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DRIVING SIMULATOR VALIDITY AND DRIVER BEHAVIOR: RESULTS OF DRIVING PERFORMANCE IN VIRTUAL VS NATURAL CONDITIONS

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ABSTRACT

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The purpose of this study was to explore the validity of a fixed-base driving simulator. The study was carried out by comparing novice and experienced drivers' driving performance results in simulated and natural driving conditions. The relationship of simulated driving to on-road driving was clarified by examining the extent to which the results obtained in the simulated condition explained the inter-individual variability of driving in real traffic.

Nine novice and experienced drivers attended the simulated and natural driving conditions. The order of the conditions was counterbalanced among the drivers in both groups. Similar to the natural driving condition, the virtual driving condition consisted of a motorway and city environment. In the natural condition, the quality of driving was assessed by an experienced driving instructor using the same method as in the official driving test. In the virtual driving condition, the driver's performance was assessed with a number of direct driving performance measures that were defined in a driving scenario specific manner.

There were no significant differences between the groups of novice and experienced drivers in the two driving conditions. However, several outcomes of simulated driving correlated with the quality of on-road driving. Also, a multiple linear regression showed that 64% of the inter-individual variability of on-road driving quality was explained by a set of outcomes of simulated driving. Especially, outcomes measured in "turning left" and "merging onto a motorway" scenarios had predictive value in terms of the quality of on-road driving. Of the outcomes of simulated driving, the measures of steering wheel movements and lateral acceleration had the most predictive values. It is discussed whether individual differences in driver behavior would explain the results. Further research is encouraged to gain knowledge on driver behavior mechanisms and driving simulator validity.

Keywords: Driving simulator, driver behavior, driving, natural driving conditions, real-world traffic, simulator validity, validation, driving experience

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Tämän tutkimuksen tarkoitus oli selvittää kiinteäalustaisen ajosimulaattorin validiteettia suhteessa oikeassa liikenteessä ajamiseen, vertailemalla kokemattomien ja kokeneiden kuljettajien suoriutumista virtuaalisessa ja oikeassa liikenteessä. Lisäksi tutkittiin, missä määrin tulokset, jotka oli mitattu virtuaalisissa ajotilanteissa, selittivät havaittuja yksilöllisiä eroja oikeassa liikenteessä ajamisessa.

Yhdeksän kokematonta ja kokenutta kuljettajaa osallistuivat sekä ajosimulaattorissa että oikeassa liikenteessä ajamista arvioivaan tutkimukseen. Tutkimustilanteiden järjestys oli tasapainotettu kuljettajien kesken molemmissa ryhmissä. Tutkimustilanteet sisälsivät ajamista moottoritien kaltaisessa ympäristössä sekä kaupungissa. Luonnollisessa liikenteessä ajamisen laatua arvioi kokenut ajo-opettaja käyttäen samaa arviointimenetelmää kuin varsinaisessa ajokokeessa. Virtuaalisessa ajotilanteessa kuljettajan suoriutumista arvioitiin useilla ajamista kuvaavilla mittareilla. Näitä mittareita sovellettiin niin, että kunkin simuloidun liikennetilanteen erityisominaisuudet otettiin huomioon.

Kokemattomat ja kokeneet kuljettajat eivät ryhmätasolla juurikaan eronneet toisistaan virtuaalisessa ja aidossa liikenneympäristössä. Toisaalta monet virtuaalisissa ajotilanteissa mitatut suoritusmuuttujat korreloivat voimakkaasti todellisessa liikenteessä arvioidun ajamisen laadun kanssa. Lisäksi regressioanalyysi osoitti, että joissain virtuaalisissa liikennetilanteissa mitatut tulokset selittivät 64 % yksilöiden välisistä eroista oikeassa liikenteessä ajamisessa. Erityisesti virtuaaliset ajotilanteet, joissa käännyttiin vasemmalle tai liityttiin moottoritielle, osoittautuivat hyviksi ennustamaan oikeassa liikenteessä ajamisen laatua. Virtuaalisissa ajotilanteissa mitatuista muuttujista erilaiset ohjauspyörän liikkeet ja lateraalinen kiihtyvyys osoittautuivat parhaiksi ennustettaessa ajamista oikeassa liikenteessä. Johtopäätöksissä pohditaan kuljettajien yksilöllisten erojen vaikutusta kuljettajakäyttäytymiseen ja esitetään jatkotutkimusta kuljettajakäyttäytymisen mekanismien ja ajosimulaattorin validiteetin tietämyksen parantamiseksi.

Avainsanat: Ajosimulaattori, kuljettajakäyttäytyminen, ajaminen, todellinen liikenne, virtuaalinen liikenne, ajosimulaattorin validiteetti, ajokokemus, validointi

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1 INTRODUCTION

The year 2013 marked the 125th anniversary of the first automobile journey as German woman Bertha Benz with her two sons drove one-way 106 km to visit her mother. Bertha's husband Karl, founder of the automobile manufacturer Mercedes-Benz, was not informed about the road trip (Leisner, 2011). It can be argued that Karl as well as the authorities would have forbidden his wife the trip because of the many unknown dangers and features of driving, and certainly, it would be easy to agree with them. Bertha was determined that Karl's hard work should gain appreciation and a road trip would be perfect marketing for his work. As we do not know Bertha personally, only for the actions she did, she can still be described as a strong person who had hopes, dreams and faith for herself and her husband's work. As a driver, Bertha was willing to take a risk and most importantly, she had the motivation.

Groeger (2000) highlights the thought that 100 years ago a motorized vehicle was a rare exception. Certainly many challenges and dangers Bertha Benz faced on her journey have now changed. After a century on the road there are now estimated to be over 1 billion cars and light trucks (WardsAuto, 2011). Driving is not anymore one individual's brave and brilliant historical achievement but an everyday task. Driving has become such a common skill (in short time) that as Hancock (1999) states, it is overlearned, taken for granted and we easily fail to recognize what complex performances it requires.

125 years on, today's scientific research community faces the very same challenge when trying to understand driving, driver behavior and how the driver perceives risk (see Groeger, 2000; Näätänen & Summala, 1976; Wilde, 1982). Search for drivers' individual differences (Häkkinen, 1958), measures of driver performance and models of driver behavior have been debated without a common consensus (see Michon 1985; Ranney, 1994). The Pursuit to understand driving is driven by safety as Rothengatter (2002) notes. Measures to change driver behavior, to improve training and road safety are needed.

At the same time one of the traffic researchers' new technological advancements has not been found under the hood of real-world automobiles or from the road side engineering measures, but from the simulated laboratory environments and driving simulators. Simulated driving in research use has gained popularity (Carsten & Jamson, 2011). Driving simulator and on-road field study comparisons have found some promising similarities (Wang, Mehler, Reimer, Lammers, D'Ambrosio & Coughlin, 2010), but at the same time questions are raised how valid driving simulators are when compared to real-world driving in natural environments and how driver behavior is perceived in such an environment (Evans, 1991).

Validity of a driving simulator not only benefits the driver behavior research but it's also an attractive alternative for assessing and training drivers; full control of experimental conditions unlike in the real-world with constantly changing conditions and driving performance measures that provide feedback for the driver and the driving instructor how the driver performs (Blana, 1996). A driving simulator also enables a training environment where even the most challenging driving scenarios can be practiced in a safe and eco-friendly environment (Kaptein, Theeuwes & van der Horst, 1996).

This thesis is a follow-up of the Tekes-funded RATTI-project titled as "Experience and accessibility for everyday life with the help of a driving simulator – a service concept for free time services." As a part of the project, Agora Center, the independent research institute within the University of Jyväskylä, Finland, investigated driving simulator validity. This thesis summarizes the Tekes-report results with additional literature review.

The aim of this thesis is to study driving simulator validity. The empirical part of the thesis explores the validity of a driving simulator by comparing novice and experienced drivers' driving performance results in simulated and natural driving conditions. Validity was approached from two perspectives and the following research questions were presented:

Is there some degree of difference, if any, between novice and experienced drivers in the driving simulator and would these possible differences be similar from those observed in natural driving conditions?

How strongly are driving performance results in the virtual driving condition associated with the quality of driving in the natural driving condition?

First a literature review is presented as chapters two, three and four introduce driving as a task and individual differences, modeling of driver behavior as a closer look is taken on the motivational theories and driving simulators validity in traffic research. Chapter five introduces the research method, chapter six results and chapter seven concludes the findings. Chapter seven reflects the previous findings on literature and the results of the study.

2 DRIVING AS A TASK AND INDIVIDUAL DIFFERENCES

Behavioral aspects of driving have gained most of the attention during the past few decades, as introduced in chapter three, but to understand a complex task such as driving, the fundamental parts of the task and what it requires from the driver controlling the vehicle are first introduced in this chapter.

2.1 Driving – a complex controlling task

Fuller (2011, p. 13) describes driving as follows:

> "Driving may be described as a control task in an unstable environment created by the driver's motion with respect to a defined track and stationary and moving objects."

Tasks such as driving consisting of vast amounts of continuously changing variables, human behavior and environmental settings, would be, if not excessively complex at least overly extensive to define in this research. The broad range of different psychological approaches on driving is highlighted by Groeger (2002) who concludes that to understand driving and traffic; traffic psychology is too pervasive for being a distinct area of psychology.

Some of these approaches are presented by Groeger (1998) in his brief overview of traffic psychology's relevant topics such as driver's perception and cognition, developmental approaches such as age and driving, social psychology of driving, the driver's state such as stress, individual differences, applications such as accident countermeasures and different education, training, law and road design aspects. Groeger (1999) refers to McKnight and Adams' (1970) suggestion that driving as a task has 40 major tasks and over 1700 subtasks.

Peters and Nilsson (2007) describe three different functional abilities for the human controller: cognitive, perceptual and motor abilities (FIGURE 1). Examples of cognitive abilities are memory, attention and decision. Perceptual abilities are vision, hearing, touch and proprioception (sense of body). Motor abilities are related to physical dimension, motion and force.

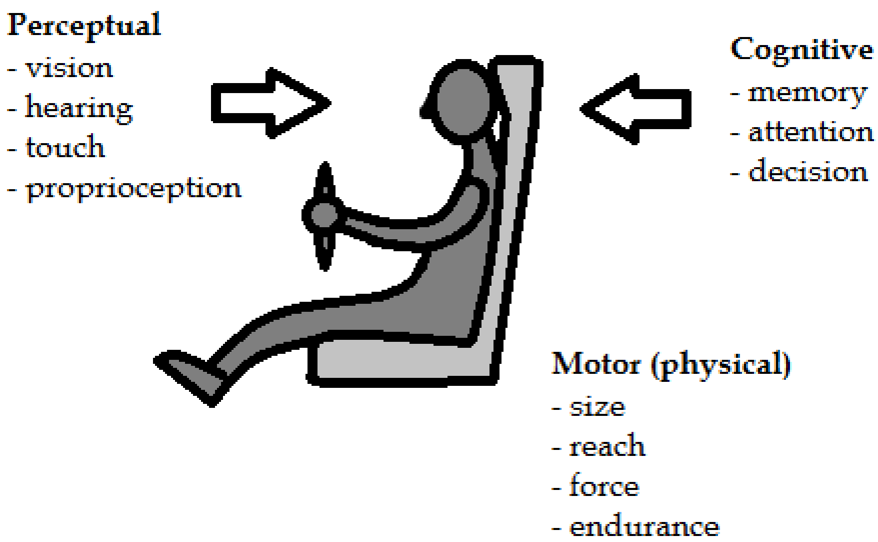


FIGURE 1 "Human abilities employed by the driver." (Adapted from Peters & Nilsson, 2007, p. 86).

Michon (1985) refers to Janssen (1979) suggesting that driving comprises three levels of activity: a control level, a tactical or maneuvering level, and a strategic or planning level (FIGURE 2). Blana (1996) describes each level including different action patterns and different preview that is dependent on the behavior in the actual situation. The trip is planned at the strategic level as goals, route, modal choice, evaluation of costs and risk are estimated. Mobility and transport choices as well as satisfaction and comfort are considered. The tactical level referred to as manoeuvring includes control maneuvers that allow drivers to overtake, turn, avoid obstacles etc. The control level includes automated processes and action patterns such as steering: driver adjusting the position of the vehicle on the road (longitudinal and lateral acceleration). (Michon 1985; Blana, 1996).

Carsten and Jamson (2011) refers to Evans (1991) who makes a distinction between driver performance and driver behavior stating that driver performance represents individuals' capabilities and skills such as perceptual and motor skills, in other words; what the driver can do, whereas driver behavior refers to how an individual chooses to drive. Fuller (2000) refers to Rothengatter (1997) who states that not only previous performance related aspects have proven difficult to link to driver behavior but also motivational aspects (e.g. attitude and sensation seeking) and individual differences as well as momentary states (e.g. mood and fatigue).

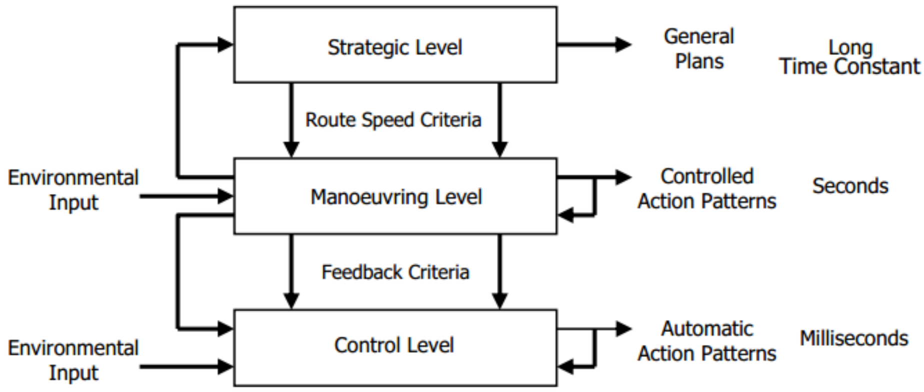


FIGURE 2 Michon (1985, p. 489) after Janssen (1979) divides drivers' problem solving task in three levels of skills and control with internal and external outputs.

2.2 Search for individual differences

Early focus on understanding driving concentrated on individual differences between humans and in accident causation (see Häkkinen, 1958; McKenna, 1982), which Michon (1985) refers to as taxonomic models. Driving was considered as a perceptual-motor skill and accidents as failures of the skill. Therefore traffic safety improvements were aimed to increase the drivers' skills, referred to as driver performance, and to decrease the environmental demands (Summala, 1986; 1996).

