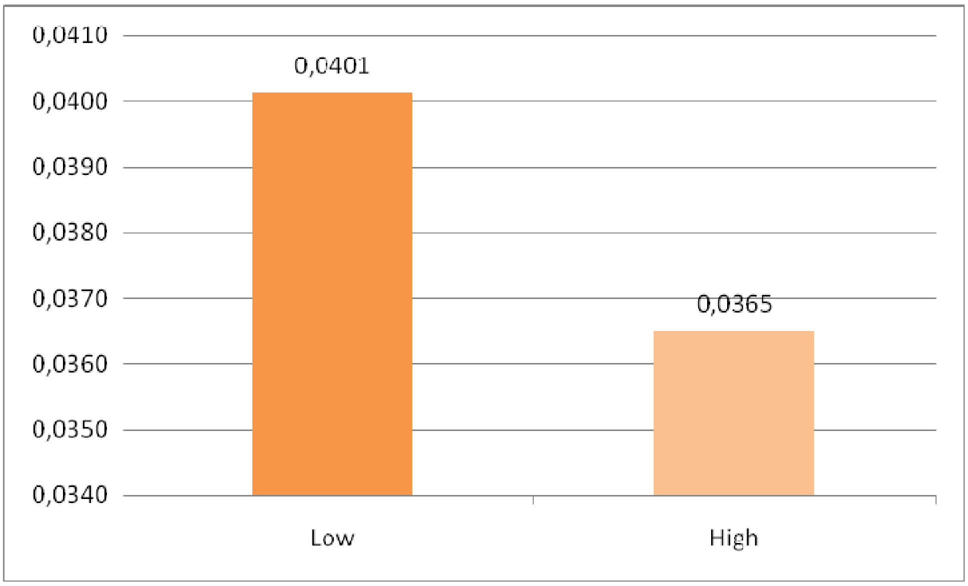


Chart 25 Standard deviation of lateral position after the intersection: average over sign and intersection

8. Speed segment of 70 km/h

In each scenario there was a speed limit of 70 km/h for 4750 metres (section III 2.3.2 for more information).

8.1 Mean speed

One drove significantly (Chart 26) slower in the trip with Secondary Task (*SE* = .59; without: *SE* = .58; $F(1, 45) = 23.24$, $p < .0005$, $\eta_p^2 = .34$). However, one drove slightly slower in the traditional (*M* = 69.49 km/h, *SE* = .53) and repetition scenario (*M* = 69.86 km/h, *SE* = .58) than in the zone condition (*M* = 70.10 km/h, *SE* = .61), there was no significant main effect of Sign ($F(2, 90) = 1.88$, $p = .16$, $\eta_p^2 = .04$), and there was no interaction effect of Sign x Secondary Task ($F(2, 90) = .92$, $p = .40$, $\eta_p^2 = .02$).

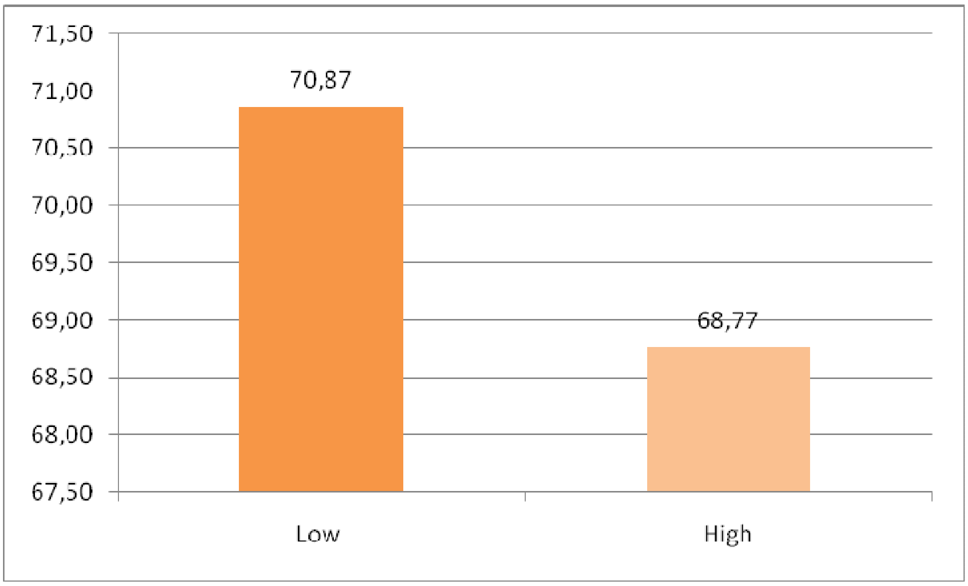


Chart 26 Average speed in 70 km/h segment: average over signs

8.2 Standard deviation of speed

In the large segment of 4750 metres, there was only a marginal main effect of Secondary Task ($F(1, 45) = 2.94$, $p = .09$, $\eta_p^2 = .06$), indicating that standard deviation of speed (Chart 27) with Secondary Task was lower ($SE = .02$) than without ($SE = .02$). The main effect of Sign ($F(2, 90) = .16$, $p = .86$, $\eta_p^2 < .0005$) was not significant. This indicates that in the long segment, there was no difference in standard deviation of speed depending on the used sign (traditional: $M = .31$ km/h, $SE = .02$; repetition: $M = .32$ km/h, $SE = .02$; zone: $M = .32$ km/h, $SE = .21$). Also, the interaction effect of Secondary Task x sign was not significant ($F(2, 90) = .10$, $p = .88$, $\eta_p^2 < .0005$).

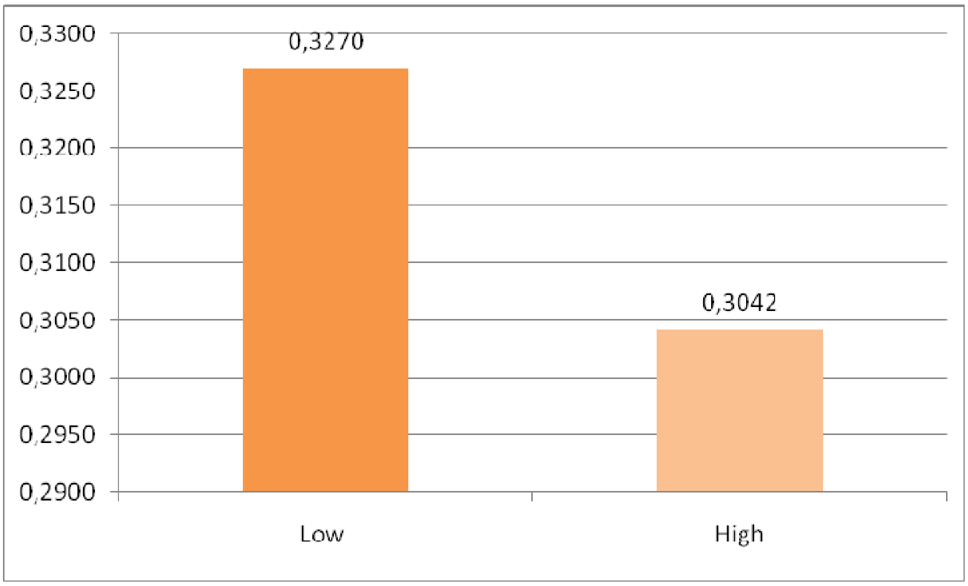


Chart 27 Standard deviation of speed in 70 km/h segment: average over signs

8.3 Standard deviation of lateral position

The long segment of 70 km/h could give a good illustration of the effect of the Secondary Task on the standard deviation of the lateral position. The main effect of Secondary Task was significant ($F(1, 45) = 5.63$, $p = .02$, $\eta_p^2 = .11$), while there was no effect of Sign ($F(2, 90) = 1.89$, $p = .16$, $\eta_p^2 = .04$), and no interaction effect of Secondary Task x Sign ($F(2, 90) = 2.08$, $p = .13$, $\eta_p^2 = .04$). The significant main effect resulted in a lower standard deviation of lateral position under a high mental load (Chart 28).

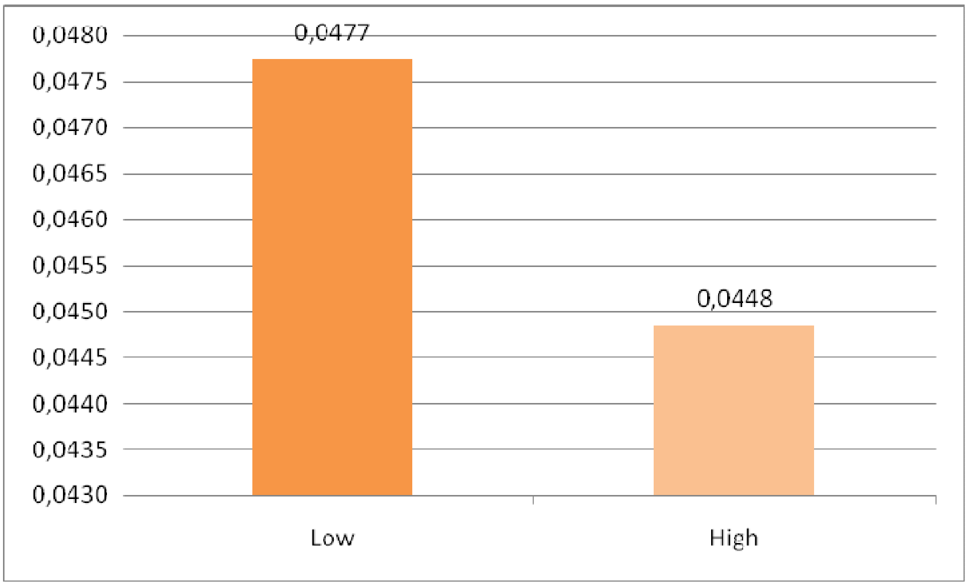


Chart 28 Standard deviation of lateral position in 70 km/h segment: average over signs

9. PERCENTAGE OF TIME AND DISTANCE OUT OF LANE

Lane exceedence was defined as when the nearest edge of the vehicle intruded outside of the nearest side of the lane (Lansdown, 2002) and this percentage could be found in the logged data files. The percentage can serve as a measure of vehicle control. The higher the time or distance out of lane, the more instable the trip was.