Individual differences in human basic capabilities were researched to define what capabilities are accident-sensitive and could predict accident involvement. McKenna (1982) considers the use of psychological tests an improvement when predicting accident involvement. This way theoretical understanding of errors and psychological abilities is improved (Ranney, 1994).

The wide range of psychometric methods was used by Häkkinen (1958) who investigated the characters of safe drivers and suggested that a safe driver has a good ability of attention, well-controlled motor behavior, master of himself, adaptability and determination and is also rather average on intelligence and reactions. Häkkinen's work is also described by Linnankoski and Ollila (1988) as follows: impulsivity, rushing and a kind of motor hypersensitivity worsened the performance especially when there was an increase in the task demands. A driver described as an accident avoider had a typical driving performance described as unhurried but fluid, flexible, certain and controlled movements.

Individual differences such as age (Cantin, Lavalliere, Simoneau & Teasdale, 2009) and driving experience (Sagberg & Bjornskau, 2006) have also been of interest. Driving experience in a simulator was studied by Sagberg and Bjornskau (2006) who used a video-based hazard perception/reaction test measuring reaction times to 31 traffic scenes for 130 drivers, divided in to three groups based on how long a driving license were held (1, 5 or 9 months) and 28 experienced drivers having held licenses several years were compared. The study did not reveal any strong relationships between hazard perception reaction time and driving experience, although some level of decrease in reactions times with more experienced drivers were observed.

Friedman and Schustack (2012) introduce the trait aspects of personality psychology such as extroversion and introversion, originally presented by Jung (1921/1967) and established by Eysenck in the early 1950s. The relationship of extraversion and intraversion has also been studied in driving research. Jung presents extroversion as an outside himself and introversion as an inside himself type of personality, as one of the types being dominant with tendency to both. Linnankoski and Ollila (1988) refer to Venables (1956), Fine (1963) and Greenshield and Platt (1967) who all have found a relationship between accident sensitivity and extraversion.

Extroversion and introversion are not the only personality characters researched as individual differences in the concept of The Big Five. The inductive model of trait approach of personality (Friedman & Schustack, 2012), has also been modified to traffic research and accident causations. Groeger (1998) refers to the research of Arthur and Graziano (1996) who found that those lacking in Conscientiousness (impulsivity) are at greater risk. Other personality related aspects and driver behavior such as sensation seekers have been studied by Heino, van der Molen and Wilde (1996) who state that sensation seekers take more risks when driving. Heino et al. (1996) conclude that the sensation avoiders preferred a longer following distance to other vehicles than sensation seekers. There were no verbal or physical measures that supported this observation.

3 MODELING DRIVER BEHAVIOR

Previous driver behavior studies focus on individual differences or traits, discussed partly in the previous chapter, and accident causations have been criticized. Ranney (1994) in his review of the evolution of driving behavior models argues, that the driving research studies have been concentrating on individual differences in search of accident predictors, only facing low correlations and creating post hoc explanations that reflect theoretical deficiencies.

Michon (1985) declares that the diversity of driver behavior research and the revolution of cognitive psychology (see Neisser, 1976), have not provided results in driver behavior modeling. According to Ranney (1994), no complete or generic driver behavior model has yet been presented. While several models have been presented and discussion around different driver behavior models continues (Rothengatter, 2002), the historical interest for driving research has concentrated more on engineering solutions to improve safety.

The 1970s remain a dark era for automobile accidents in the US and OECD countries (OECD, 2009). Many improvements made to reduce the accident rates were due to engineering measures and these measures mostly reduced the consequences of the driver behavior. Rothengatter (2002) notes' that measures to change the driver behavior to improve training and road safety are needed and encourages the development of models and theories that summarise different factors of driving (Rothengatter, 1997).

Whether or not a complete model of driver behavior is needed, the research work versatility is also reflected as Michon (1989) suggests two levels of explanation for driver models that are frequently confounded; first the rational or intentional level that presents the whole population and secondly the functional level concentrating on intra-individual information processing.

3.1 Short review of driver behavior research

After engineering measures improved traffic safety in the 1970s, the 1980s presented a prosperous time in driver behavior development. According to Vaa

(2001), ten different models were published in the 1980s, almost twice as many as all the models in total in the preceding and following decades. The main debate on modeling the driver behavior has concentrated on driver risk taking.

One of the first models presented was the Gibson and Crooks' (1938) "A Theoretical Field-Analysis of Automobile Driving", which according to Summala (1986) presented the idea of driver reaction to environmental changes. Almost three decades passed by as Taylor (1964) presented his research on the drivers' galvanic skin responses (GSR) and the risk of accidents. Taylor's results gained popularity in the 1960s and 1970s, giving direction for future research. Taylor considered driving as a self-paced task as it's done in a stable and predictable environment where the driver determinates the outcome. Findings suggested that the GSR activity was not dependent on the nature of the road or conditions. The underlining statement was that the drivers constantly adjust the level of emotional tension or anxiety to maintain the desired level.

After Taylor's findings several theories have been published such as Fuller's (1984) risk avoidance model. Ranney (1994) refers to Michon (1985) who in addition to taxonomic models (chapter 2.2) distinguished functional models of driving behavior which includes motivational models and information-processing models.

Lewis-Evans, Waard and Brookhuis (2010) divides the two other motivational theories into two groups as the Risk Homeostasis Theory (RHT) by Wilde (1976) presents the monitoring type of motivational theory, where drivers are constantly trying to maintain a preferred level of a variable, i.e. risk. The second group of motivational theories considers drivers perceiving variables such as risk only in specific situations during driving as presented by the Zero-Risk theory of Näätänen and Summala (1976). Both of these motivational theories have provided the most interesting and discussed results in the field of academic research (see i.e. Michon 1985; Ranney, 1994).

3.2 Most influential motivational models of driver behavior

The next three chapters review motivational theories. The following three theories are presented: first the Zero-Risk theory, secondly the Risk Homeostasis Theory and thirdly the task-capability interface (TCI) model by Fuller (2000) that combines the previous research of the two preceding theories of driver behavior research.

3.2.1 Zero-risk Theory

Näätänen and Summala (1976) originally proposed and Summala later evolved the zero-risk theory which aims to describe any situation where a driver is maintaining a certain safety margin while keeping the subjectively perceived risk at zero level.

Summala (1986) recaps the previous work with Näätänen on driver behavior focusing on motivation and warning processes, what motivates the driver and how the driver adapts to risk on the road. Näätänen and Summala (1976) consider the zero-risk theory as “what the driver actually does in any given traffic conditions rather than his driving skill and/or the traffic conditions as such."

Zero-risk theory reflects speed as the human behavior motivational tendencies to satisfy his motives in traffic. Speed is related i.e. for the motivation to reach a destination in time or to show off, presenting easy access to achievement. (Summala, 1986)

The drivers’ warning mechanism comes through learning, as the driver faces different driving scenarios and the outcome of those scenarios. The risk of driving is controlled by the driver with safety margins. Summala (1986) refers to Taylor (1964) and Wilde (1982) having proposed that the driver regulates risk measure as the human being does in any potentially hazardous situation. Summala (1986) concludes that driving task automatization and avoidance learning make driving a habitual activity based on largely automatized control of safety margins in partial tasks.

The problem with the motivational aspect of speed and adaptation to risk is that the subjective probability distribution and speed-utility functions are both distorted as Summala (1986, p. 13) states:

> "Drivers' speed-utility function is distorted due to perceptual, cognitive, and motivational factors. This results in too small safety margins and, consequently, in accidents due to the very ‘normal’ behavior.”

Summala continues that drivers learn to discard random risks that occur rarely and when the speed-utility is also distorted, the result is not seen to fit in the rational individual or societal decision making. In FIGURE 3 driver behavior is presented on the left (speed) indicating actual speed and environmental opportunities on the right (max. speed possible in the curve) indicating outlets for motives. Accident risk is presented as overlapping in the objective distributions. Drivers’ subjective variance is to be smaller than the objective one, even zero in both of the scenarios.

Summala (1986) refers to Brehmer and Allard (1986) suggesting that we need simple heuristics in fast dynamic decision making and that driving is mainly based on avoidance learning as the driver faces similar driving situations and learns some subjective probability of the possible outcomes such as a crash.

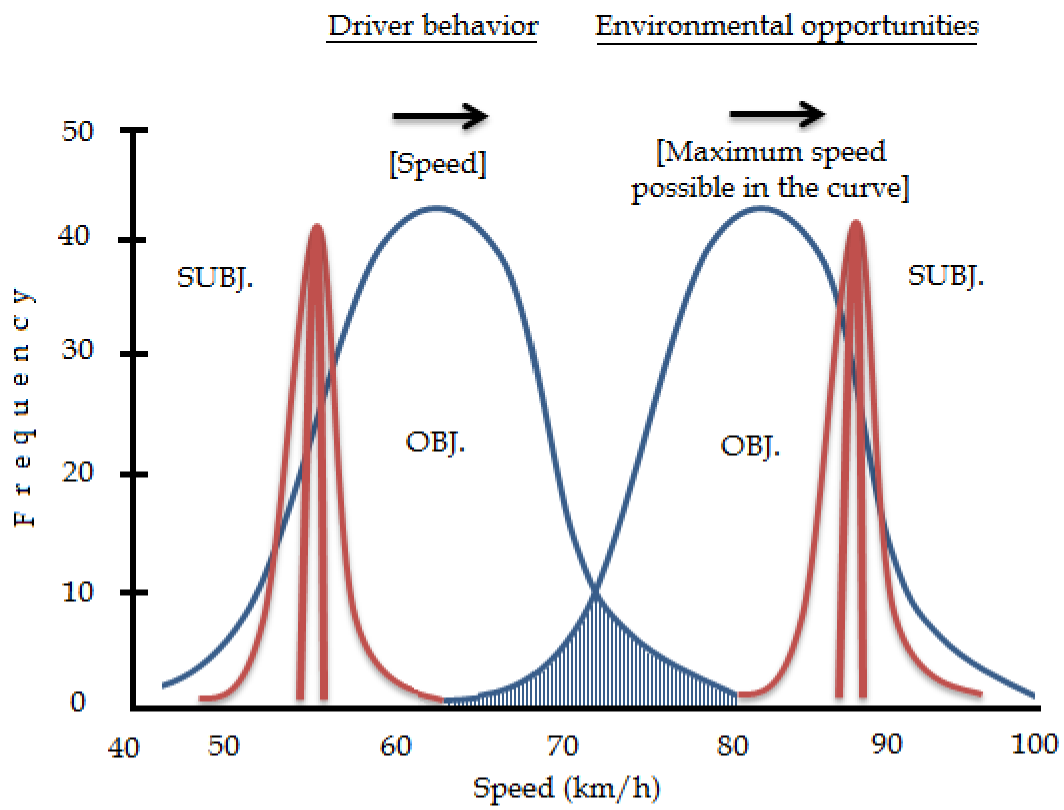


FIGURE 3 Driver behavior and environmental opportunities. (Adapted from Summala, 1986, p. 11).

To conclude from the early works of Näätänen and Summala (1976) who state that the importance of driving skills, at least in certain limits, does not present crucial importance to traffic safety but rather what the driver attempts to do with the skills. Therefore driving task difficulty varies according to driver behavior as task demands are not seen to have any fixed degree, Näätänen and Summala (1976, p. 152) mention:

> "The demands of the driver's task are more a function of the driver's choice than of the characteristics of the task itself (conditions set by the vehicle, traffic environment, and the other road users)."

To understand the mechanism Summala argues that analyzing different subtasks in driving i.e. lane keeping, car following, curve negotiation, and crossing would provide the explanation of simple heuristics and controlled variables behind it. (Summala, 1986)

3.2.2 Risk Homeostasis Theory

When Summala (1986) states in the zero-risk theory that the driver aims to keep the subjectively perceived risk at zero level, Wilde (1982) suggests that drivers try to maintain the level of risk within acceptable limits (Engström & Hollnagel, 2007). The risk homeostasis theory also called risk compensation (Wilde, 2002) originates from accident measures. According to Wilde (1988, p. 1) one of the key factors of the theory is related to how the accident measures are interpreted and related to driver behavior:

> "…accident loss per capita and road-user behaviour are mutually related in a closed-loop regulation process, with the level of preferred risk as the controlling variable outside the closed loop."

The risk homeostasis theory suggests that there is no behavior without some level of risk and that the drivers are constantly optimizing the level of risk rather than trying to eliminate it (see FIGURE 4). This optimization is called as target level of risk that aims to maximize drivers' overall benefits. (Wilde, 1998; 2002)

The amount of risk people are preferring to take depends on four utility factors, with factors one and four being higher: First the expected benefits of risky behavior, second the expected costs of risky behavior, third the expected benefits of safe behavior and fourth the expected costs of safe behavior. (Wilde, 1998)

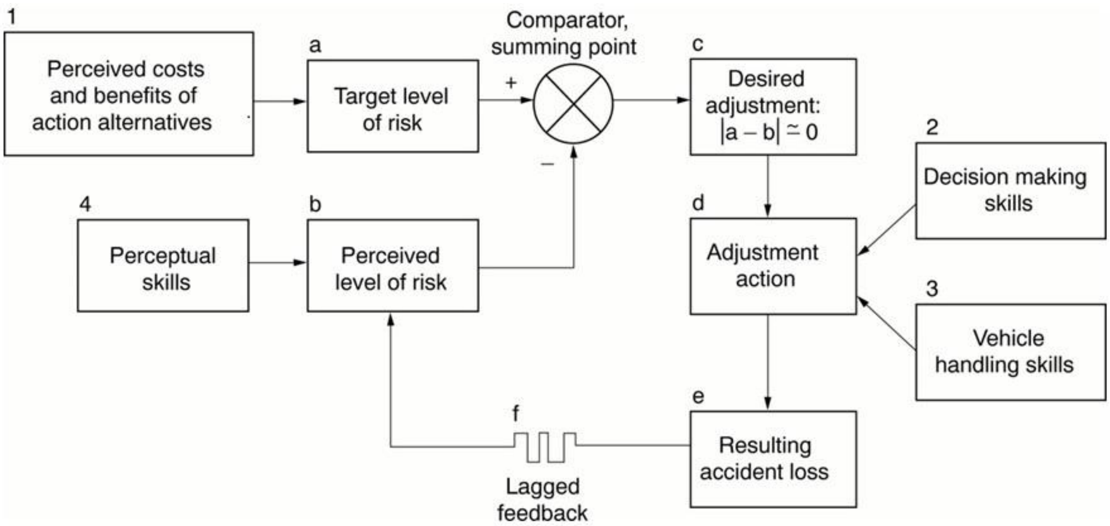


FIGURE 4 Homeostasis mechanism with the average target level of risk as the controlling variable. (Wilde, 1998, p. 90).

For evidence of the theory Wilde (1998) mentions Sweden that changed over from left hand to right hand traffic resulting in a reduction of traffic fatality rates. Eventually after one and a half year later the fatality rates returned to normal. Wilde also mentions that for example business cycles in economy as well as cultural, social or psychological factors influence the accepted level of risk.

3.2.3 Task-Capability Interface model

The Task Capability Interface (TCI) model combines two opposite view points of previous research, Wilde's (1982) Risk homeostasis theory and Näätänen and Summala's (1976) zero-risk model. During normal driving conditions drivers perceive no risk and therefore operate with zero risk, however when exceptions occur the driver may accept some level of possibility for negative outcomes. (Fuller, 2008)

The TCI model reasons that drivers have demands on the driving task that they are continuously observing in the limitations of their perceptual process and control actions. This interaction between demands of the driving task and the drivers' capability defines driving task difficulty (see FIGURE 5). Speed regulation is seen as the drivers' primary solution to affect the task difficulty. (Fuller, 2000; 2005; 2011)

When demands of the task increase and the driver is starting to operate within the limits of capability the control is not immediately lost but becomes more fragile. This fragile momentum is sensitive and eventually as the task demands exceed the driver's capability, loss of control occurs. (Fuller, 2000; 2005).

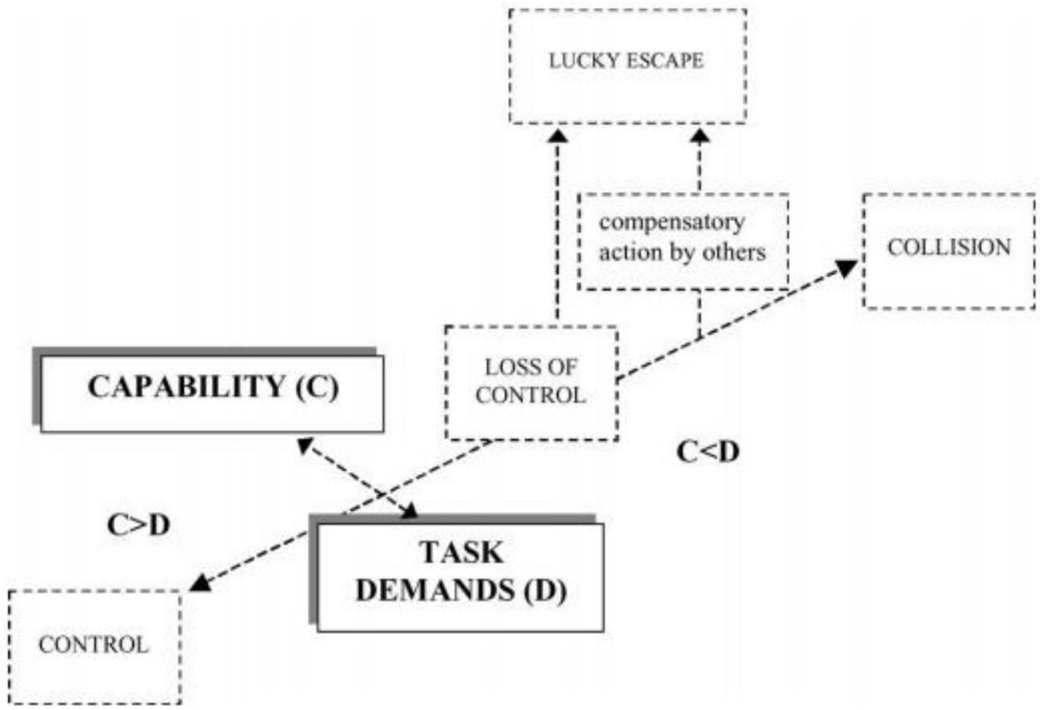


FIGURE 5 Outcomes between driving task demand and driving task capability (Fuller, 2005, p. 464).

Fuller (2005; 2011) reasons that as the driver capability is more or less stable, defined by the biological characteristics of the driver, changes in the task demand directly affect driving tasks difficulties. Fuller (2005) refers to another human behavior researcher Kahneman (1973) to link the concept of task difficulty to mental workload. As the workload increases (in other words task demands increase) the driver may be exposed to performance errors. Therefore the driver's actual safe margin is the difference between driver capability and task demand as presented in FIGURE 4. It should also be noted that capability is vulnerable to human factors such as attitude, motivation, effort, fatigue, drowsiness, time-of-day, drugs, distraction, emotion and stress (Fuller, 2005).

4 DRIVING SIMULATOR VALIDITY IN TRAFFIC RESEARCH

Driving simulators have gained popularity in recent years mostly for research purposes (Carsten & Jamson, 2011). One of the most recent general publications of traffic psychology (ed. Porter, 2011) addresses the issue of driving simulator validity as Carsten and Jamson (2011) present the discussion, that validation studies have concentrated on mid-level and top-end simulators and no standard evaluation tests have yet been presented.

The main purpose of driving simulators, if no other perspective in research is taken, is to be a re-enactment of reality. As driving simulators have become more frequently used in research, the question of validity has gained more interest. The word ‘validate’ is defined by the Collins English Dictionary as “to give legal force or official confirmation.” The Oxford English Dictionary refers to validity as a “Value of worth; efficacy.”

Topics addressed such as differences between real-world driving and simulators and the concepts of validity are discussed in the next paragraphs. Other academic publications considering driving simulator validity are also reviewed.

4.1 Assessing validity

In psychology validity is referred to as consistency; “the measuring device is measuring what it’s supposed to measure” (Coolican, 2009, p. 36). Blana (1996) also notes the importance to test the validity of a simulator as more critical than simulator reliability which can include each of the simulator’s subsystems, for example; a half working braking system gives consistent results but not the correct ones, the braking system will be reliable but not valid.

Driving simulator evaluation is separated by Blana (1996) into three stages: the transferability of the results obtained from a driving simulator to real world, the reliability of a driving simulator and the validity of a driving simulator. Blana (1996, p. 17) states on driving simulator validation criteria:

> "If the results are primarily concerned with driver behaviour and transferability of driving behaviour to real world then we are referring to the internal and external validity criteria; if they are primarily concerned with driver performance and performance differences between the two environments then we are referring to the relative and absolute validity criteria."

Such validation criteria in driving simulator studies suggested by Blana (1996) is further discussed in Reimer, D'ambrosio, Coughlin, Kafrissen and Biederman (2006) who state that the issue of validity is rarely addressed and that there is a lack of consensus on the vocabulary; social scientists distinguish measurement, internal and external validity while driving simulator literature discusses absolute and relative validity of behavioral validity.

Kaptein, Theeuwes and van der Horst (1996) note that the main goal of a driving simulator in behavioral research purposes is to measure what it is supposed to measure; a specific task or behavior under research. To measure driving simulator validity Carsten and Jamson (2011) present two common distinctions in research; physical and behavioral validity as well as absolute and relative validity. Physical validity, also referred to as simulator 'fidelity', is used to describe the simulators similarity to the real-world components. The physical validity is argued to be defined mostly by costs (Rudin-Brown, Williamson & Lenne, 2009). Physical and behavioral validity are described by Carsten and Jamson (2011, p. 93):

> "Physical validity refers to the physical components and subsystems of a simulator, whereas behavioral validity refers to how close the experience of the participants and the driving elicited approximates that in a real vehicle on real roads."

Although a high level physical validity, such as a high-end motion platform simulator, is presumed to offer an authentic driving experience, the behavioral validity might as well be achieved with a low-end fixed base simulator. Behavioral validity can comprise basic levels of driving performance such as speed and lateral position (Carsten & Jamson, 2011). When parameters such as above are extracted the two conditions of simulation and real-world can be compared.

The most effective method to assess driving simulator validity is to compare in as similar as possible tasks how the driver manages in the simulator versus the real-world driving performance. The comparison of virtual and natural driving environments creates two previously mentioned validities: relative and absolute. (Rudin-Brown, Williamson & Lenne, 2009 refering to Blaauw, 1982).

Absolute and relative validity have been discussed in Blaauw (1982) and Kaptein et al. (1996) who state that when performance differences between experimental conditions in the simulator are compared with similar conditions on road, the same order and direction of the differences in both systems enables relative validity. Absolute validity can be defined if numerical values are about equal in both systems. Blana (1996) describes relative validity as a qualitative criterion and absolute validity as a quantitative criterion that should be used mainly when investigating driving tasks on the control level (being less complicated), and that the internal and external validity should be used when investigating driver behavior on the tactical and strategic level (referring to driver problem solving, see Chapter 2.1. and FIGURE 2, Michon, 1985).

4.2 A critical view of driving simulator validity

The question of whether driving simulators are able to create a genuine feeling of driving has been discussed. The ability to learn to operate the driving simulator has also been questioned. Ranney (1994) refers to McKenna, Duncan and Brown (1986) on individual differences reflected by general intelligence contributing to driving simulator research results.

According to Carsten and Jamson (2011) a strong argument for and against simulators comes from Evans (1991), who argues that driving simulators are a suitable research method when driver performance, consisting of driver capabilities and skills is investigated. On the other hand, Evans states that what the driver actually does cannot be investigated in the driving simulator. Evans also discards the use of laboratory and instrumented vehicle studies. Evans considers that a realistic driving scenario in the real-world and in the simulator would be unlikely to be repeated in driving research conditions, as the artificiality of the experiment environment would not reflect real driving situations. Thirdly Evans questions the lack of danger as a noticeable problem.

Blana (1996) discusses that although the majority of previous researches assumes that drivers behave in the simulator as they do in the real world; there are still concerns such as Allen, Mitchell, Stein and Hogue (1991) addressing possible problems in the “operator motivation” and how the data is recorded in the natural environment. Blana (1996) continues to outline the problem of the accuracy of the real road data recorded depending and varying on the method used, controlled experiment conditions (instrumented vehicle, real road or test track) and uncontrolled observation conditions (realistic road user behavior, e.g. observation from video). At the same time Blana (1996) makes a distinction between the use of instrumented vehicles and test tracks and genuine road user data, as the first mentioned is criticized as an artificial environment and the later mentioned lacking previous research and comparison studies.

4.3 On-road comparison studies

According to Blana (1996) driving simulator behavioral validation studies began after 1980 when the development of powerful workstations and computer graphics advanced. One of the first studies of this era was Blaauw 's (1982) experiment on driving experience and task demands in a simulator and an instrumented vehicle on a real road.

The Blaauw's (1982) study results concluded in the first of the two questions on task difficulty, required attention and monotony that all drivers (inexperienced and experienced) rated the simulator more unfavorable. The second question concerning the simulator realism confirmed that higher task difficulties were found in the simulator. Data comparison of the simulator and the instrumented vehicle concluded that smaller standard deviation of lateral position, yaw rate and steering wheel angel was found by the experienced drivers (greater in the simulator than in real road). Good relative and absolute validity were proposed for longitudinal vehicle control but only relative for lateral control. A similar experiment was reconstructed by Kappe and Körteling (1995) and no differences between inexperienced and experienced drivers were found in lane keeping in natural and virtual conditions.

More recent research on simulator validity was conducted by Wang, Mehler, Reimer, Lammers, D'Ambrosio and Coughlin (2010) who studied driver interaction with the in-vehicle information system (IVIS) using three different manual address entry methods. One group of participants drove on-road and another separate group in a medium fidelity, fixed-base driving simulator. Both groups had similar test protocols. Eye tracking data of glance frequency, total glance duration and percent of time spend looking forward presented almost identical data in simulator and field. Also the initial response time and mean task time presented similar results.

Relative and absolute validity was found on different levels at De Winter, de Groota, Mulder, Wieringaa, Dankelmana and Mulder (2009) study as medium-fidelity fixed-base simulator data from learner drivers (N=804) who had not taken lessons in a real car was analyzed. There was an average of six months period between the simulator drive and the driving test. There were two significant findings. First the results suggested that fewer steering errors correspond with higher chance of passing the driving test on the first attempt. Secondly fewer steering errors, fewer violations and faster task execution corresponded to a shorter required training time.

5 METHOD

5.1 Experiment procedures

Each participant (*N* = 18) completed three driving experiments between October 2012 and February 2013. At the beginning of the experiments all participants drove one practice run in the driving simulator. After the practice run participants drove either in the driving simulator or in the traffic, one drive each. The driving orders were counterbalanced in the way that half of the participants in both driving groups (novice and experienced) drove first in the simulator and the other half first on the real road (APPENDIX 8).

5.1.1 Driving scenario design

The driving simulator tasks (two different tasks in two different maps) were also counterbalanced as presented in the APPENDIX 8. The map Mlaakso contained motorway driving with merging and exiting scenarios and the City map offered downtown driving with roundabouts and numerous intersections, one-way streets and traffic lights. The real-world driving scenario was a combination of these two virtual maps including motorway and city driving. Route planning was done in cooperation with a driving instructor. TABLE 1 presents more detailed information and comparison between the driving simulator and real-world driving scenarios.

Each driving simulator scenario was marked with a trigger in the driving scenario design phase as presented in FIGURE 6. The triggers were indicated in the software by marking the start and the end point of each scenario. Instructions of turning direction were given during start triggers of corner or motorway merging. Motorway and city straight triggers were marked between the end and start trigger of two consecutive corners.