For time out of lane (Chart 29), there was a marginal main effect of Secondary Task ($F(1, 45) = 3.74$, $p = .06$, $\eta_p^2 = .08$), indicating that without Secondary Task ($SE = .20$) one was more time out of the lane than with Secondary Task ($SE = .19$). For distance out of lane (Chart 29), there was also a main effect of Secondary Task ($F(1, 45) = 4.16$, $p = .05$, $\eta_p^2 = .09$) in the same direction, indicating that with Secondary Task ($SE = .19$), one was less of the distance out of the lane than without a Secondary Task ($SE = .21$). Both measures stated that one drove more stably when one performed a Secondary Task. This sounds somewhat contradictory, but the lower speeds under a higher mental load could explain this finding.

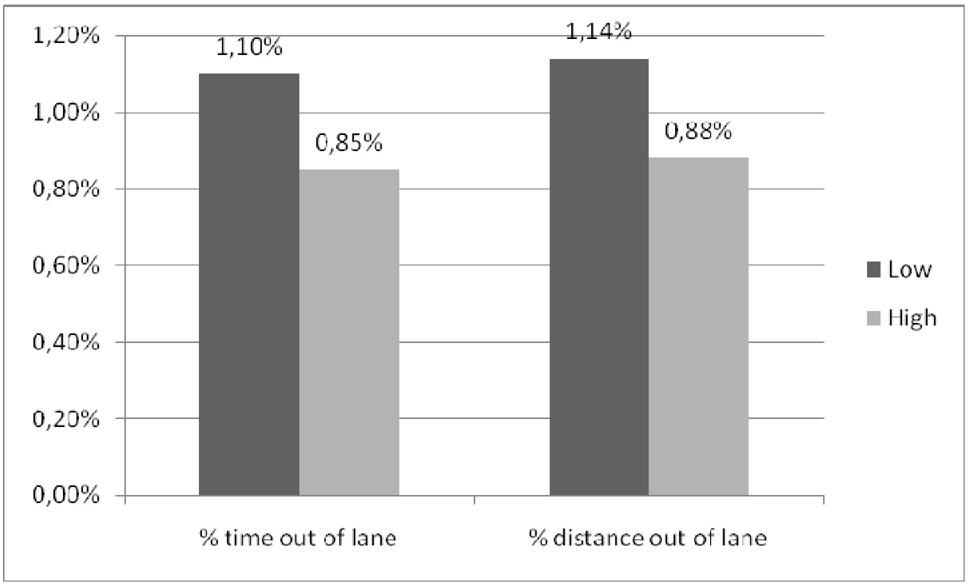


Chart 29 Percentage of time and distance out of lane

10. SECONDARY TASK

To determine how good one performed on the secondary task, the boundaries of the response time were determined first. Sometimes, people responded abnormally quick to the projected stimulus and so the results are biased. To determine the lower and upper limit, one can look at the histogram of the correct responses (Chart 30). As one can see, there is a small island of responses on the left side and this stops approximately at 150 milliseconds. According to Cantin et al. (2009) reaction times faster than 150 ms and slower than the mean plus two standard deviations must be removed. Reaction times faster than 150 ms were considered as anticipation and did not reflect information processing. One can conclude that only the correct responses between 150 ms and 2.13 s were considered to determine the average response time (4.39% was removed). Even when these considerations were taken into account, the data remained skewed to the right and did not follow a normal, bell-shaped curve because the reaction time varied from trial to trial (A. Johnson & Proctor, 2004).

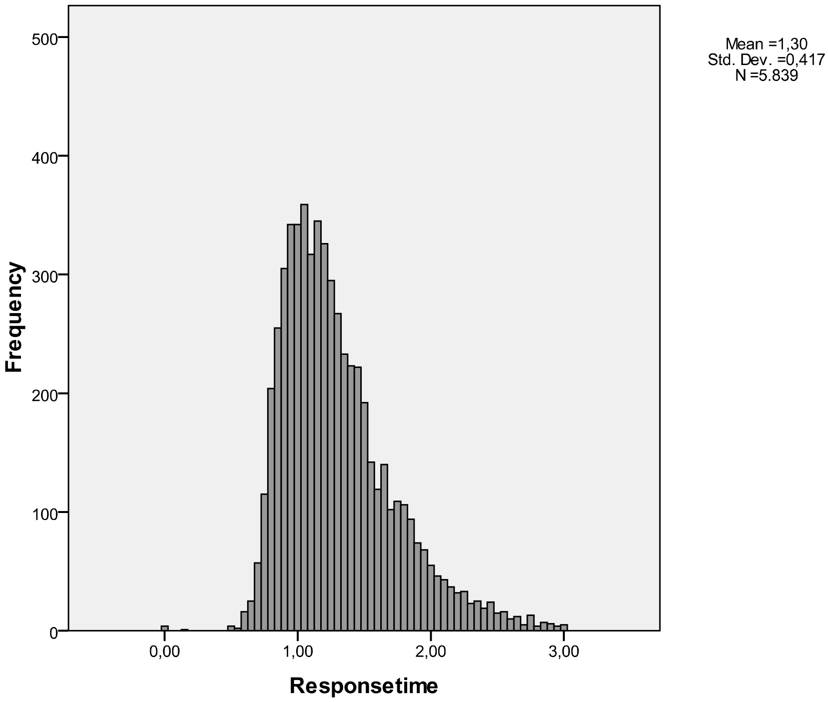


Chart 30 Frequency of response time of correct responses

If one computed an average response time for the correct responses for each segment, there was no significant main effect of Sign ($F(2, 90) = .23$, $p = .80$, $\eta_p^2 < .0005$). This means that there was no different reaction time in the three different speed indications. The overall average response time, with responses between 150 milliseconds and 2.13 seconds, was 1.25 s (*SE* = .03). One reacted in 96.2% of the cases correct (reaction time higher than 150 ms, note that there was no upper limit), in 3.0% incorrect and in 0.8% of the cases one reacted not or too late to the projected stimulus (no reaction within 3 seconds). Nor in the number of correct answers ($F(2, 90) = .04$, $p = .93$, $\eta_p^2 < .0005$), nor in the number of incorrect answers ($F(2, 90) = .15$, $p = .80$, $\eta_p^2 < .0005$), nor in the number of missed responses ($F(2, 90) = .07$, $p = .92$, $\eta_p^2 = .00$) there was a significant main effect of Sign. So, one could conclude that one performed equally in the three scenarios.

V. Conclusion & discussion

1. Conclusion parameters – research questions

In the following paragraphs an answer is given to the research questions of this Master's Thesis (section II 5. at page 37). These questions are repeated in italics and the main questions are in bold.

Question A: Is there an effect of the speed sign on mean speed?
→ main effect Before/After?

Yes, each transition resulted in a difference of speed between the situation of 250 m before and 250 m after the sign.

- Transition from 90 to 70 km/h at 1000 m: the mean speed was higher before than after the transition.
- Transition from 70 to 90 km/h at 5750 m: the mean speed was lower before than after the transition.

Question B: Is there a direct effect of the type of speed sign on mean speed?
→ main effect Sign?

No, in each transition there was no effect of sign, meaning that no matter which sign was used (C43 or F4a and C45 or F4b), the average speed over before and after and over secondary task was the same. Neither had the type of sign an effect on the mean average speed in the 70 km/h segment.

- Transition from 90 to 70 km/h at 1000 m: the mean speed did not depend on the type of sign (C43 versus F4a).
- Transition form 70 to 90 km/h: the mean speed did not depend on the type of sign (C45 versus F4b).
- 70 km/h segment: the mean speed did not depend in the type of sign.

Question C: Is there an effect of time – or in other words, an effect of the order of intersections – on mean speed?
→ main effect Intersection?

Yes, there was an effect of the order of intersections on the average mean speed in the 250 m after it.

- Intersection analysis: the first two intersections had the same average speed, but the speed was lower after the third intersection (differed from the other three) and was highest after the fourth intersection (differed from the other three).

Question D: Is there an effect of distraction on mean speed and on the standard deviation of lateral position?
→ main effect Secondary Task?

Yes, on drove slower, one had a smaller standard deviation of lateral position and one was less time and distance out of the lane in the trips with secondary task compared to the trips without.

- Transition from 90 to 70 km/h at 1000 m: one drove slower and one had a smaller standard deviation of lateral position with secondary task.
- Transition form 70 to 90 km/h: one drove slower with secondary task but there was no effect on the standard deviation of lateral position.
- Repetition sign: one drove slower and one had a smaller standard deviation of lateral position with secondary task.
- Intersection analysis: one drove slower and one had a smaller standard deviation of lateral position with secondary task.
- 70 km/h segment: one drove slower and one had a smaller standard deviation of lateral position with secondary task.
- Control zone: one drove slower with secondary task but there was no effect on the standard deviation of lateral position.
- Percentage of time/distance out of lane: one was less time and distance out of the lane in the trips with secondary task.

Question E: Is there, at the (potential) repetition sign, a difference in mean speed between before and after and does this depend on the scenario? **&**
Is there a difference in mean speed in the situation of 250 m after the transition points and does this depend on the type of speed sign?
→ interaction effect of Sign x Before/After?

Yes, the repetition sign was only effective in the zone-repetition scenario, meaning that only in this scenario a difference was found in mean speed between before and after.

- Repetition sign at 3500 m: for the repetition scenario on drove faster before than after the repetition sign, while there was no difference between before and after in the other two scenarios (where no repetition sign was placed).

No, no matter which sign was used to indicate a lower (C43 or F4a) or higher (C45 or F4b) limit, the effect in the 250 m *after* the transition point was the same.