TABLE 1 Real-world traffic and driving simulator Mlaakso and City driving scenarios

Driving scenario	Real-world traffic	Simulator: City	Simulator: Mlaakso	Simulator: Overall
Right turn	14	8	3	11
Left turn	5	12	4	16
Merging to motorway	4	0	4	4
Exiting from motorway	3	0	4	4
Straight	20	16	4	20
Roundabout	1	2	0	2
SUM	47	38	19	57
SUM (turns)	19	20	7	27
SUM (motorway)	7	0	8	8

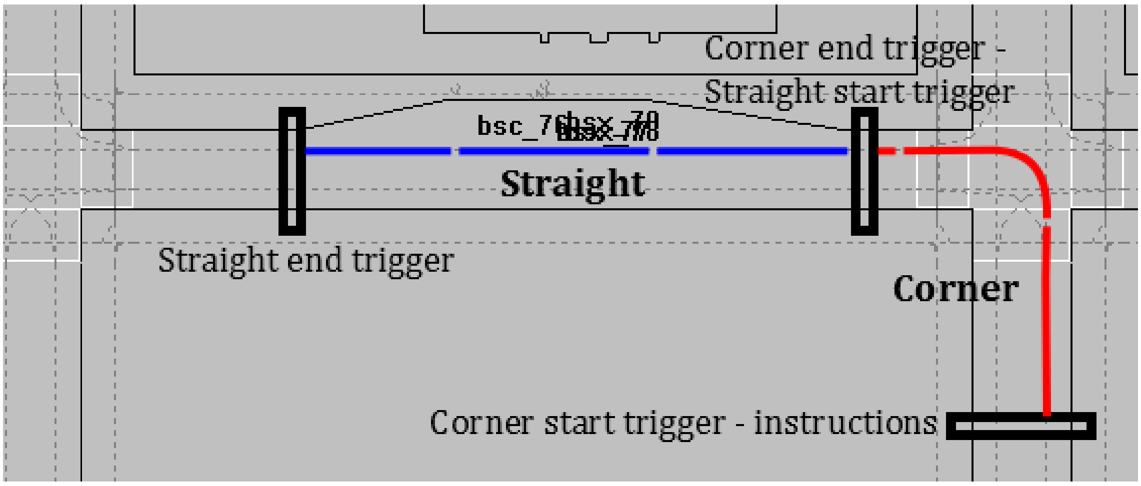


FIGURE 6 Example of corner and straight start and end triggers.

5.1.2 Driving simulator practice run

A driving simulator practice run was conducted first. Participants were interviewed before and after the experiments for their background information and feelings towards the simulator. Data was not collected or used from this phase. The practice phase's main purpose was for the participant to get familiar with the driving simulator environment and its controlling systems.

The second purpose was to find out whether participants might have simulator sickness symptoms that could prevent participating in the experiments. Previous research has indicated that virtual driving environments might cause simulator sickness such as general discomfort, vision or eye problems and digestion symptoms that could negatively affect experiment outcomes (Johnson, 2005; Kolasinski, 1995; Kennedy, Lane, Berbaum & Lilienthal, 1993).

5.1.3 Driving simulator experiment

Driving simulator experiments were guided and supervised by the research assistant. From these experiments data was collected of two different driving scenarios each of which included approximately 15 minutes of driving on a guided road.

The first of the two virtual routes of motorway driving named Mlaakso is based on a real-world place in South Finland called Martinlaakso (FIGURE 7). The second is a fictional city environment (FIGURE 8). Both FIGURES 7 and 8 include start, finish and turning direction markings (indicated with dots and arrows) as well as corner numbers in red (such as S5).

Computer aided navigation was used to guide the participant through the driving route using Finnish language auditory instruction and a green arrow visual instruction. The City map also included an additional blue background traffic signs, with a white capital letters "REITTI" (Eng. route), that indicated the driving direction.

The research assistant monitored the experiments and marked in the driving log any possible errors, problems or traffic rule violations during the experiment that would not appear in the driving data (APPENDIX 9). The simulator experiment was also recorded with a High Definition video camera to help track down unclear situations later on.

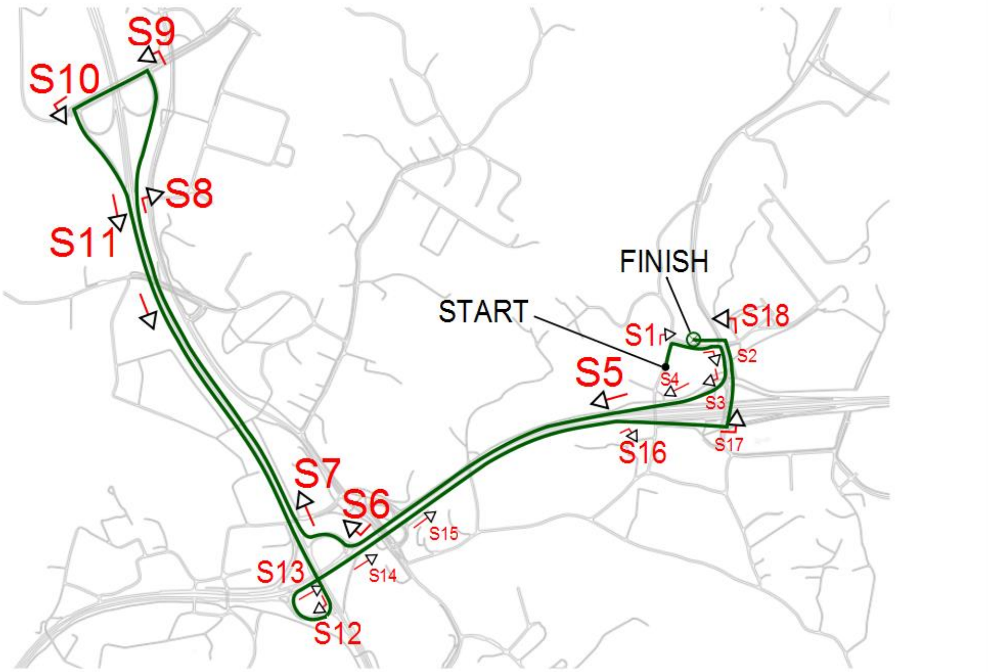


FIGURE 7 Driving simulator map Mlaakso (Ratti_Requirements_D3 3-Route_Final)

The Mlaakso map drive route represented common Finnish motorway sections. The motorway consisted of two driving lanes in each direction. The Mlaakso map drive route has four motorway sections and a similar amount of merging and exiting lanes to join or exit the motorway.

The City map also had common characteristics of Finnish city streets. The map consisted of eight right and twelve left turn intersections and sixteen straights. The straights were a combination of two- and one-way streets with one or two lanes.

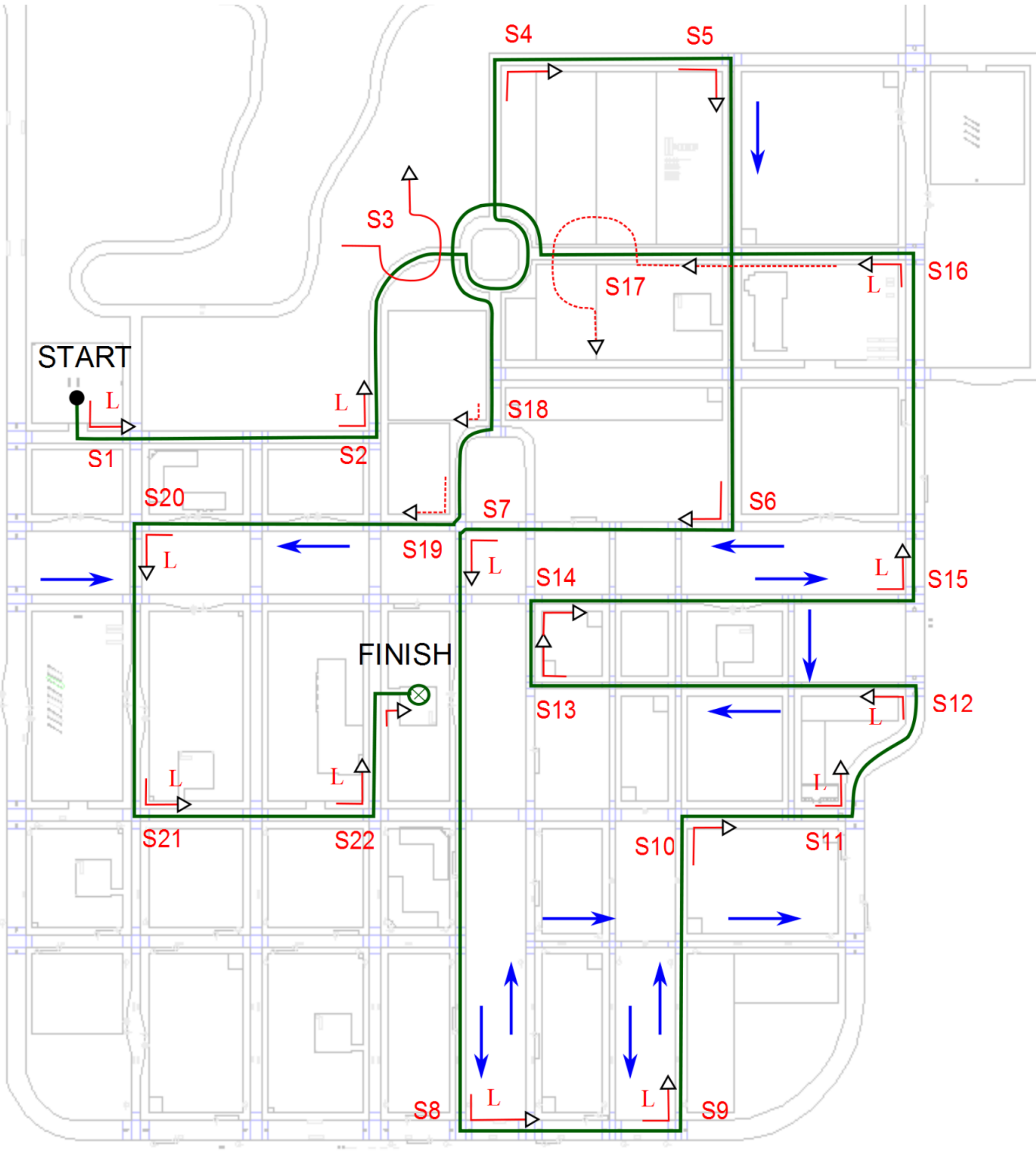


FIGURE 8 Driving simulator map City (Ratti_Requirements_D3 3-Route_Final)

5.1.4 Real-world traffic experiment

The driving scenario in the natural environment was designed as closely as possible to the driving simulator scenarios of the motorway and the city. FIGURE 9 presents the real-world driving route consisting of half motorway (sections S4 to S10 and S12 to S16) and half city (sections Start to S3 and S16 to Finnish) driving.

The traffic experiment was instructed and monitored by a highly experienced driving instructor from the company Suomen Ajokykyarvioinnit Oy (Eng. Finnish driving ability evaluations) that educates other driving instructors and works as a consultant for the Jyväskylä Aikuisopisto (engl. Jyväskylä Educational Consortium).

While driving in natural conditions, participants were considered responsible drivers. The driving direction for the participants was given by the driving instructor. Before the driving experiment participants evaluated their own driving skills and style by filling in the “Assessment of one’s own driving skill before the driving test” segment from the Finnish Transport Safety Agency Trafi’s E101 (Trafi.fi). The assessment was done on a scale from 1 to 5 where the number one refers to poor and the number five to excellent driving performance (Trafi.fi). This study used the new and modified version of the Trafi’s E101 form that was launched at the beginning of the year 2013 (Trafi, 2013).

During the on-road evaluation the driving instructor completed the E101 form’s evaluation segments of operational situations and basic skills for possible errors, conflicts or good performance. After the experiment, the driving instructor evaluated participants’ driving performance by using the E101 form segment “Driving test assessment table” (driving test inspector part of the form) which was similar (same scale from 1 to 5) as the one that participants filled in before the drive. Finally the driving instructor gave a short feedback of the drive to the participant.

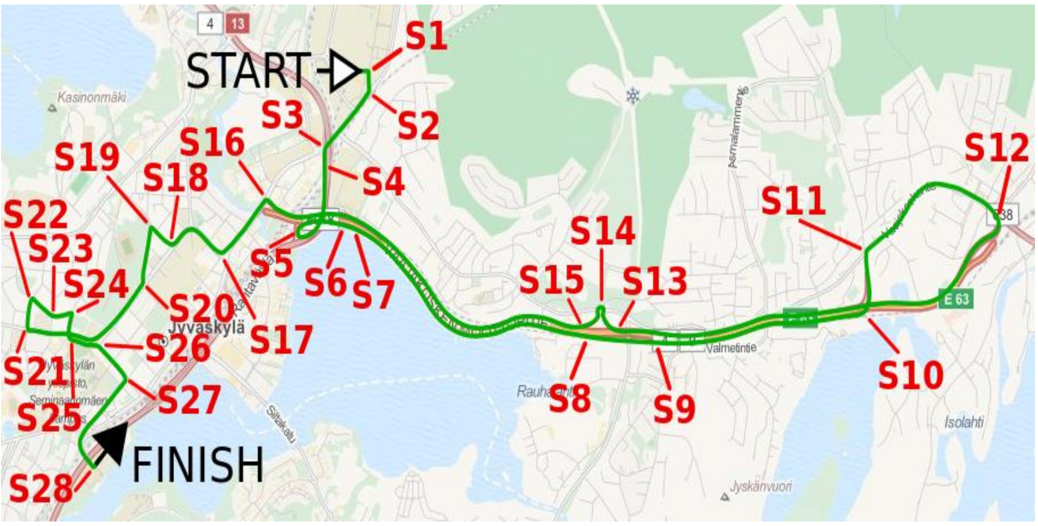


FIGURE 9 Driving route in real-world traffic (OpenStreetMap).

5.2 Equipment

At the University of Jyväskylä Department of Computer Science and Information Systems the fixed base driving simulator was used in the experiments (FIGURE 10). The simulator is built on a static platform and its physical main frame consists of two doors and a dashboard. A Logitech G25 steering wheel and pedals were used as a controlling device and the transmission was automatic. A Volvo V60 was used in the on-road evaluation; the vehicle was operated with manual transmission.

The driving simulator software was delivered by the Finnish software company Eepsoft Oy that provides high-end vehicle simulators for educational and entertainment use. Picture comparisons of six virtual and natural environment driving scenarios are presented in FIGURE 11. Eepsoft developed the software to meet the RATTI-project´s requirements such as driving scenarios and participant route guidance.

The eye movements were also measured during the driving experiments in the simulator and in the natural driving conditions using the iViewX HED 4 device made by SensoMotoric Instruments (SMI). The HED 4 device is a mobile head-mounted eye- and gaze tracking device with eye- and scene camera (FIGURE 12).