- Transition from 90 to 70 km/h at 1000 m: there was no difference between the type of sign (C43 or F4a) in the 250 m after the transition, meaning that there was no influence of the type of sign.
- Transition form 70 to 90 km/h at 5750 m: there was no difference between the type of sign (C45 or F4b) in the 250 m after the transition, meaning that there was no influence of the type of sign.

Question F: ***Is there a variation of mean speed in time and does this variation depend on the used type of speed sign*****?**
→ interaction effect of Sign x Intersection?

Yes, as time went by (or when more intersections were added) the speed after each intersection remained more or less the same in the traditional scenario and one drove constantly faster in the zone scenario (linear trend). This last fact was also true for the repetition scenario, but there was a drop at the repetition sign and thereafter the speed increased again (cubic trend).

- Intersection analysis: For the traditional sign there was a linear and quadratic effect of intersection and more important, there was cubic (and quadratic) effect for the repetition scenario and a linear effect for the zone scenario. The cubic effect of intersection for the repetition sign means that the speed increased, or was more or less the same, after each intersection (intersection one: *M* = 71.10 km/h; intersection two: *M* = 70.56 km/h) until the repetition sign was placed by which the speed dropped (intersection three: *M* = 67.91 km/h) to increase again after the repetition sign (intersection four: *M* = 70.91 km/h). In the zone scenario there was a linear trend of intersection because the speed increased continuously (intersection one: *M* = 69.59 km/h; intersection two: *M* = 69.52 km/h; intersection three: *M* = 69.97 km/h; intersection four: *M* = 71.37 km/h).

Question G: Is there an effect of distraction on mean speed and does this depend on time?
→ interaction effect of Secondary Task x Intersection

No, there was an influence of distraction but it did not depend on time.

- Intersection analysis: One drove slower and had smaller standard deviations of lateral position with secondary task but there was no influence of time on this (also question D).

Question H: *Is there a variation of mean speed depending on the type of speed sign and does this variation depend on distraction?*
→ interaction of Sign x Secondary Task

No, but there was only a difference at the repetition sign, while there was no influence of secondary task on the difference between signs in the other analyses.

- Transition from 90 to 70 km/h at 1000 m: the differences between signs did not depend on secondary task.
- Transition from 70 to 90 km/h at 5750 m: the differences between signs did not depend on secondary task.
- Repetition sign at 3500 m: without secondary task there was an effect of sign while there was no effect of sign with secondary task.
- 70 km/h segment: the differences between signs did not depend on secondary task.
- Intersection analysis: the differences between signs did not depend on secondary task.

Question I: ***Does the mean speed over time depend on the type of speed sign and if so, does this variation depend on distraction?***   *→ interaction effect of Sign x Secondary Task x Intersection?*

No, however there was an influence of the type of sign in time (also question F), distraction did not influence this relation.

- Intersection analysis: the differences between signs – as time went by – did not depend on secondary task.

2. DISCUSSION

2.1 Situation awareness

After the different trips in the simulator, the participant was asked to recall the different signs next to the road. **Most of the people knew the five signs but when one asked the colour of the repetition sign, not everyone knew it.** Similar to the study by Charlton (2006) 73.9% knew the five signs. This high percentage can be attributed to motivational factors because persons were motivated to be a good driver in the experiment.

Chart 31 Recall of the speed signs

Nobody could completely tell the purpose of the study but most participants gave a good approach, and especially distraction was reported. Nine persons did not have any idea about the subject of the study.

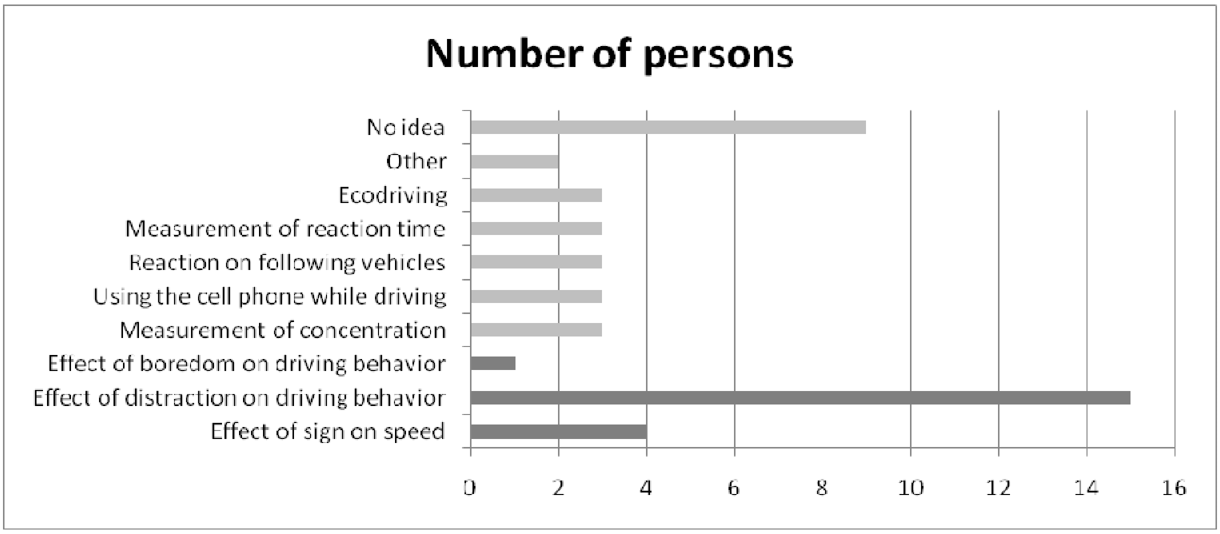


Chart 32 Purpose of the study

2.2 Questionnaire related to the traffic rules

Chart 33 shows an overview of the number of correct answers of the traffic rules (a list of questions can be found in section VII Annex 5. at page 117). The dark bars refer to speed questions and are the most interesting for this study, while the light coloured bars refer to the general traffic regulations. On average, **participants knew significantly better the traditional sign C43** – question 9b – (100% correct, *SE* = .00) **than the zone sign F4a** – question 2 – (67.4% correct, *SE* = .07; $t(45) = 4.67$, $p < .0005$). Question 7 should review if the zone-repetition sign was correctly understood (71.7% correct) and like question 2, the percentage was relatively low, which confirmed the idea of Lajunen et al. (1996): **drivers will not be able to deal with changes in traffic regulations**. Question 5 (89.1% correct, *SE* = .05) and question 9c (93.5% correct, *SE* = .04) verified if one knew respectively sign F4b and C45 and this showed that the traditional removal of the current speed by C45 was known slightly better than his zone equivalent. However, when this was tested statistically, it appeared that the difference was not statistically proven, so **C45 and F4b were equally known** ($t(45) = 1.00$, $p = .32$). Question 9a (95.7% correct) and 9d (97.8% correct) verified if the general rule of 90 km/h outside built-up areas, unless indicated otherwise, was known. The other questions were not related to this study, but it is worth mentioning that only 23.9% of the participants knew the meaning of the traffic sign for a level crossing for a single track (question 10).

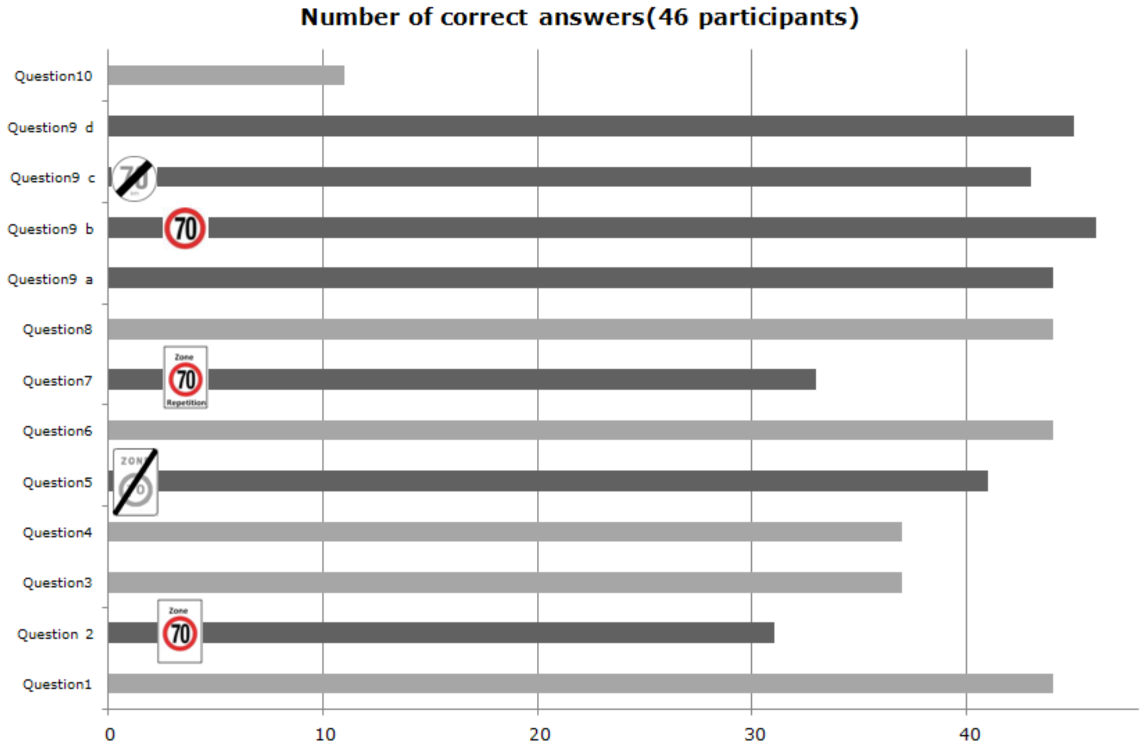


Chart 33 Overview of the number of correct answers (traffic rules)

2.3 Driving simulator parameters

It was concluded that **no matter which sign was used to indicate a lower or higher limit, the effect in the 250 m *after* the transition point was the same.** So, C43 and F4a were equally efficient even so for C45 and F4b. This is in contrast with the findings by Daniëls et al. (2010), they said that the classic C43 sign was more effective than the speed zone sign F4a at the transition point itself because decelerating started earlier and was faster. A reason for this can be the fact that this Master's Thesis had corrected for poorly consciousness of traffic rules while this was not the case in the study by Daniëls et al. (2010). So, everyone who drove in the simulator knew the meaning of the traditional and zone speed signs.

The effect of the repetition sign itself was clear because depending on the scenario, the difference in mean speed before and after the repetition sign was

different. There were no differences between before and after, at the location of the (potential) repetition sign, for the traditional and zone scenario (there was no repetition sing), but there was a difference in the zone-repetition scenario (before: *M* = 70.15 km/h; after: *M* = 68.32 km/h). When this finding was linked with the standard deviation of speed, one can see that the deviation depended on the scenario. One deviated more at the repetition sign in the zone-repetition scenario (*M* = .36 km/h) than in the traditional (*M* = .21 km/h) and zone scenario (*M* = .20 km/h) because one adapted the speed.

Since one went from a long 70 km/h segment to a new limit of 90 km/h at 5750 m, one could expect differences in mean speed in the 250 m before this sign. It is logical that one drove fastest in the zone scenario (*M* = 73.05 km/h) because the beginning of the zone was presented 4750 m earlier without a recall. The speed in the traditional (*M* = 71.13 km/h) and repetition scenario (*M* = 71.28 km/h) were both lower because one had respectively a recall at 750 m and 1250 m before the transition. It was expected that there was a higher speed when more time went by (more intersections were added). This hypothesis seemed to be true: the speed was lowest in the traditional scenario, followed by the repetition scenario and highest in zone scenario and this was influenced by the number of intersections. **As time went by, or when more intersections were added, there was a linear trend in the zone scenario and a cubic trend in the repetition scenario, while the speed remained more or less the same in the traditional situation.**

As expected, most analyses showed a **decreased speed when one was distracted.** In the control zone, where there were no differences between the scenarios, a lower speed with distraction (*M* = 81.48 km/h) than without (*M* = 85.56 km/h) was encountered. One drove below the 70 km/h limit in the long 70 km/h segment when one was distracted (*M* = 68.77 km/h), while one drove a little above the limit without a secondary task (*M* = 70.87 km/h). The lower speed when one was distracted was also found in other studies (a.o. Lansdown et al., 2004; Liu & Y. Lee, 2006; Shinar, 2007) and only the study by Recarte & Nunes (2002) is an exception on this. They found that if one had to maintain, under a high load, an imposed speed, one drove faster. Shinar, Tractinsky & Compton (2005) stated that a distracting task made it more difficult to maintain the desired speed and as a consequence the requirements to perform the distracting task caused drivers to lower the driving-related information processing which resulted in lower speeds than required. By doing this, one performed a compensatory behaviour and one relied on an own and preferred speed. This compensation took place because higher speeds were associated with a higher risk of overload and one chose an optimal speed to minimize attentional load. So, drivers do not only want risk but also task difficulty homeostasis and they achieved this homeostasis by lowering their speed (Fuller, 2005). By doing this, drivers adopted the level of task difficulty that they wished to experience when driving, and drove so to maintain it. When drivers needed attentional resources to control their speed and their mind was absorbed with mental tasks (i.e. distraction), attentional resources were diverted from speed, which then became uncontrolled until its normal preferred level (Recarte & Nunes, 2002). This Master's Thesis revealed a decrease of speed which contradicts Recarte & Nunes (2002) but was in accordance with the common assumption of a positive increasing function between speed and effort. Another possible reason for a lower speed with distraction, was the inattention of the current limit. It is possible that, when one did not know what the limit was, one chose a lower speed than permitted and this mainly due to motivational reasons since one observed the behaviour.

The effect of an extra task on the standard deviation of speed was not clear. Sometimes there was a smaller standard deviation of speed in case of distraction. This means that one had a better speed control under a high mental load than under a low load. This sounds contradictive but it can be explained by the fact that one drove slower when one was distracted and it was easier to maintain this (lower) speed. Another explanation can be the fact that if one had to perform a secondary task, the driver returned to his own optimal preferred speed (Recarte & Nunes, 2002). By doing this, it was easier to maintain an own chosen and preferred speed. However, this was opposite to the theorem of Shinar, Tractinsky & Compton (2005) that said that a distracting task makes it more difficult to drive at the desired speed and as a consequence the variance around the mean speed should increase with increasing distraction.

One drove more precisely – less swerving – with secondary task compared to the situation without. This is not very logical but a reason may be the lower speed when one was distracted, so it was easier to drive more stable. Also, this was in contrast with the theorem of Shinar, Tractinsky & Compton (2005) because they said that the variance of lateral position will increase in the presence of a demanding distracting task. However, these authors did not found a main effect of distraction on the variance of lateral position. Liu & Lee (2006) had found the same, namely there was no difference in standard deviation of lateral position when one was distracted (phone task). Another way to measure vehicle control, is to calculate the percentage of time of being out of the lane. The higher the time or distance that the nearest edge of the vehicle intruded outside of the nearest side of the lane, the more instable the trip was. Both the percentage of time (low: 1.10%; high: 0.85%) and the percentage of distance (low: 1.14%; high: 0.88%) showed that one drove more stable under a high mental load because one was less time and distance out of lane. This contradicts to Pohlman & Traenkle (1994) because they had found that drivers deviated more from their lane when they drove with a complex visual route guidance system compared to the situation with a common paper map and this due to long glances at the display. Just as in the analysis of standard deviation of lateral position, the findings of time and distance out of lane sound illogical but can be attributed to the lower speed in the trips with secondary task. So, again, one compensated (drive slower) to maintain a manageable workload.

The average response time for the correct answers between 150 ms and 2.13 s, was 1.25 seconds. This reaction time did not differ between the three scenarios. In 96.2% of the stimuli one reacted correct, in 3.0% incorrect and in the remaining 0.8% one reacted too late or not (no reaction within 3 seconds). As in the mean reaction time, there was no effect of the scenario in the number of correct, incorrect and missed. Based on this, on could conclude that **the performance on the secondary task was constant.**

3. LIMITATIONS

The study was conducted in a simulator environment which results in additional assumptions in order to be able to conclude whether the conclusions are real phenomena. Since simulators register driving performance and thus what a driver *can* do, and traffic safety is determined by driving behaviour (what a driver *chooses* to do), there are additional assumptions (Evans, 2004). The generalized application of the results is challenged by some, while other research showed that most of the results of a simulator study have a relationship with on-road studies (Kaptein et al., 1996; Törnros, 1998). Freund, Gravenstein, Ferris & Shaheen (2002) stated that relative changes were very resembling and correlate significantly which means that the direction – and not necessarily the absolute value – of the effect is similar. A study by Bella (2005), Godley et al. (2002) and Klee, Bauer, Radwan & Al-Deek (1999) demonstrated that speeds in a simulator were lower than in the real situation but the direction was the same. The setting of this Master's Thesis appeared to be sensitive enough to detect effects when variables were manipulated. Examples were the shift in mean speed and in standard deviation of lateral position that was noticed when distraction was added. When there were no differences between the trip with and without secondary task, one should have doubts about the validity of the results. On the other hand, unchanged conditions (e.g. control zone) resulted in unchanged behaviour so one can conclude that the assumption of relative validity seemed to be supported. The simulator seemed to be physically valid because nobody suffered from simulator sickness.

Another important concern was the limited legibility of road signs. It had been ensured that the various road signs were readable at the same distance in the simulator, but due to technical reasons this was only from a distance of 30 metres. In real world, road signs are at a much larger distance readable (100 m to 250 m), so, the question is raised whether the effects are similar.

4. IMPLICATIONS

The analysis and interpretation have a few implications in the field of road safety. As already has been pointed out in other research, drivers do not deal really with changes in traffic regulations. The questionnaire had demonstrated that the more recent zone signs were known less than the traditional signs. As a result, drivers, when they are in a zone, may accelerate after an intersection because there is no indication of the speed regime and they are no aware of the meaning of a zone.

Since it is generally accepted that maladjusted speed is one of the most important causes of a road accident, it is important that drivers first and foremost know the meaning of the different speed signs. Besides this, even when the three speed signs were equally known, there was still a difference in the driving speed. After each intersection one drove slowest in the traditional scenario while one accelerated constantly in the zone scenarios. This phenomenon is attributed to the absence of a speed sign after each intersection and has as a consequence that, although one knew the meaning of each sign (corrected by the questionnaire), the difference in speed was caused by the unconsciousness of the speed regime. A repetition sign was a useful instrument to weaken this effect because one is reminded to the current speed limit.

This study illustrated that if the situation was more difficult, or in other terms, the workload became higher because of a secondary task, one compensated the information by driving slower. So, most drivers spontaneously reduced their speed in difficult traffic situations because speed choice is the primary solution to keep task difficulty within some boundaries. Drivers adjusted their speed to deal more easily with potential difficulty and this finding was similar to Fuller (2005) who said that one wants task difficulty homeostasis. Recarte and Nunes (2002) said that one fell back on an own preferred speed if one was distracted.