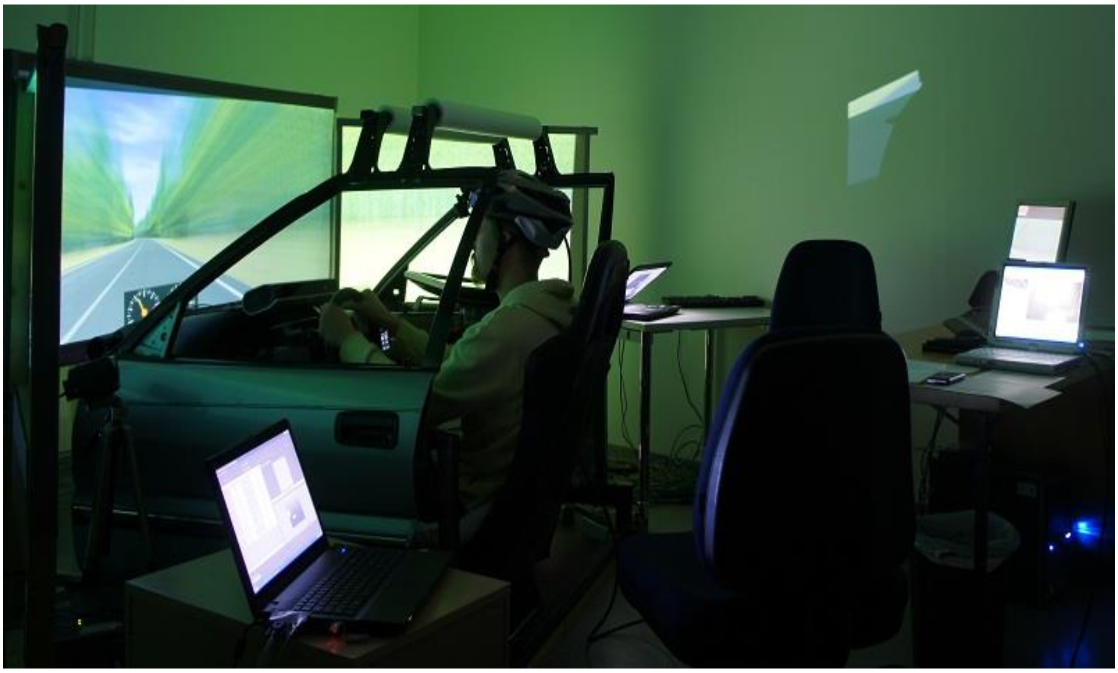


FIGURE 10 Participant driving the University of Jyväskylä Department of Computer Science and Information Systems fixed base driving simulator.

FIGURE 11 Comparison pictures of 1 to 6 from the virtual and natural environments

FIGURE 12 SMI iViewX HED 4 device installed in a helmet.

5.3 Variables

Dependent variables of driving speed, steering wheel input, longitudinal acceleration and lateral acceleration were collected from the driving simulator at 10 Hz frequency. Participant driving was evaluated in traffic by the driving instructor and also in the simulator by the research assistant. Additionally participants filled in questionnaires concerning their cognitive workload and estimating their level of success in the tasks.

TABLE 2 below presents the main dependent variables between the two experiments in traffic and driving simulation. The TABLE 3 below presents a complete list of the analyzed driving simulator variables. The "Driver performance evaluation" questionnaires used in the experiments are presented in chapter 5.3.4 "Driver performance evaluation & questionnaires".

TABLE 2 Dependent variables of driving simulator and traffic experiments.

Variables / Experiment	Eye Movements	Driving speed	Steering wheel input	Longitudinal acceleration	Lateral acceleration	Driver performance evaluation
Driving simulator	X	X	X	X	X	X (Driving log)
Traffic	X					X (Trafi E101)

TABLE 3 Analyzed driving simulator variables

Outcome variables of driving performance
Mean speed
Speed standard deviation
Speed violations
Speed violations in seconds
Rapid steering wheel movements (>=20 degrees)
Total time (between the start and end trigger)
Longitudinal acceleration
Lateral acceleration
Longitudinal acceleration maximum value
Lateral acceleration maximum value
Longitudinal acceleration minimum value
Lateral acceleration minimum value
Longitudinal acceleration standard deviation
Lateral acceleration standard deviation
Lateral velocity
Wheel rotation standard deviation

5.3.1 Eye movements

Eye movements were collected from the natural and virtual environments. The SMI eye tracker provides data from eye fixations and saccades. The eye movement data was not a part of the original requirements for the project and the results will be evaluated later.

5.3.2 Driving speed and longitudinal acceleration

A driving speed mean value was calculated from the driving simulator data and the vehicle's longitudinal acceleration was also monitored and saved for further evaluation.

5.3.3 Steering wheel input and Lateral acceleration

To get an indication on how the participants position their car on the road, the steering wheel input from the driving simulator data was extracted. The number of rapid steering wheel movements (>=20-degrees) per second was determined (Jamson & Merat 2005). The simulator car's lateral acceleration and steering wheel standard deviation were also measured.

5.3.4 Driver performance evaluation and questionnaires

At the first experiment the participant answered two questionnaires, first in the Ajokysely (engl. Driving questionnaire, APPENDIX 4) to gather background information and secondly the Drive Behaviour Questionnaire (DBQ) (Reason, 1990; Parker, Reason, Manstead & Strad-ling, 1995; Mesken, Lajunen & Summala, 2002) (APPENDIX 5).

Participants' driving assessment in the natural environment was done by the driving instructor using the Trafi's E101 form. In the driving simulator, the research assistant used a simple driving log when evaluating the participants' driving (APPENDIX 9).

After the on-road and two driving simulator drives, participants' subjective self-evaluation was asked using two questionnaires the first of which was used was the Visual Analogue Scale (VAS) -questionnaire (APPENDIX 6). Using the VAS, participants marked a vertical line to the 100 mm lateral line to describe how well they thought they performed (Aitken, 1969; Bond & Lader, 1974; Gould, 2001). Participants answered the Visual Analogue Scale (VAS) question: "How well do you think you performed in the driving task?" The second post questionnaire was the NASA Task Load Index (TLX) to measure the perceived work load during the tasks (Hart & Staveland, 1988; Hart, 2006; Nasa TLX) (APPENDIX 7). The NASA-TLX perceived mean workload score was calculated for each task ranging from 1 to 100. The workload is firstly compared in a between-subjects design between driving groups of novice and experienced drivers and secondly in a within-subjects design between the driving simulator and real-world traffic tasks.

5.4 Participants

Twenty drivers participated in the research; final results included data and results of eighteen (*N* = 18) participants. Participant recruiting was done through Jyväskylä Aikuisopisto (engl. Educational Consortium), JAMK University of Applied Sciences, the University of Jyväskylä student organizations' mailing lists, driving school Koljander Oy and Suomen Ajokykyarvioinnit Oy.

The participants were divided into two driving groups, novice drivers (TABLE 4, participant code 'N') and experienced drivers (TABLE 5, participant code 'E'). Participants' age and gender were balanced in the sample.

Novice driver (N) was defined as a person that has completed the Finnish driving school systems basic phase 1, has not participated in the phase 2 and has a driving experience of less than 5,000 kilometers overall. An experienced driver (E) was considered having a driving experience of at least five years and driving a minimum of 10,000 kilometers per year.

TABLE 4 Novice drivers background information.

Novice (participant code)	Gender	Age	Driving experience (months)	km overall
N1	F	20	11	150
N2	F	21	4	900
N3	F	19	2	500
N4		Data not collected		
N5	F	32	6	4900
N6	M	20	12	1000
N7	M	18	2	3000
N8	M	18	5	4900
N9	M	18	9	4000
N10	M	18	3	3000
Mean		*20*	*6*	*2483*

TABLE 5 Experienced drivers background information.

Experienced (participant code)	Gender	Age	Driving experience (months)	km overall
E1	F	34	120	200000
E2	Data not collected			
E3	M	37	228	300000
E4	M	23	60	150000
E5	F	35	204	300000
E6	M	25	84	100000
E7	M	23	60	100000
E8	M	41	216	500000
E9	F	29	132	200000
E10	F	48	360	240000
Mean		*33*	*163*	*232222*

5.5 Driving simulator data analysis

After each simulator drive the participant driving data was saved. For the data analysis, three different driving scenarios presented in TABLE 6 were selected from the City (left turn, right turn and straight) and Mlaakso (merging, exiting and straight). Overall 33 different driving scenarios were analyzed from the 57 available (58 percent) with 21 out of 38 in the City map (55 percent) and 12 out of 19 in the Mlaakso map (63 percent).

The collected data was extracted in a table format and analyzed using a Java code that calculated the variable values separately from each different scenario using the triggers as indicators when the scenario starts and ends (as explained in the chapter 5.1.1. “Driving scenario design”).

The main reason to limit the calculated scenarios was the available time and the computer calculating power as the data mining from the tables was time consuming.

TABLE 6 Analyzed scenarios from City and Mlaakso maps

Scenario number	Scenario name	Map	Scenario explained
1	cl	City	Intersection left turn
2	cr	City	Intersection right turn
3	cs	City	Straight forward driving
4	me	Mlaakso	Exiting motorway
5	mm	Mlaakso	Merging motorway
6	ms	Mlaakso	Straight forward driving

5.5.1 Analyzed driving scenarios in the City map

Seven corner and straight scenarios from the city map were chosen for the analysis. Overall 7 of the 12 left turns (58 percent), 7 of the 8 right turns (88 percent) and 7 of the 16 straights (44 percent) scenarios available were analyzed (TABLE 7).

TABLE 7 Analyzed City scenarios

Analyzed scenarios City					
Left turn		Right turn		Straight driving	
SN	corner(s)	SN	corner(s)	SN	corner(s)
1	S7	2	S4	3	S4-S5
1	S8	2	S5	3	S5-S6
1	S11	2	S6	3	S6-S7
1	S12	2	S10	3	S7-S8
1	S15	2	S13	3	S10-S11
1	S16	2	S14	3	S12-S13
1	S20	2	S19	3	S15-S16
Overall 7/12		Overall 7/8		Overall 7/16	

The City map left and right corners were analyzed and grouped to get different turning scenarios for the analysis. Intersection types and corner numbers for left turns are presented in TABLE 8 and right turns in TABLE 9.

TABLE 8 City map left turns selected for the analysis

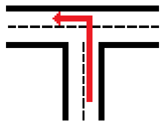
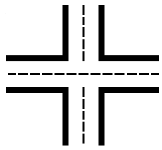
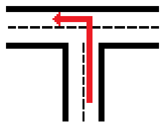
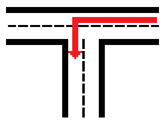
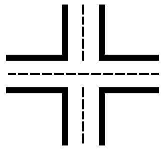
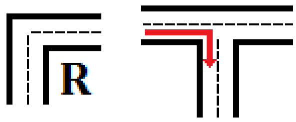
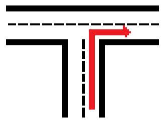
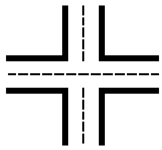
Left turns		
Corner number	Intersection/Corner type	Picture
S8 (first analysis)	T-Intersection	
S7 & S20	Intersection	
S11 & S15	T-Intersection	
S12 & S16	T-Intersection	

TABLE 9 City map right turns selected for the analysis.

Right turns		
Corner number	Intersection/Corner type	Picture
S19	T-Intersection	
S4 & S5	T-Intersection	
S6 & S13	Intersection	
S10 & S14	T-Intersection	

5.5.2 Analyzed driving scenarios in the Mlaakso map

From the Mlaakso map driving scenarios, four scenarios were chosen for the analysis: motorway exiting, motorway merging and motorway straight scenarios (100 percent overall) (TABLE 10).

TABLE 10 Analyzed Mlaakso driving scenarios

Analyzed scenarios Mlaakso					
Exiting motorway		Merging motorway		Straight Driving	
SN	corner(s)	SN	corner(s)	SN	corner(s)
4	S6	5	S5	6	S5-S6
4	S8	5	S7	6	S7-S8
4	S12	5	S11	6	S11-S12
4	S16	5	S13	6	S13-S16
Overall 4/4		Overall 4/4		Overall 4/4	

6 RESULTS

6.1 Participant background information – questionnaires

Participant background information was gathered using two questionnaires. First questionnaire gathered information about driving locations, such as type of road driven. Secondly a Driver Behavior Questionnaire was used to find out more about the participants driving habits.

6.1.1 Driving questionnaire

Driving questionnaire (Ajokysely, APPENDIX 4) purpose was to gather background information on where the participants drove and how often. The questionnaire also included questions about driving fatigue, possible medication and the amount of car crashes. All the participants reported to have slept 7 or more hours before taking the experiment and only one participant had taken aspirin to her mild headache.

The driving questionnaire qualitative analysis presented that the experienced drivers drove more often (FIGURE 13) and used frequently different kinds of roads such as city, motorway, highway and village roads (FIGURE 14 - 17). All the experienced drivers drove “every day or almost every day” (six out of nine) or “3-5 days a week” (three out of nine). Three novice drivers out of nine drove “every day or almost every day” and one “3-5 days a week” as three drove “1-2 days a week” and two “less than once a month”.

Only one experienced driver had never been in an accident as the rest of the experienced drivers had driven at least one accident and four of them two accidents. Only one novice driver had been in an accident (FIGURE 20).

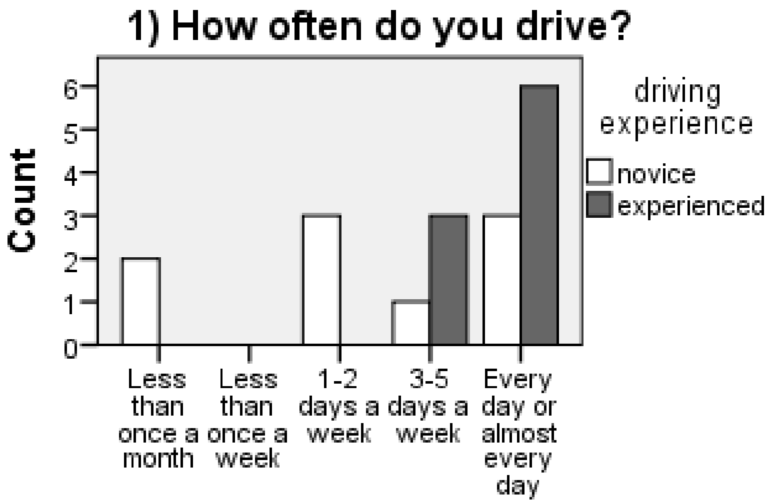


FIGURE 13 Driving questionnaire 1) How often do you drive?