5. RECOMMENDATIONS

Based on the results of the simulator study, one gives an advice to not implement large speed zones without any supporting indication. If the design of the road does not change at speed transitions and therefore the speed is indicated only by a traffic sign (no self-explaining roads), it is recommended to remind drivers often to the speed regime by, for example, a traffic sign at regular distances. When the infrastructural environment represents a continuous area, and therefore a zone is justified, it is recommended to make use of a repetition sign in the middle of the zone because it was proved to be effective. Another recommendation is to let people know better the meaning of changes in regulation (e.g. speed zones). It was showed in the questionnaire that one was not aware of new legislation on speed signs, and this is of primary importance to enforce an appropriate speed. The literature showed that more and more municipalities move away from the general speed limit of 90 km/h and switch to 70 km/h which results in an abundance of speed signs. Given the inefficiency of zone signs, the policy should switch to a general speed limit of 70 km/h. By doing this, a large part of the speed signs can be deleted. It should be noted, however, that one should do this in the whole of Belgium and not only in Flanders and, further, a very intensive campaign is required to spread out this new general rule. This last aspect is not easy because people are not aware of, or sensitive to, changes in the Highway Code. Further, it is important that a study will examine if this new general rule will be followed in practice.

There are also a few things to keep in mind for further research. The current study has only looked at the subject of road safety in a simulator, but it is possible to find other conclusions in the real world. Secondly, is should be investigated if there really is a correlation between the higher speed in zones and the number of traffic crashes because it is possible that the speed differences are negligible. In addition, one can examine the economic benefits and/or costs of the conversion to a situation with fewer road signs because each sign does not only have a behavioural impact but also results in a cost (placement, maintenance, etc.). It costs approximately €150 to €350 to maintain and place a traffic pole and sign (Appeltants, 2010; Vaes, 2010; Vanlangenaeker, 2010) and, on average, one replaces the sign every ten years (J. Willems & Vertriest, n.d.). So, a removal of all the abundant signs can be beneficial for monetary reasons. To determine whether or not one is sure about the current speed regime, it is possible to make use of eye-tracking devices. If there is no uncertainty, the eyes will not actively look for a target (i.e. speed sign at the right) while the opposite is true when one is uncertain and this accordingly to the model of visual search in driving (developed by Theeuwes, 1989; described in Ranney, 1994). Another aspect regarding to eye-movements, is the study by Muttart et al. (2007) that said that drivers who performed a cell phone task (i.e. distraction) mad less mirror glances and scanned less far to the right and left so they had a more centrally focused search pattern when multitasking.

VI. References

Aarts, L. (2004). *Snelheid, spreiding in snelheid en de kans op verkeersongevallen* (No. R-2004-9) (p. 57). Leidschendam, the Netherlands: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.

Appeltants, D. (2010, May 18). Price of a traffic sign - inquiry with municipality Kortenaken.

Ariën, C. (2010). *Driving simulator study on the effectiveness of different thoroughfare configurations*. Diepenbeek, Belgium: Hasselt University.

Baarda, D. B., & Goede, M. D. (2001). *Basisboek methoden en technieken - Handleiding voor het opzetten en uitvoeren van onderzoek* (3rd ed.). Groningen/Houten, the Netherlands: Stenfert Kroese.

Belgian Federal Government. (n.d.). Evolutie van de voornaamste doodsoorzaken volgens ICD-10, naar geslacht, ingezetenen Belgen en vreemdelingen. Vlaams Gewest, 1998, 1999, 2004. Retrieved November 21, 2009, from http://statbel.fgov.be/nl/modules/publications/statistiques/bevolking/Doodsoorzaken.jsp

Bella, F. (2005). Validation of a Driving Simulator for Work Zone Design. *Transportation Research Record*, *1937*(1), 136-144.

Cantin, V., Lavalliere, M., Simoneau, M., & Teasdale, N. (2009). Mental workload when driving in a simulator: Effects of age and driving complexity. *Accident Analysis & Prevention*, *41*(4), 763-771. doi:10.1016/j.aap.2009.03.019

CARE. (2009). Road safety evolution in EU - Fatalities by population. European Commission.

Charlton, S. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis & Prevention*, *38*(3), 496-506.

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as a function of task demands: a study of car drivers. *Ergonomics*, *47*(2), 218-236.

Daniëls, S., Vanrie, J., Dreesen, A., & Brijs, T. (2010). Additional road markings as an indication of speed limits: Results of a field experiment and a driving simulator study. *Accident Analysis & Prevention*, *42*(3), 953-960.

Devos, H., Vandenberghe, W., Nieuwboer, A., Tant, M., Baten, G., & De Weerdt, W. (2007). Predictors of fitness to drive in people with Parkinson disease. *Neurology*, *69*(14), 1434-1441.

Engels, D., Devriendt, K., & Lauwers, D. (2003). *Handboek secundaire wegen [niet officiële publicatie]* (p. 147). Brussels, Belgium: Tritel en Iris Consulting (i.o.v. Ministerie van de Vlaamse Gemeenschap).

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F*, *8*(2), 97-120.

Ethologie.nl. (n.d.). Onderzoeksmethoden en statistiek - Random getallen. Retrieved December 2, 2009, from http://www.ethologie.nl/methoden/random.htm

ETSC. (1995). Reducing traffic injuries resulting from excessive and inappropriate speed. European Transport Safety Council ETSC.

Eurostat. (2010). Regional transport statistics - Victims in road accidents at regional level. European Commission.

Evans, L. (2004). *Traffic Safety*. Michigan, USA: Science Serving Society Bloomfield Hills.

Field, A. P. (2005). *Discovering statistics using SPSS (and sex, drugs and rock 'n' roll)* (2nd ed.). London, United Kingdom: Sage Publications.

Freund, B., Gravenstein, S., Ferris, R., & Shaheen, E. (2002). Evaluating Driving Performance of Cognitively Impaired and Healthy Older Adults: A Pilot Study Comparing On-Road Testing and Driving Simulation. *Journal of the American Geriatrics Society*, *50*(7), 1309-1310.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention*, *37*(3), 461-472. doi:10.1016/j.aap.2004.11.003

Godley, Triggs, & Fildes. (2002). Driving simulator validation for speed research. *Accident Analysis & Prevention*, *34*(5), 589-600.

Haigney, D., & Westerman, S. (2001). Mobile (cellular) phone use and driving: a critical review of research methodology. *Ergonomics*, *44*(2), 132-143.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention*, *38*(1), 185-191.

van der Horst, R., & de Ridder, S. (2007). Influence of roadside infrastructure on driving behavior - Driving simulator study. *Transportation Research Record*, (2018), 36-44.

ISO. (2004). Road vehicles - Ergonomic aspects of transport information and control systems - Occlusion method to assess visual distraction due to the use of in-vehicle systems. ISO - International Organization for Standardization.

Johnson, A., & Proctor, R. W. (2004). *Attention*. SAGE.

Jordan, P., & Johnson, G. (1993). Exploring mental workload via TLX: The case of operating a car stereo whilst driving. *Vision in Vehicles-IV*, 225-262.

Jourquin, B. (2008). *Transport en Ruimte - Movement, Transport and locations*. Presented at the Colleges: Bachelor in Transportation Sciences, Diepenbeek, Belgium: Hasselt University.

Kappé, B., & Emmerik, V. M. (2005). *Mogelijkheden van rijsimulatoren in de rijopleiding en het rijexamen* (p. 66). Soesterberg, the Netherlands: TNO Defensie en Veiligheid.

Kaptein, N., Theeuwes, J., & Van Der Horst, R. (1996). Driving Simulator Validity: Some Considerations. *Transportation Research Record*, *1550*(1), 30-36.

Klee, H., Bauer, C., Radwan, E., & Al-Deek, H. (1999). Preliminary Validation of Driving Simulator Based on Forward Speed. *Transportation Research Record*, *1689*(1), 33-39.

Kline, D., Kline, T., Fozard, J., Kosnic, W., Schieber, F., & Sekular, R. (1992). Vision, aging and driving: the problems of older drivers. *Gerontology: Psychological Sciences*, *47*, 27-34.

Kuipers, J., Wieringa, P., Winter, J. D., & Boschloo, H. (2005). Rijsimulator is een goed alternatief voor de lesauto. Technical university of Delft, the Netherlands, faculteit Werktuigbouwkunde, Maritieme Techniek en Technische Materiaalwetenschappen.

Lajunen, T., Hakkarainen, P., & Summala, H. (1996). The ergonomics of road signs: Explicit and embedded speed limits. *Ergonomics*, *39*(8), 1069-1083.

Lansdown, T. (2002). Individual differences during driver secondary task performance: verbal protocol and visual allocation findings. *Accident Analysis & Prevention*, *34*(5), 655-662.

Lansdown, T., Brook-Carter, N., & Kersloot, T. (2004). Distraction from multiple in-vehicle secondary tasks: vehicle performance and mental workload implications. *Ergonomics*, *47*(1), 91-104.

Lee, Y., Lee, J., & Boyle, L. (2007). Visual Attention in Driving: The Effects of Cognitive Load and Visual Disruption. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *49*(4), 721-733.

Liu, B., & Lee, Y. (2006). In-vehicle workload assessment: Effects of traffic situations and cellular telephone use. *Journal of Safety Research*, *37*(1), 99-105.

Longley, P., Goodchild, M., Maguire, D., & Rhind, D. (2005). *Geographic information systems and science* (2nd ed.). Chichester, United Kingdom: John Wiley and Sons.

Martens. (2000). Assessing Road Sign Perception: A Methodological Review. *Transportation Human Factors*, *2*(4), 347-357.

Martens, M., & van Winsum, W. (n.d.). *Measuring distraction: the Peripheral Detection Task* (p. 7). Soesterberg, the Netherlands: TNO Human Factors.

McCarley, J., Vais, M., Pringle, H., Kramer, A., Irwin, D., & Strayer, D. (2004). Conversation Disrupts Change Detection in Complex Traffic Scenes. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*(3), 424-436.

McLane, R., & Wierwille, W. (1975). The influence of motion and audio cues on driver performance in automobile simulator. *Human Factors*, *17*(5), 488-501.

Meex, N. (2009). *Simulatoronderzoek omleidingsignalisatie*. Hasselt University, Belgium - Master Thesis, Promotor: Prof. dr. Tom Brijs.

Michon, J. A., Evans, L., & Schwing, R. (1985). A critical view of driver behavior models - What do we know, what should we do?, 485-520.

Mobiliteit en Vervoer. (2007). *29 januari 2007 - Koninklijk besluit tot wijziging van het koninklijk besluit van 1 december 1975 houdende algemeen reglement op de politie van het wegverkeer en van het gebruik van de openbare weg*. Retrieved from http://www.juridat.be/cgi_loi/loi_N.pl?cn=2007012937

Mollu, K. (2008). Verkeerskundig project - Verkeersveiligheid/conflictobservatie en microsimulatie. Studentpaper Hasselt University, Belgium.

Moons, E. (2009). *Onderzoek Verplaatsingsgedrag Vlaanderen 3 (2007-2008) - Tabellenrapport - i.o.v. de Vlaamse overheid* (p. 272). Diepenbeek, Belgium: Instituut voor Mobiliteit IMOB.

Muttart, J., Fisher, D., Knodler, M., & Pollatsek, A. (2007). Driving without a clue: Evaluation of driver simulator performance during hands-free cell phone operation in a work zone. *Transportation Research Record*, (2018), 9-14.

Näätänen, R., & Summala, H. (1976). Road-user behavior and traffic accidents. North-Holland Publishing Company: Amsterdam, Oxford.

Nederhoed, P. (2007). *Helder rapporteren* (9th ed.). Houten, the Netherlands: Bohn Stafleu van Loghum.

Noy, Y. (1987). Theoretical review of the secondary task methodology for evaluating intelligent automobile displays. *Human Factors Society. Proceedings of the 31st Annual Meeting*, 205-209.

Parkes, A., & Coleman, N. (1990). Route guidance systems: A comparison of methods of presenting directional information to the driver. *Ergonomics*, 480-485.

Pohlmann, S., & Traenkle, U. (1994). Orientation in road traffic. Age-related differences using an in-vehicle navigation system and a conventional map. *Accident Analysis & Prevention*, *26*(6), 689-702.

Ranney, T. (1994). Models of driving behavior - A review of their evolution. *Accident Analysis & Prevention*, *26*(6), 733-750.

Rasmussen, R. (1986). Information processing and human-machine interaction. An approach to cognitive engineering. North-Holland: New York.

Recarte, M. A., & Nunes, L. (2002). Mental load and loss of control over speed in real driving - Towards a theory of attentional speed control. *Transportation Research Part F*, *5*(2), 111-122.

Reed, M., & Green, P. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics*, *42*(8), 1015-1037.

Sabey, B., & Taylor, H. (1980). *The known risks we run: The Highway* (No. 567). Crowthorne, United Kingdom: Transport and Road Research Laboratory.

Shinar, D. (2007). *Traffic safety and human behavior.* Amsterdam, USA: Elsevier.

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention*, *37*(2), 315-326. doi:10.1016/j.aap.2004.09.007

Sivak, M. (1996). The information that drivers use: is it indeed 90 percent visual.

Perception, *25*, 1081-1089.

Sojourner, R., & Antin, J. (1990). The effects of a simulated headsup display speedometer on perceptual task performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *32*, 329-339.

Strayer, D., Drews, F., & Johnston, W. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, *9*(1), 23-32.

Theeuwes, J. (1989). *Visual selection: Endogenous and exogenous contro - a review of literature* (No. IZF 1989 C-3). Leiden, The Netherlands: TNO Institute for Perception.

Törnros, J. (1998). Driving behaviour in a real and a simulated road tunnel--a validation study. *Accident Analysis & Prevention*, *30*(4), 497-503.

Treat, J., Tumbas, N., McDonald, S., Shinar, D., Hume, R., Mayer, R., Stansifer, R., et al. (1979). *Tri-level study of the causes of traffic accidents: final report* (Volume I: Causal factor tabulations and assessments No. DOT HS 805 085). Washington DC.: National Highway Traffic Safety Administration U.S. Department of Transportation.

Vaes, G. (2010, May 20). Price of a traffic sign - inquiry with municipality Zutendaal.

Vanlangenaeker, M. (2010, May 18). Price of a traffic sign - inquiry with municipality Diepenbeek.

Vanrie, J., & Willems, B. (2006). *De visuele waarneming en visuele aandachtsprocessen van verkeersdeelnemers: Een overzicht van de beïnvloedende factoren* (No. RA-2006-99) (p. 40). Diepenbeek, Belgium: Steunpunt verkeersveiligheid:

onderzoeksgroep gedrag.

Verwey, W., & Veltman, H. (1996). Detecting short periods of elevated workload: A comparison of nine workload assessment techniques. *Journal of Experimental Psychology: Applied*, *2*(3), 270-285.

Vlaams Ministerie van Mobiliteit en Openbare Werken. (2008). *Verkeersveiligheidsplan Vlaanderen* (No. D/2008/3241/095) (p. 247). Brussels, Belgium: Flemish Department of Mobility and Public Infrastructure.

Vlassenroot, S., Vandenberghe, W., & De Mol, J. (2008). *Snelheidsmanagement en snelheidsbeheer - literatuurstudie* (No. RA-MOW-2008-006) (p. 73). Diepenbeek, Belgium: Steunpunt Verkeersveiligheid bij Stijgende Mobiliteit: spoor verkeersveiligheid.

Weller, G., Schlag, B., Gatti, G., Jorna, R., & Van den Leur, M. (2006). Human Factors in Road Design. State of the art and empirical evidence. Ripcord – Iserest.

WHO. (2008). *Fact Sheet - The top ten causes of death* (p. 5). World Health Organisation.

Wickens, C. (1976). The effects of divided attention on information processing in manual tracking. *Journal of Experimental Psychology: Human Perception and Performance.*, *2*(1), 1-13.

Wickens, C. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159-177.

Willems, J., & Vertriest, M. (n.d.). Snoeien in het bordenbos. Hogeschool voor Verkeerskunde, Diepenbeek: Belgium.

Wood, J., & Troutbeck, R. (1992). Effect of restriction of the binocular visual field on driving performance. *Ophthalmic and Physiological Optics*, *12*, 291-298.

Young, M., & Stanton, S. (2002). Attention and automation: new perspectives on mental underload and performance. *Theoretical Issues in Ergonomics Science*, *3*(2), 178-194.

Young, M., & Stanton, N. (2002). Malleable attentional resources theory: A new explanation for the effects of mental underload on performance. *Human Factors*, *44*(3), 365-375.

VII. Annexes

1. Annex 1: Scenario

1.1 General terms for each scenario

	70 km/h part	90 km/h part
Density[5]	12 vh/km	9 vh/km
Weather	Dry	
Time	Day	
Road type	Secondary road type III	
Number of tracks	2 (3.25 m); straight road	
Environmental planning	Buildings and grass	
Bicycle track	Adjacent	
Lighting	Yes	
Other road users	Bus, truck, car	
Intersections	Traffic light at green	

[5] Based on the fundamental relation between density, intensity and speed (based on a comparison road Mollu, 2008)

1.2 Terms for each separate scenario

Distance	Speed	General signs	Sc_1: Traditional	Sc_2: Zone	Sc_3: Zone-repetition
0 m	90 km/h	30 m: C43_90 km/h			
1000 m	70 km/h		1000 m: C43	1000 m: F4a	1000 m: F4a
2000 m	70 km/h	2000 m: left crossing	2030 m: C43		
3000 m	70 km/h	3000 m: left crossing	3030 m: C43		3500 m: F4a_repetition
4000 m	70 km/h	4000 m: crossing	4030 m: C43		
5000 m	70 km/h	5000 m: right crossing	5030 m: C43		
	90 km/h		5750 m: C45	5750 m: F4b	5750 m: F4b

1.3 Filler pieces

Filler pieces	**Sc_1: Traditional**	**Sc_2: Zone**	**Sc_3: Zone-repetition**
0 – 750 m	250 m: right curve 20°	250 m: right curve 20°	250 m: right curve 20°
1250 – 1780 m	1300 m: left curve 30° 1500 m: wind harp left 1500 m: right curve 25° Trees between the houses	1300 m: left curve 30° 1500 m: water tower right 1500 m: right curve 25° Trees between the houses	1300 m: left curve 30° 1500 m: water tower left 1500 m: right curve 25° Trees between the houses
2280 – 2780 m	2500 m: supermarket left 2500 m: right curve 20°	2500 m: supermarket left 2500 m: right curve 20°	2500 m: supermarket right 2500 m: curve 20°
4280 – 4780 m	4300 m: left curve 25° 4500 m: water tower left	4300 m: left curve 25° 4500 m: water tower left	4300 m: left curve 25° 4500 m: wind harp right
5280 – 5500 m	Trees between the houses	Trees between the houses	Trees between the houses

2. Annex 2: Used traffic signs[6]

C43_70 km/h

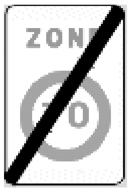
C43_90 km/h

C45

F4a

F4a_repetition

F4b



3. Annex 3: Overview of the scenario order

Rit code	***Order***
1	Traditional – Zone – Zone-repetition
2	Traditional – Zone-repetition – Zone
3	Zone – Zone-repetition – Traditional
4	Zone – Traditional – Zone-repetition
5	Zone-repetition – Traditional – Zone
6	Zone-repetition – Zone – Traditional

[6] Royal Decree of December 1st 1975 (Mobiliteit en Vervoer, 2007)

4. Annex 4: Trip order by participant

The table below gives an overview of the trips of the 48 participants. The numbers 1 to 24 refer to a woman while the numbers 25 to 48 refer to a man. Half of each gender drove first a trip without secondary task while the other part drove first a trip with secondary task. The trips with secondary task were divided into two groups: group A (above the diagonal) and group B (below the diagonal). These groups refer to the response of the stimuli.