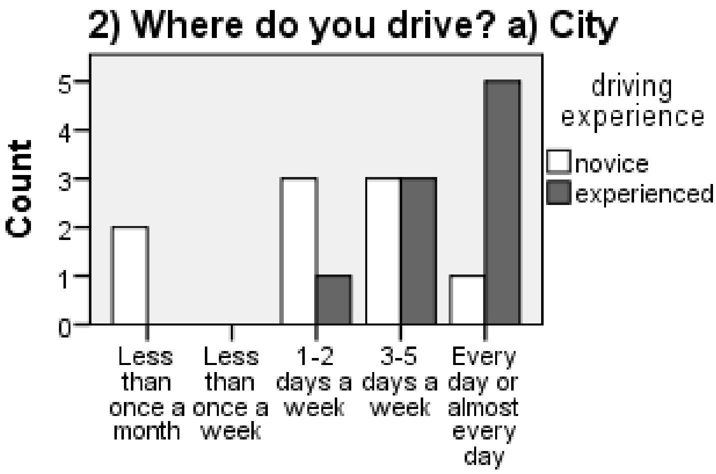


FIGURE 14 Driving questionnaire 2) Where do you drive? a) City

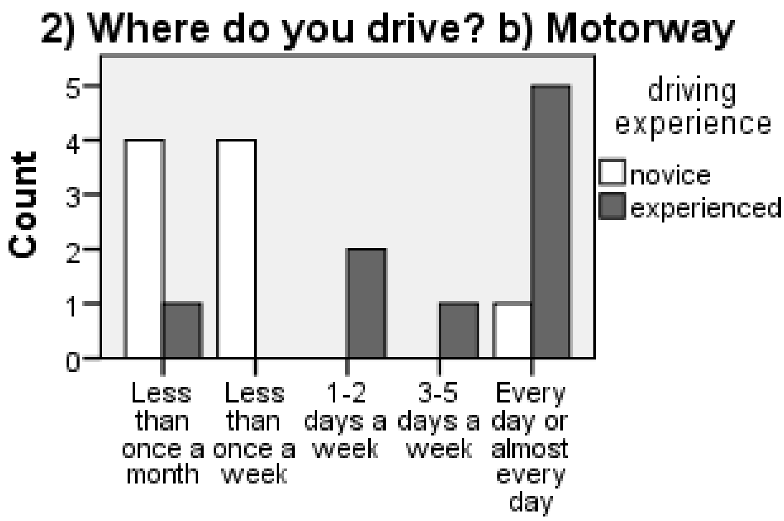


FIGURE 15 Driving questionnaire 2) Where do you drive? b) Motorway

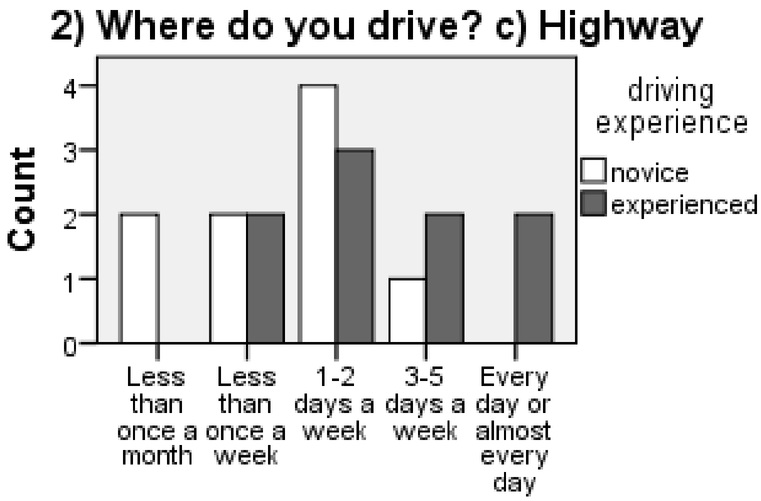


FIGURE 16 Driving questionnaire 2) Where do you drive? c) Highway

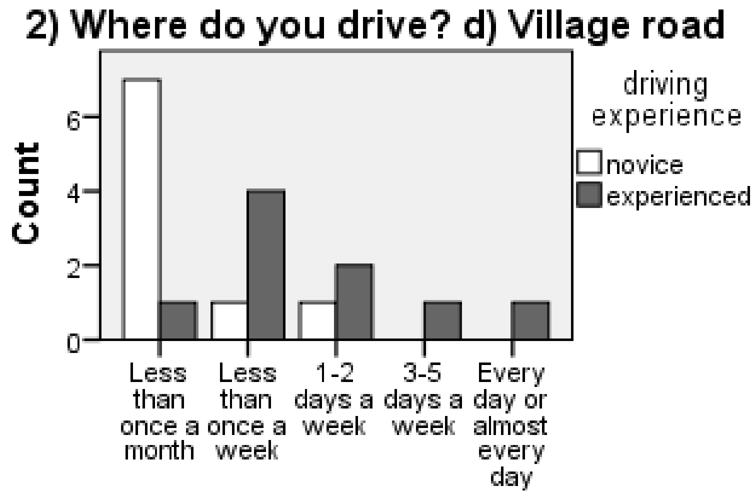


FIGURE 17 Driving questionnaire 2) Where do you drive? d) Village road

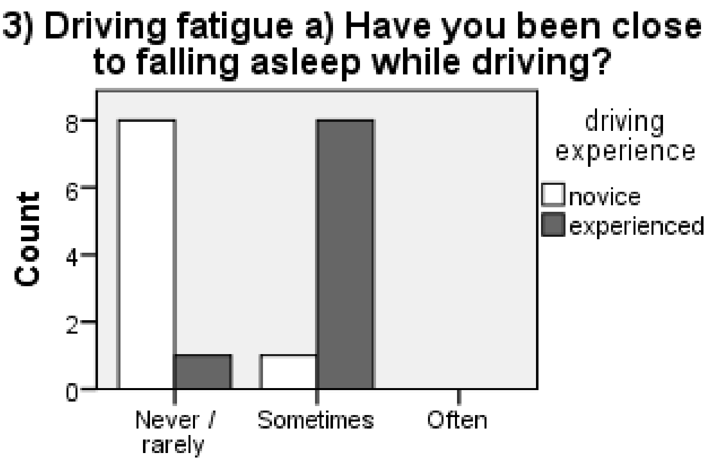


FIGURE 18 Driving questionnaire 3) Driving fatigue a) Have you been close to falling asleep while driving?

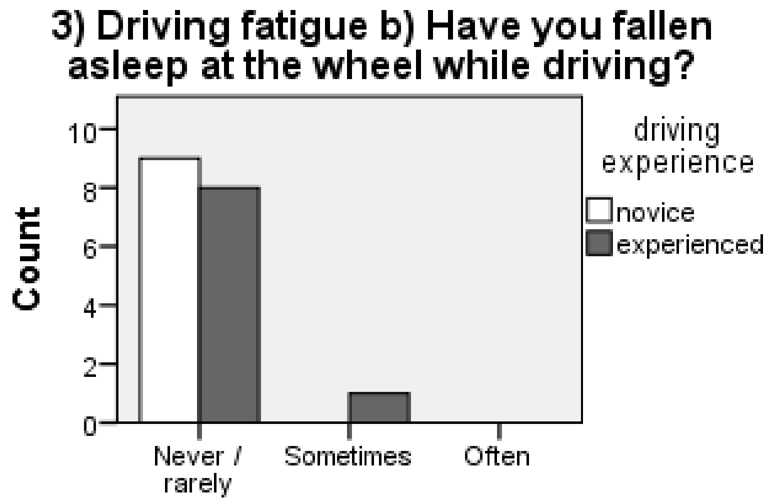


FIGURE 19 Driving questionnaire 3) Driving fatigue b) Have you fallen asleep while driving?

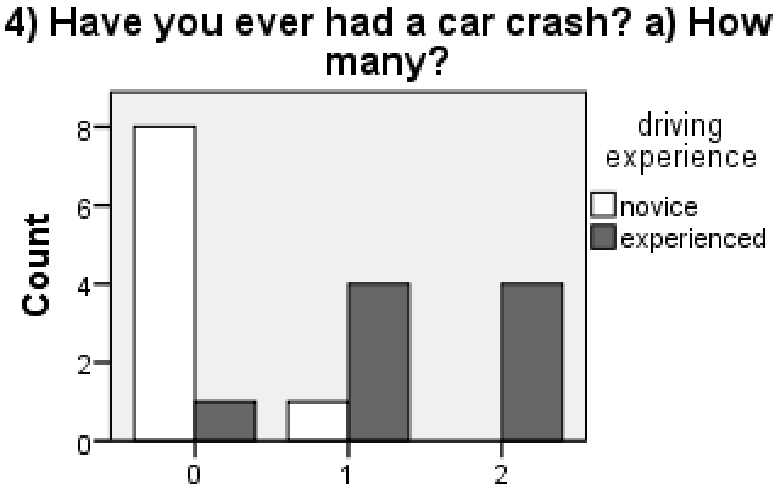


FIGURE 20 Driving questionnaire 4) Have you ever had a car crash? a) How many?

6.1.2 Driver Behaviour Questionnaire

The Driving Behavior Questionnaire's (DBQ) 28-item Finnish language translation version was used to collect information of the participants' behavior behind the wheel (Reason, 1990; Parker ym., 1995; Mesken, Lajunen & Summala, 2002). Analyses were conducted using the four-factor solutions referred by Lajunen et al. (2004) and Mattsson (2012). The four factors were Aggressive violations, Ordinary violations, Slips and Lapses (Mattsson, 2012). The analyses were carried by using the Mann-Whitney U test. The DBQ answer scale is from 0 to 5 where 0 is "never" and 5 is "very often".

The statistical analyses revealed that the driver groups differed from each other in terms of aggressive violations and ordinary violations. In case of aggressive violations, the median was higher (2) for the experienced drivers than the novice drivers (0) (U = 66, z = 2,352 and p = 0.024). The same held true for the ordinary violations (novice drivers: median = 7; experienced drivers (median = 12) (U = 54, z= 2,394 and p = 0.016). The scores of slips and lapses presented no group differences.

6.2 Real-world traffic results

The real-world driving evaluation was conducted using the Trafi's E101 form. Two sections from the form were filled. At first the participants filled section "Assessment of one's own driving skill before the driving test" before each drive. The second section "Driving test assessment table" was filled by the driving instructor after the drive. Both assessments were from scale 1 to 5 where the number one refers to "poor" and the number five to "excellent".

Both of the two previously mentioned sections included five assessments for driver evaluation as presented in TABLE 11. Assessment number one "Having mastery over the vehicle" indicates the use of car's control devices and the driver's car handling abilities. Assessment number two "Showing consideration to cyclists and pedestrians" indicates how the driver notices pedestrians and obeys the traffic control. Assessment number three "Showing consideration to other traffic" indicates how the driver co-operates with other traffic and vehicles, for example keeping safety distance to the vehicle in front. Assessment number four "Foresight" indicates how the driver recognizes traffic situations and dangerous scenarios so that driving feels safe and consistent. Assessment number five "Having mastery over one's own condition" indicates how the driver is concentrated to the driving task and how independent and calmly s/he is driving even in more demanding traffic situations. (Trafi, 2013).

TABLE 11 Trafi E101 form for driver assessment.

Trafi E101 form explanations (Evaluation items 1 to 5 explained)
1. Having mastery over the vehicle (Ajoneuvon hallinta)
2. Showing consideration to cyclist and pedestrians (Kevyen liikenteen huomiointi)
3. Showing consideration to other traffic (Muun liikenteen huomiointi)
4. Foresight (Ennakointi)
5. Having mastery over one's own condition (Oman tilan hallinta)

6.2.1 Driving instructor's evaluation

The results of the driving instructor's evaluations based on the Trafi E101 form for the drive groups are shown in TABLE 12 and 13. When comparing separately the five assessment sections there were no statistically significant differences between the two driving groups as the Mann-Whitney test results are presented in TABLE 14. All participants are presented in rank order at TABLE 15.

TABLE 12 Driving instructor's evaluations for the novice drivers.

Participant	Evaluation item					
Novice (n=9)	1	2	3	4	5	Overall
N1	2	3	2	1	4	12
N2	3	4	3	2	3	15
N3	3	3	2	2	4	14
N5	3	3	2	2	3	13
N6	5	4	4	4	4	21
N7	5	3	3	2	4	17
N8	4	4	3	3	4	18
N9	5	5	4	3	5	22
N10	4	3	2	2	3	14
Overall	34	32	25	21	34	146
Mean	3,78	3,56	2,78	2,33	3,78	16,22

TABLE 13 Driving instructor's evaluations for the experienced drivers.

Participant	Evaluation item					
Experienced (n=9)	1	2	3	4	5	Overall
E1	3	4	3	2	4	16
E3	4	3	3	2	3	15
E4	5	4	5	5	5	24
E5	4	5	4	4	4	21
E6	4	4	3	3	4	18
E7	5	3	3	3	4	18
E8	5	4	4	3	5	21
E9	4	2	3	1	2	12
E10	3	2	2	1	2	10
Overall	37	31	30	24	33	155
Mean	4,11	3,44	3,33	2,67	3,67	17,22

TABLE 14. Driving instructor's evaluations broken down into the five factors of the Trafi E101 form for the novice vs. experienced drivers. The statistical tests are based on the Mann-Whitney U Test.

Assessment number	Explanation	*Mdn* =		*U* =	*z* =	*p* =
		E	N			
1	Control of vehicle	4.0	4.0	33.5	−0.649	.516
2	Pedestrians	4.0	3.0	41.5	0.094	.925
3	Other traffic	3.0	3.0	26.5	−.1.316	.188
4	Foresight	3.0	2.0	34.5	−0.553	.580
5	Own condition	4.0	4.0	40.5	0.000	1.000

TABLE 15 All drivers ranked in order of the quality of driving in the natural driving condition based on the driving instructor's evaluations.