GROUP A ***GROUP B***	***Without secondary task – with secondary task***	***With secondary task – without secondary task***
1. Traditional – Zone – Zone-repetition	1, 25 13, 37	2, 26 14, 38
2. Traditional – Zone-repetition – Zone	3, 27 15, 39	4, 28 16, 40
3. Zone – Zone-repetition – Traditional	5, 29 17, 41	6, 30 18, 42
4. Zone – Traditional – Zone-repetition	7, 31 19, 43	8, 32 20, 44
5. Zone-repetition – Traditional – Zone	9, 33 21, 45	10, 34 22, 46
6. Zone-repetition – Zone – Traditional	11, 35 23, 47	12, 36 24, 48

5. ANNEX 5: PAPER OF INFORMATION

Introduction

Dear participant

First of all, I would like to thank you for your participation in my Master's Thesis at the University of Hasselt. It is important that you wait here until the researcher will pick you up and that you lock up your cell. While waiting, you can enjoy a drink and eat some snacks. To limit the time in the research room, there are already a few acts that can be performed in advance. Please read this paper carefully and fill it in where it is asked:

- On the next page (page 118), you will find the **informed consent form**. Please read this form thoroughly and sign it as correct. If you have any questions about this, you can always ask them.

- At page 119 some **personal questions** are asked to simplify the analysis of the results.

- Beginning at page 120, I would like to ask you to answer a few questions (circle or fill it out) related to general **traffic rules**. It is important that you solve them based on ready knowledge without a third party. If a question is not clear, you can always ask for an explanation.

Kristof Mollu

Informed consent form Master‛s Thesis

In this Master‛s Thesis of Kristof Mollu (Researcher, Student Master of Transportation Sciences, University of Hasselt) research will be carried out on the driving behaviour of car drivers. In order to investigate this, first there will be given a brief introduction and there are a few warming up trips. After these warming up trips, two research trips are performed with a short pause between them. During and after these trips, there may be some additional tasks. Data related to the driving performance will be collected and this information will be kept completely anonymous and analyzed. The data can be handed over – anonymous – to other scientific research or the results of this research can be published. Your name will not be published as a participant and the confidentiality of the information is guaranteed in each stage of the Master‛s Thesis.

It is possible that you will suffer from ‵simulator sickness’ during the trips because you are kept a long time in a simulator environment. Symptoms of this disease are lightheaded or feelings of sickness because there are disrupted expectations and there is a limited depth perception. When this occurs, you must immediately report this and you are free to stop the research. The trips are, however, as much as possible, limited in time so the risk is extremely small.

Although you do not directly benefit from taking part in this research, your participation has a social impact as part of the transport policy.

I, the undersigned participant, give permission to this Master‛s Thesis of Kristof Mollu (Researcher, Student Master of Transportation Sciences, University of Hasselt). Hereby I declare that I am taking part in this study, I will not ask a compensation for inconveniences, I have the right to stop the research at any time, I will not pass information to others and I will behave as I normally do.

Date: ___ / ____ / ______

Signature of the researcher:

Name and signature of the participant:

Personal questions

What is your day of birth?: ___ /___ /19___

What is your sex? *(encircle the correct answer)*

a) Man
b) Female

Since when have you got your driver license? ___ / ___ /_____

How many kilometres do you drive a year *(give an estimation)*: _____________ km/year

Do you wear a pair of glasses? *(encircle the correct answer)*

a) Yes
b) No

Traffic rules

Question 1

(encircle the correct answer)

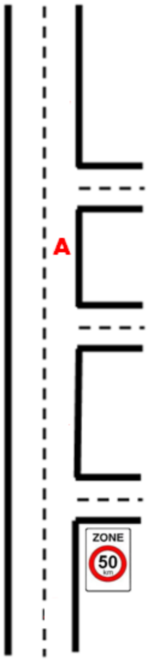
I drive with my car inside the built-up area. In front of me, a bus indicates, with the aid of his direction indicator, that he wants to leave the staging point. What should I do?

a) I must slow down and if necessary I must stop.

b) I can drive on.

c) I can choose what seems best to me.

Question 2



The figure on the left represents a road with a few intersections (for two directions), outside the built-up area. On the road the location A is indicated. What is the maximum permitted speed for cars at this location? *(encircle the correct answer)*

a) 50 km/h

b) 70 km/h

c) 90 km/h

d) I can not distract this form this figure

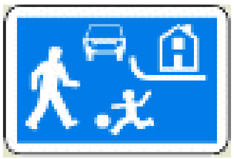
<u>Question 3</u>

(encircle the correct answer)

As a pedestrian, I would like to take this zebra that crosses the tram tracks. Just at that time, a tram rides up. Who has priority?

a) The tram
b) The pedestrian

<u>Question 4</u>

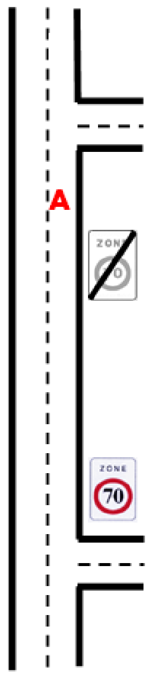


(encircle the correct answer)

May children play in the street in a home zone?

a) Yes
b) No

<u>Question 5</u>



The figure on the left represents a road with a few intersections (for two directions), outside the built-up area. On the road the location A is indicated. What is the maximum permitted speed for cars at this location? *(encircle the correct answer)*

a) 50 km/h

b) 70 km/h

c) 90 km/h

d) I can not distract this form this figure

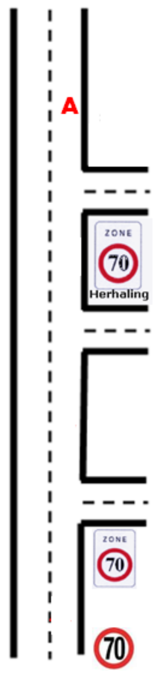
Question 6

(encircle the correct answer)

May I park my car – with the use of the four flashing lights – here on the bicycle path, just for a while, to get a bread?

a) Yes, always
b) Yes, but only if the bicyclist can pass via the roadway or foothway
c) No, never

Question 7



The figure on the left represents a road with a few intersections (for two directions), outside the built-up area. On the road the location A is indicated. What is the maximum permitted speed for cars at this location? *(encircle the correct answer)*

a) 50 km/h

b) 70 km/h

c) 90 km/h

d) I can not distract this form this figure

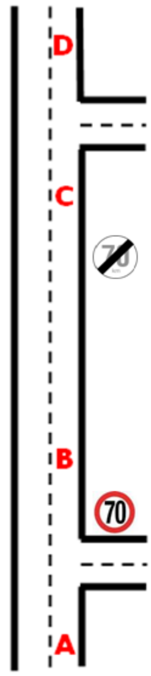
Question 8

(encircle the correct answer)

If this sign is placed in a street, I may …?

a) Stand still for a while to drop the children
b) Stand still to make a phone call
c) Not stand still and not park my car

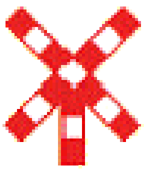
<u>Question 9</u>



The figure on the left represents a road with a few intersections (for two directions), outside the built-up area. On the road the **locations** A, B, C & D are indicated. What is the maximum permitted speed for cars at these locations?

- At location A?: ______ km/h
- At location B?: ______ km/h
- At location C?: ______ km/h
- At location D?: ______ km/h

<u>Question 10</u>



(encircle the correct answer)

This traffic sign means?

a) A level crossing without barriers
b) A level crossing with barriers
c) A level crossing for two or more tracks
d) A level crossing for one track

6. Annex 6: Randomization of the secondary task

To determine the order of the stimuli, a random number generator – that can be found on the website of Ethologie.nl (n.d.) – was used. First, every stimulus, out of the 44, received a sequential number or code (1 = YS, 2 = RS, 3 = YD, 4 = RD, 5 = YS). The random number generator determined 6 different rankings of the 44 random numbers. Subsequently, these numbers were replaced by 44 stimuli corresponding to their code. An example illustrates this (Group A traditional scenario): the first random sequence of numbers was drawn as follows: 11, 13, 19, 25, 39, and so on. The sequential order shows that 11 matches with YD, 13 with YS, and so on. So the first presented stimulus was a yellow diamond, the second a yellow square, etc (Figure 8).

Sequential order	YS	RS	YD	RD	YS	RS	YD	RD	YS	RS	YD	RD	YS	RS	YD	RD
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A Scenario trad	YD	YS	YD	YS	YD	YD	RD	YD	YD	RS	RD	RS	YD	YD	YD	YS
Random order 1	11	13	19	25	39	23	24	31	35	6	28	10	43	27	15	17
A Scenario zone rep	RS	YD	RD	RD	YD	YD	RS	RS	YS	YD	RS	YS	RD	YS	RS	RD
Random order 2	22	23	4	44	31	15	38	2	13	7	42	17	28	33	14	40
A Scenario zone	RS	RD	RD	YS	RD	YD	RD	RS	RS	RS	YD	YS	YD	RD	RD	YS
Random order 3	42	12	20	5	8	23	44	14	22	6	31	1	27	28	16	37
B Scenario trad	YS	YD	YD	RS	YS	YD	YS	RD	YD	YD	RS	RD	YS	YD	RD	RS
Random order 4	13	7	35	10	9	39	29	44	27	23	30	4	33	19	40	42
B Scenario zone rep	RD	RS	YS	RS	RD	RS	YD	YS	RD	YS	YS	RD	RD	YS	YS	YD
Random order 5	20	18	13	42	32	26	3	25	36	5	17	4	28	41	33	7
B Scenario zone	RD	RS	RS	RS	YS	YS	YS	RD	RD	RD	YS	YD	RD	YD	YS	YS
Random order 6	16	38	42	26	13	41	29	36	24	28	37	39	8	15	33	1

Figure 8 Illustration of the randomization of the stimuli

The study by Martens & van Winsum (n.d) used an interval time of 3 to 5 seconds. Every scenario of 6 kilometres could be divided into three segments: 1000 m at 90 km/h, 4750 m at 70 km/h and finally 250 m at 90 km/h. It was assumed that the average speed in the 70 km/h segment was equal to the speed limit and there would appear a stimulus every 3 to 5 seconds. When these assumptions were true, one had to present every 58 m to 97 m a stimulus in the 70 km/h segment. The same assumptions applied in the two 90 km/h segments, which means that one showed a stimulus every 75 m to

125 m. The study by Devos et al. (2007) showed an average response time of 2.22 seconds, but said nothing about the time that a stimulus lighted up. Therefore, the length of the stimuli was determined at 3 seconds. If one assumed that every stimulus appeared for 3 seconds (or 75 metres in a 90 km/h segment and 58 metres in a 70 km/h segment) and the interval time/distance varied as described above, there were presented 44 stimuli in every scenario of 6 kilometres, and each stimulus was presented 11 times. Thus, in the trip of 18 kilometres with distraction, 132 symbols were presented.

Figure 9 shows for the three scenarios the calculation of the location (based on common sense) where a particular stimulus (based on a random number generator) was provided. The stimuli were projected at the same distances in each of the three scenarios, but the stimulus itself was different for each scenario and for each group (A and B). So, there were six random rankings created. Below the black line, the interval time between each stimulus is expressed in metres. When a cell is coloured, the regular interval time of section III 2.4 was violated. Above the horizontal black line, the time (and the conversion to distance) that a stimulus was projected is indicated. This time was a constant value of 3 seconds. An example (Group A traditional scenario) illustrates this: the first stimulus – yellow diamond (YD) – appeared in the rearview mirror at 50 metres, and was continued to be projected for 3 seconds. This means that if one drove 90 km/h on the road (or 25 metres per second) the projection disappeared after 75 metres, and the total distance covered was 125 metres (50 m + 75 m). Then began the interval time of 75 metres (3 seconds at 90 km/h) where nothing was presented. The following stimulus – yellow square (YS) – was projected at 200 metres (125 m + 75 m) for 3 seconds. This projection disappeared again after 75 metres, or 275 metres after the start. After this, there was an interval time of 85 metres by which the following stimulus was presented at 360 metres (275 m + 85 m). In practical terms, this means that only the red letters and numbers are interesting because these represent the distance that a stimulus (during 3 seconds) was presented and what the stimulus was.

	Seconds		3		3		3		3		3		3		3		3		3		3		3		3
	Metre		75		75		75		75		75		58		58		58		58		58		58		58
Projection time/ distance	Travelled distance		125		275		435		620		780		938		1081		1204		1337		1445		1573		1696
	A Scenario trad		YD		YS		YD		YS		YD		YD		RD		YD		YD		RS		RD		RS
	A Scenario2 zone rep		RS		YD		RD		RD		YD		YD		RS		RS		YS		YD		RS		YS
	A Scenario3 zone		RS		RD		RD		YS		RD		YD		RD		RS		RS		RS		YD		YS
	B Scenario trad		YS		YD		YD		RS		YS		YD		YS		RD		YD		YD		RS		RD
	B Scenario2 zone zone		RD		RS		YS		RS		RD		RS		YD		YS		RD		YS		YS		RD
	B Scenario3 zone		RD		RS		RS		RS		YS		YS		YS		RD		RD		RD		YS		YD
	Travelled distance	50		200		360		545		705		880		1023		1146		1279		1387		1515		1638	
Interval time	Interval distance	50		75		85		110		85		100		85		65		75		50		70		65	

	3		3		3		3		3		3		3		3		3		3		3		3		3		3
	58		58		58		58		58		58		58		58		58		58		58		58		58		58
	1824		1967		2100		2216		2344		2460		2583		2721		2854		2972		3120		3263		3441		3574
	YD		YD		YD		YS		YD		RD		RD		RS		RD		RD		RD		RD		RD		YS
	RD		YS		RS		RD		RS		RD		RD		RD		RD		YS		YD		YD		YS		YS
	YD		RD		RD		YS		RS		RS		YS		RS		YD		RS		YS		YD		RS		YS
	YS		YD		RD		RS		YS		RS		YS		YD		YD		RS		RS		RS		RD		YS
	RD		YS		YS		YD		YS		YD		RS		YD		RS		YS		YS		YD		RS		YD
	RD		YD		YS		YS		RD		YD		RS		YD		RS		YS		YD		RD		RS		YD
1766		1909		2042		2158		2286		2402		2525		2663		2796		2914		3062		3205		3383		3516	
70		85		75		58		70		58		65		80		75		60		90		85		120		75	

	3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	58		58		58		58		58		58		58		58		58		58		58		58		58		75		75		75		75
	3815		3968		4101		4224		4352		4468		4586		4709		4837		4965		5098		5241		5379		5534		5684		5844		5994
	RD		YS		YS		RS		RS		YS		RS		YS		RS		YS		RS		RS		RS		YD		YS		YS		RS
	YD		RD		YD		YS		RD		RD		YS		RS		YD		RS		YD		YD		RS		RS		YS		YS		RS
	YS		RS		YD		YS		RD		YD		RD		YS		YD		YD		YS		RD		RD		YD		YD		RS		RD
	YS		RD		RS		RS		RD		RD		YS		RS		YS		RS		YD		RD		RD		YD		RD		YD		YS
	RD		RS		RS		RS		RD		YS		YD		YD		RS		RS		RD		YD		YD		RD		RD		RD		YD
	RS		YD		YS		YS		RS		YD		YS		RS		YD		RD		YS		YD		RD		RD		YD		RS		RS
3757		3910		4043		4166		4294		4410		4528		4651		4779		4907		5040		5183		5321		5459		5609		5769		5919	
65		95		75		65		70		58		60		65		70		70		75		85		80		80		75		85		75	

Figure 9 Implementation of the secondary task

7. Annex 7: Exploring the data

The tables below (Table 6 and Table 7) give an overview of the amount of outliers (between 1.5 and 3 times the interquartile range) and extreme values (at least three times the interquartile range) for each person (when there was an outlier) in the different analyses in a total of 72 zones (6 for the control zone, 12 for the sign at 1000 m, 12 for the repetition sign, 12 for the sign at 5750 m, 6 for each intersection and 6 for the 70 km/h segment). Table 8 gives the extreme values and outliers for the analysis of percentage time/distance out of lane (a total of 4).

Table 6 Outliers and extreme values for speed analysis

	Average speed			*StDev Speed*		
Personid	***Amount of outliers***	***Amount of extreme***	***Total***	***Amount of outliers***	***Amount of extreme***	***Total***
1	1		1	1		1
2	4		4	2		2
4	1		1	1		1
5			0	6	2	8
6	1		1	7		7
7			0	5	1	6
8	1		1			0
9	2		2	5	1	6
10	4		4	1		1
12	3		3	1	1	2
13			0	2		2
14	2		2	4		4
15	4		4	3		3
16	2	1	3	1		1
17	2		2	1	1	2
18	4	1	5			0
19	3	1	4			0
20	2		2			0
21	4		4	2		2
22	2		2	10	20	30
23			0	2		2
25	20	1	21	3		3
26	2		2	1		1
27	1		1	5	3	8
28			0	5	3	8

29	20	1	21			0
30	2		2	3		3
31	2		2	4	3	7
33	28	21	49	4	1	5
34	3		3	1		1
36	11	2	13	1		1
37			0	7	3	10
38	4		4	9	5	14
39	6		6			0
40	3	1	4	4		4
41	14		14	2		2
43			0	1		1
44	2		2	1		1
45			0	1		1
47			0		1	1

Table 7 Outliers and extreme values for lateral position analysis

	StDev lateral position		
Personid	***Amount of outliers***	***Amount of extreme***	***Total***
3	1		1
6	3		3
9	9	2	11
10	2		2
12	5		5
13	4		4
14	1		1
15	6	2	8
16	4	1	5
18	3		3
22	12	13	25
26	3		3
27	3		3
28	3		3
30	1		1
31	8		8
34	4		4
35	1		1
42	1		1

47	1		1
48	1		1

Table 8 Outliers and extreme values for percent time/distance out of lane

	% time/distance out of lane		
Personid	***Amount of outliers***	***Amount of extreme***	***Total***
9	1		1
16	2	2	4
20	2		2
21	1		1
28	2		2
30	2	2	4
34	1		1

Auteursrechtelijke overeenkomst

Ik/wij verlenen het wereldwijde auteursrecht voor de ingediende eindverhandeling:
Simulator study on the effects of sign typology, distraction and time on driving

Richting: **master in de verkeerskunde-verkeersveiligheid**
Jaar: **2010**

in alle mogelijke mediaformaten, - bestaande en in de toekomst te ontwikkelen - , aan de Universiteit Hasselt.

Niet tegenstaand deze toekenning van het auteursrecht aan de Universiteit Hasselt behoud ik als auteur het recht om de eindverhandeling, - in zijn geheel of gedeeltelijk -, vrij te reproduceren, (her)publiceren of distribueren zonder de toelating te moeten verkrijgen van de Universiteit Hasselt.

Ik bevestig dat de eindverhandeling mijn origineel werk is, en dat ik het recht heb om de rechten te verlenen die in deze overeenkomst worden beschreven. Ik verklaar tevens dat de eindverhandeling, naar mijn weten, het auteursrecht van anderen niet overtreedt.

Ik verklaar tevens dat ik voor het materiaal in de eindverhandeling dat beschermd wordt door het auteursrecht, de nodige toelatingen heb verkregen zodat ik deze ook aan de Universiteit Hasselt kan overdragen en dat dit duidelijk in de tekst en inhoud van de eindverhandeling werd genotificeerd.

Universiteit Hasselt zal mij als auteur(s) van de eindverhandeling identificeren en zal geen wijzigingen aanbrengen aan de eindverhandeling, uitgezonderd deze toegelaten door deze overeenkomst.

Voor akkoord,

Mollu, Kristof

Datum: **27/05/2010**