Driving instructor evaluation - All Participants ranked

		Evaluation item					
	Participant	**1**	**2**	**3**	**4**	**5**	Overall
1	E4	5	4	5	5	5	24
2	N9	5	5	4	3	5	22
3	N6	5	4	4	4	4	21
4	E5	4	5	4	4	4	21
5	E8	5	4	4	3	5	21
6	N8	4	4	3	3	4	18
7	E6	4	4	3	3	4	18
8	E7	5	3	3	3	4	18
9	N7	5	3	3	2	4	17
10	E1	3	4	3	2	4	16
11	N2	3	4	3	2	3	15
12	E3	4	3	3	2	3	15
13	N3	3	3	2	2	4	14
14	N10	4	3	2	2	3	14
15	N5	3	3	2	2	3	13
16	N1	2	3	2	1	4	12
17	E9	4	2	3	1	2	12
18	E10	3	2	2	1	2	10
	Mean	3,94	3,50	3,06	2,50	3,72	**16,72**

6.2.2 Drivers' self-evaluations before driving in real traffic

TABLE 16 presents the novice drivers' (N = 9) and TABLE 17 the experienced drivers' (N = 9) self-evaluations given before the driving assessment in real traffic. The novice and experienced drivers estimated their driving skills quite similarly. No significant differences were found between the groups (TABLE 18). TABLE 19 presents all participants in rank order.

TABLE 16 Novice drivers's self-evaluations measured with the Trafi E101 form.

Participant	Evaluation item					
Novice (n=9)	1	2	3	4	5	Overall
N1	3	3	3	2	4	15
N2	4	4	4	3	3	18
N3	4	4	4	3	4	19
N5	3	4	4	4	4	19
N6	5	4	5	5	4	23
N7	4	3	4	3	4	18
N8	4	3	3	4	4	18
N9	4	4	4	4	4	20
N10	4	3	3	4	3	17
Overall	35	32	34	32	34	167
Mean	3,89	3,56	3,78	3,56	3,78	18,56

TABLE 17 Experienced drivers' self-evaluations measured with the Trafi E101 form.

Participant	Evaluation item					
Experienced (n=9)	1	2	3	4	5	Overall
E1	3	2	3	3	3	14
E3	4	5	3	4	4	20
E4	4	3	4	3	3	17
E5	4	5	4	4	3	20
E6	4	3	4	4	3	18
E7	4	4	4	4	4	20
E8	5	5	5	5	5	25
E9	4	3	3	3	4	17
E10	3	4	4	4	3	18
Overall	35	34	34	34	32	169
Mean	3,89	3,78	3,78	3,78	3,56	18,78

There were no statistically significant differences between the two driver groups when their self-assessments were compared separately in the five assessment factors of the Trafi E101 form (TABLE 18).

TABLE 18 Novice and experienced drivers' self-evaluations on the five factors of the Trafi E101 assessment form. The statistical results are based on the Mann-Whitney U Test.

Assessment number	Explanation	*Mdn* =		*U* =	*z* =	*p* =
		E	N			
1	Having mastery over the vehicle	4.0	4.0	40.5	0.000	1.000
2	Pedestrians	4.0	4.0	35.0	−0.518	.605
3	Other traffic	4.0	4.0	40.5	0.000	1.000
4	Foresight	4.0	4.0	35.0	−0.530	.596
5	Having mastery over one's own condition	3.0	4.0	50.5	1.005	.315

TABLE 19 All drivers ranked in order according to their self-evaluations.

	Evaluation item					
Participant	1	2	3	4	5	Overall
E8	5	5	5	5	5	25
N6	5	4	5	5	4	23
N9	4	4	4	4	4	20
E3	4	5	3	4	4	20
E5	4	5	4	4	3	20
E7	4	4	4	4	4	20
N3	4	4	4	3	4	19
N5	3	4	4	4	4	19
N2	4	4	4	3	3	18
N7	4	3	4	3	4	18
N8	4	3	3	4	4	18
E6	4	3	4	4	3	18
E10	3	4	4	4	3	18
N10	4	3	3	4	3	17
E4	4	3	4	3	3	17
E9	4	3	3	3	4	17
N1	3	3	3	2	4	15
E1	3	2	3	3	3	14
Mean	3,89	3,67	3,78	3,67	3,67	18,67

6.3 Driving simulator

6.3.1 Comparison between novice and experienced drivers in the virtual driving condition

A Mann-Whitney test was run to determine if there were difference in driving scenarios between the novice and experienced drivers. Only two outcome variables of the 34 compared, lateral acceleration maximum and longitudinal acceleration maximum in the City map straights, turned out to be significant (TABLES 20 and 21).

TABLE 20. Statistical comparisons between the novice and experienced drivers in three driving scenarios of the virtual city environment. The statistical results are based on the Mann-Whitney U-test. Table continues on next page.

Map	City					
Mean value of	Straight		Left turn		Right turns	
Speed	p=.605		p=1.000		p=.666	
Experienced	M=7,15	SD=1,55	M=4,55	SD=0,94	M=4,45	SD=0,97
Novice	M=7,31	SD=1,20	M=4,56	SD=0,94	M= 4,70	SD=0,68
Rapid steering wheel movement	p=.436		p=.730		p=.489	
Experienced	M=1,10	SD=,67	M=25,45	SD=3,39	M=20,89	SD=2,84
Novice	M=1,33	SD=1,38	M=26,49	SD=4,79	M=21,79	SD=2,06
Wheel standard deviation	p=.931		p=.190		p=.063	
Experienced	M=0,01	SD=0,003	M=,20	SD=,01	M=0,21	SD=0,02
Novice	M=0,01	SD=0,004	M=0,21	SD=0,03	M=0,22	SD=0,02
Longitudinal acceleration	p=.297		p=.436		p=.666	
Experienced	M=0,10	SD=0,09	M= −0,12	SD=0,05	M=4,45	SD=0,97
Novice	M=0,14	SD=0,09	M= −0,15	SD=0,06	M=4,70	SD=0,68
Continues on next p.						

TABLE 20 Continues			
Lateral acceleration	p=.730	p=.796	p=.931
Experienced	M= −0,02 SD=0,01	M=0,28 SD=0,09	M= −0,36 SD=0,14
Novice	M= −0,02 SD=0,01	M=0,26 SD=0,08	M= −0,37 SD=0,09
Lateral acceleration min	p=.489	p=.258	p=.863
Experienced	M= −0,52 SD=0,14	M= −1,50 SD=0,37	M= −3,19 SD=0,92
Novice	M= −0,49 SD=0,16	M= −1,33 SD=0,41	M= −3,23 SD=0,85
Longitudinal accel-eration min	p=.489	p=.796	p=.222
Experienced	M= −3,75 SD=1,20	M= −6,84 SD=1,36	M= −5,72 SD=1,68
Novice	M= −3,12 SD=1,15	M= −6,28 SD=0,57	M= −4,95 SD=0,95
Lateral acceleration max	p=.003**	p=.387	p=.222
Experienced	M=0,49 SD=0,10	M=3,58 SD=0,89	M=0,79 SD=0,14
Novice	M=0,34 SD=0,07	M=3,15 SD=0,65	M=0,68 SD=0,13
Longitudinal accel-eration max	p=.019*	p=.258	p=1. 000
Experienced	M=3,19 SD=0,71	M=3,04 SD=0,727	M=2,29 SD=1,00
Novice	M=4,01 SD=0,76	M=2,62 SD=0,59	M=2,15 SD=0,71

* p <= ,05 and ** p <= ,01

TABLE 21. Statistical comparisons between the novice and experienced drivers in three driving scenarios of the virtual motorway environment (Mlaakso). The statistical results are based on the Mann-Whitney U-test. Table continues on next page.

Map	Mlaakso					
Mean value of	Straight		Merging		Exiting	
Speed	p=.436		p=.222		p=.113	
Experienced	M=18,03	SD=1,91	M=9,51	SD=1,03	M=12,94	SD=3,06
Novice	M=17,00	SD=2,53	M=8,91	SD=1,73	M=10,72	SD=1,72
Rapid steering wheel movement	p=.258		p=.436		p=.258	
Experienced	M=1,92	SD=1,38	M=7,31	SD=3,04	M=4,11	SD=2,19
Novice	M=8,25	SD=17,58	M=9,92	SD=5,99	M=5,42	SD=3,01
Wheel standard deviation	p=.605		p=.436		p=.436	
Experienced	M=0,01	SD=0,003	M=0,05	SD=0,004	M=0,04	SD=0,01
Novice	M=0,02	SD=0,02	M=0,06	SD=0,03	M=0,04	SD=0,01
Longitudinal accel-eration	p=.340		p=.931		p=.190	
Experienced	M=0,08	SD=0,05	M=0,07	SD=0,11	M= −0,33	SD=0,21
Novice	M=0,05	SD=0,06	M=0,05	SD=0,05	M= −0,20	SD=0,07
Lateral acceleration	p=.730		p=.730		p=.190	
Experienced	M=0,03	SD=0,02	M= −0,36	SD=0,10	M= −0,33	SD=0,21
Novice	M=0,01	SD=0,06	M= −0,34	SD=0,06	M= −0,20	SD=0,07
Lateral acceleration min	p=.796		p=.931		p=.387	
Experienced	M= −1,77	SD=0,54	M= −2,17	SD=0,39	M= −2,50	SD=1,10
Novice	M= −1,69	SD=0,59	M= −2,11	SD=0,28	M= −2,03	SD=0,70
Continues on next p.						

TABLE 21 Continues						
Longitudinal acceleration min	p=.931		p=.340		p=.297	
Experienced	M= −5,04	SD=1,26	M= −4,82	SD=1,57	M= −5,41	SD=1,78
Novice	M= −5,09	SD=1,51	M= −3,99	SD=1,20	M= −5,98	SD=1,16
Lateral acceleration max	p=.931		p=.546		p=.436	
Experienced	M=1,60	SD=0,57	M=1,02	SD=0,35	M=1,27	SD=0,56
Novice	M=1,49	SD=0,54	M=1,02	SD=0,56	M=1,06	SD=0,46
Longitudinal acceleration max	p=.605		p=.222		p=.863	
Experienced	M=3,85	SD=0,63	M=3,69	SD=0,53	M=2,42	SD=1,05
Novice	M=4,05	SD=0,59	M=3,22	SD=0,87	M=2,58	SD=1,03

* p <= ,05 and ** p <= ,01

6.4 Correlations in driving performance between natural and virtual environments

A Spearman's rank-order correlation test was run to assess the relationship between the driving instructor's evaluations in real traffic and driving performance on the virtual driving scenarios.

A total of 31 outcomes of the driving simulator data correlated with the driving instructor's evaluations given in the real-world driving condition. These outcomes presented 13 different driving scenarios (TABLE 22). In case of the virtual city environment, driving performance on all three selected driving scenarios correlated with the driving instructor's evaluations. A total of four outcomes collected in the two straight road scenarios correlated with the driving instructor's evaluations. In case of the left turn corners, the number of the outcomes of driving performance that correlated had the highest number of correlation with total of four corners and 13 variables overall. Also one right turn corner correlated with one variable.

In the motorway section at the Mlaakso map, all nine outcomes of the four motorway straight scenarios correlated with the driving instructor's evaluations. In case of the four motorway merging scenarios, three outcomes extracted from two scenarios correlated with the quality of on-road driving. The only driving scenario type in motorway that did not present any significant correlation with on-road driving was the exiting motorway one.

TABLE 22. The number of the outcomes of driving performance in the two virtual traffic environments that correlate with the driving instructor's evaluations in real traffic.

City environment		Motorway environment	
2 straights (4 variables)		4 straights (9 variables)	
4 left corners (13 variables)		2 merging to motorway (3 variables)	
1 right corner (2 variables)		0 exiting to motorway	
7 scenarios	19 variables	6 scenarios	12 variables

The next chapters present more in detail these driving scenarios and the correlated variables. Corners, straights and motorway scenarios are presented in numerical order as they were driven during the experiments. The City map scenarios are presented first and the Mlaakso map motorway scenarios second in order. Each scenario analysis includes a scenario description, a figure presenting the driving scenario situation (Eepsoft Oy Exercise editor; also National Land Survey of Finland, 2012), Spearman's correlations results in a table, a short analysis of the correlations and a qualitative scenario analysis.

6.4.1 City straight between corners S6 and S7

The City straight between corners S6 and S7 has two t-intersections and no other traffic (FIGURE 21). Line changes were not required. Near end of the straight lane traffic lights start to blink yellow (indicating that they are not in use) when the driver gets in a close position. The instruction trigger to the next corner is given at the same time (end trigger and the end of straight and data recording).

A Spearman's rank-order correlation test was run and two outcomes correlated with the driving instructor's evaluations: rapid steering wheel movements and wheel rotation standard deviation (TABLE 23). These outcomes are related to each other as they both represent the vehicle steering wheel movements. The negative correlation coefficient indicates that the participants who made fewer steering wheel movements in the driving simulator performed better in the real-world driving condition.

Scenario qualitative analysis suggests that the straight itself indicated no additional reasons for steering wheel input. The right turn (S6) that has a right of way preceding the straight might have an effect. Because of slow traffic coming from the left and a wide visibility, the corner can be driven faster. There is also a bicycle coming from behind in the right corner. The bicycle catches the driver if corner approach is driven slowly. During the experiment one participant crashed and one almost crashed with the bicycle.

Faster speed in the following corner, bicycle affecting the positioning of the car, driving line during the right turn that leads to the straight; the combination of these may affect the results as the drivers that performed better in the driving instructor's evaluations took the preceding right corner more with ease and positioned the car better to the opening straight.

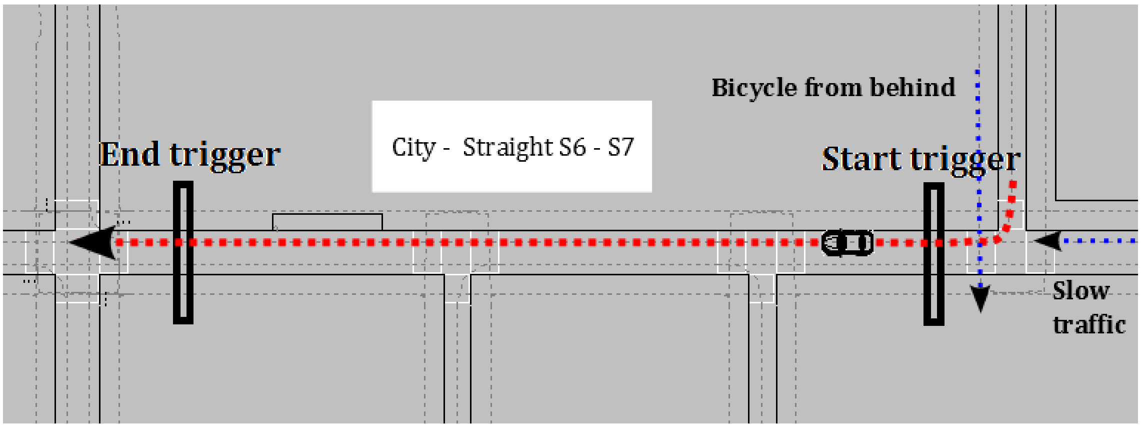


FIGURE 21 City straight S6 - S7 driving scenario (Eepsoft Oy, 2013)

TABLE 23 City straight S6 – S7 - Variables correlated with the driving instructor evaluations.

City straight S6 - S7			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Rapid steering wheel movements	18	$r_s(16) = -,530$	p = ,024
Wheel rotation standard deviation	18	$r_s(16) = -,586$	p = ,011

6.4.2 City left corner S8

The City S8 left corner is a T-intersection with two lanes on both ways (FIGURE 22). The corner approach is a two lane one-way street with a possibility to turn left from both lanes. In the middle of the corner three pedestrians cross the street through traffic island and have to be waited before completing the corner. There are two cars coming from both directions in the intersection. These cars are driving slowly and for the driver it seems clear to drive across the intersection.

A Spearman's rank-order correlation test revealed that the number of rapid steering wheel movements correlated with the driving instructor's evaluation (TABLE 24). The negative correlation indicates that a lower number of rapid steering wheel movements in the driving simulator were associated with a better score in the real-world traffic evaluation.

The qualitative analysis revealed that the outcome of rapid steering wheel movements can be divided into two cases: corner approach with a possible lane change and the execution of the corner while giving a way to pedestrians.

First, the lane changes were analyzed qualitatively (TABLE 25) and there were overall 11 lane changes between the novice (6 lane changes) and experienced drivers (5 lane changes). Both driving lanes were available for left turn but majority of the participants (11) chose to change the driving lane from right to left for turning. There were no other traffic and therefore no over takings. The corner preceding the straight that leads to the scenario S8 was also left corner and therefore some participants already were in the left lane. Participants had a long straight and time to choose a lane before given the corner S8 turning instructions. Three participants hesitate changing the lane before turning and canceled the decision while making a fast steering correction.

Second case was the corner execution where the participants had to wait pedestrians pass through the traffic island before continuing. For some participants the car positioning near the traffic island and keeping the car in the current driving lane proved difficult. If the car's position was too close to the traffic island, when stopped to wait the pedestrians, participant had to drive forward and correct the car not to go too deep for the other lane or not to hit the inside traffic island pavement.

The combination of these two cases may affect the results, as the drivers who performed better in the real-driving condition were consistent in the lane change and positioned their car better while executing the corner.

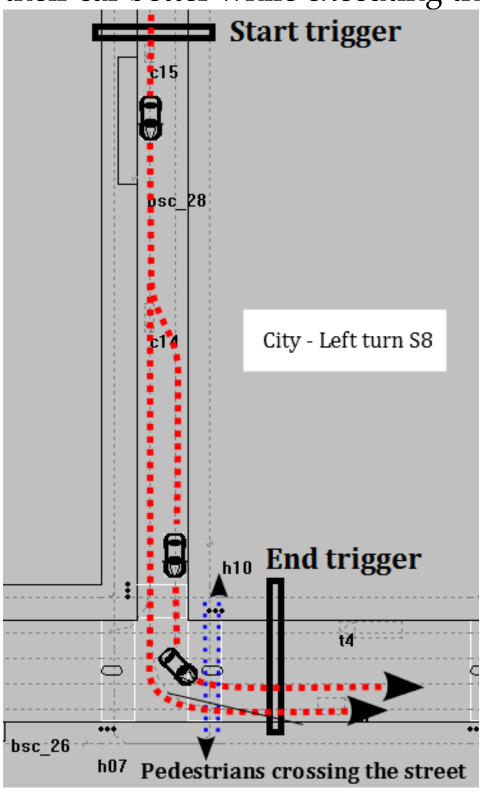


FIGURE 22 City left turn S8 driving scenario (Eepsoft Oy, 2013)

TABLE 24 City left turn S8 - Variables correlated with the driving instructor's evaluations.

City Left turn S8			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Rapid steering wheel movements	18	$r_s(16) = -,507$	$p = ,032$

TABLE 25 City Left turn S8 quantitative analysis

	lane changes	overtaking	number of cars
Overall	11	0	0
N	6	0	0
E	5	0	0
Mean	0.61	0	0

6.4.3 City right corner S10

The City right corner S10 is in the end of a one- way one lane street (FIGURE 23). The corner has a stop sign and a pedestrian and bicycle crossing the street. There are no other cars or traffic.

A Spearman's rank-order correlation test showed a correlation between two outcomes of the driving simulator condition and the results of the real-world driving condition (TABLE 26). These outcomes were the standard deviation of lateral acceleration and the minimum value of lateral acceleration. These outcomes are related to each other as they both represent the vehicle lateral acceleration. The positive correlation of the standard deviation of lateral acceleration (related to the negative correlation of the lateral acceleration minimum value) indicates that the participants who performed better in the real-world driving condition had variation in the lateral acceleration measure.

Scenario qualitative analysis revealed that the corner's turning instruction was given in good time and the participant tended to reduce speed early to the stop sign. This gave time for the drivers to observe and position the car for the corner. The stop sign (and pedestrians) forced the drivers to stop the car and start from standstill when proceeding to the intersection. With regard to the lateral acceleration measures, the position of the car before turning to the corner was the most decisive factor and the found correlations indicated that this position was different for the drivers who performed better in the real-world driving condition and those who performed worse.

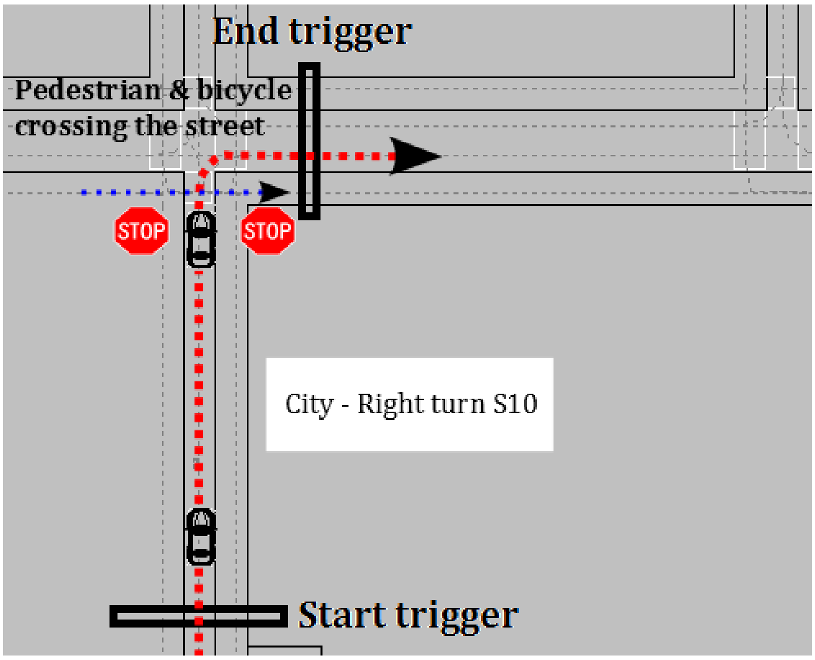


FIGURE 23 City right turn S10 driving scenario (Eepsoft Oy, 2013)

TABLE 26 City right turn S10 - Variables correlated with the driving instructor evaluation

City right turn 10			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Lateral acceleration standard deviation	18	$r_s(16)$ = . 496	*p* = . 036
Lateral acceleration minimum	18	$r_s(16)$ =.,–572	*p* =.,013

6.4.4 City straight between corners S10 and S11

City straight between corners S10 and S11 is a short straight with no other cars or traffic (FIGURE 24). The straight is approached after a right turn S10 behind a stop sign and pedestrian and bicycle crossing the crosswalk. Instructions are given early before the next intersection.

A Spearman's rank-order correlation test showed that two outcomes of the driving simulator condition correlated with the real-world driving condition (TABLE 27). These outcomes, which are closely related to each other, were mean speed and total time. The positive correlation of mean speed indicated that the participants who performed better in the real-world driving condition drove faster in the straight.

The straight profile was easy and short and because the road was quiet with no other traffic and the next intersection (left turn S11) was visible, faster driving pace may have been tempting for the drivers. It should be noted that driving on the short straight was probably affected by the preceding right turn corner (S10).

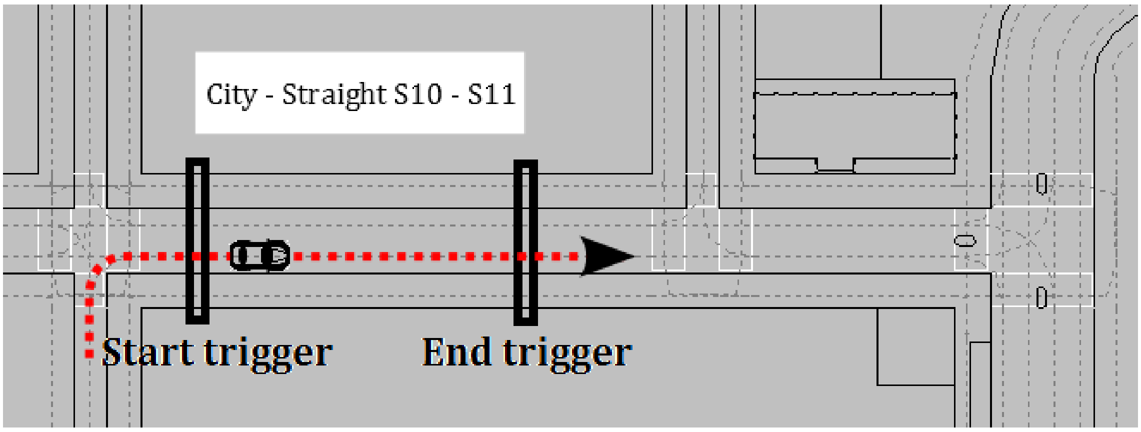


FIGURE 24 City straight S10 - S11 driving scenario (Eepsoft Oy, 2013)

TABLE 27 City straight S10 - S11 - Variables correlated with the driving instructor evaluation

City straight S10 - S11			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Mean speed	18	$r_s(16) = .539$	$p = .021$
Total time	18	$r_s(16) = -.566$	$p = .014$

6.4.5 City left corner S12

City left corner S12 is preceded by consecutive right-left bend (FIGURE 25). The road has two lanes on both directions and lane change is possible. Turning to the corner is done from the left lane. There was a possibility of a car driving in front, if the previous left corner waiting time has increased.

A Spearman's rank-order correlation test showed that five outcomes of the driving simulator condition correlated with the results of the real-world driving condition (TABLE 28). These outcomes were the standard deviation of speed, mean speed, lateral acceleration, the maximum value of lateral acceleration and lateral velocity. All correlations were positive and the outcomes of the driving simulator conditions closely related with one another.

Instruction trigger was positioned in such a way that the data was recorded when driving in the consecutive right-left bends. The actual measurement was therefore from the two consecutive turnings that led to the left corner. Participants also had some problems remembering the left turn, possible early instruction or preceding consecutive corners difficulty may have affected. Every participant except one was already in the left lane before turning left and one participant canceled the lane changes in middle as presented in TABLE 29.

The positive correlations indicated that the drivers who performed better in the real-world driving condition completed the preceding turn section and the left turn faster than the drivers who performed worse in the real-world driving condition.

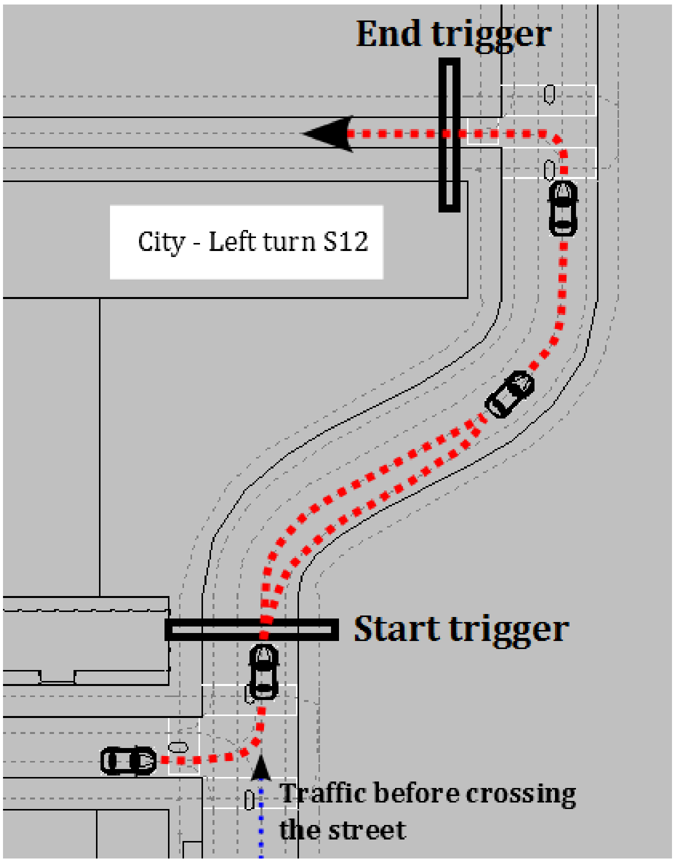


FIGURE 25 City left turn S12 driving scenario (Eepsoft Oy, 2013)

TABLE 28 City left turn S12- Variables correlated with the driving instructor evaluation

City Left turn S12			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Speed standard deviation	18	$r_s(16)$ = ,564	p = ,015
Mean speed	18	$r_s(16)$ = ,492	p = ,038
Lateral acceleration	18	$r_s(16)$ = ,615	p = ,007
Lateral acceleration maximum	18	$r_s(16)$ = ,553	p = ,017
Lateral velocity	18	$r_s(16)$ = ,574	p = ,013

TABLE 29 City left turn S12 quantitative analysis

	lane changes	overtaking	number of cars
Overall	1.5	0	0
N	0.5	0	0
E	1	0	0
Mean	0.083	0	0

6.4.6 City left corner S16

City left corner S16 has two lanes and only minor traffic (FIGURE 26). The intersection left turn is maneuvered across the street. A lane change is possible before turning. Other traffic is coming from far ahead and it may be waited but the turning can also be done immediately when the intersection is reached.

A Spearman's rank-order correlation test showed that four outcomes of the driving simulator condition correlated with the results of the real-world driving condition (TABLE 30). These outcomes were total time, the standard deviation of lateral acceleration, mean speed and the minimum value of longitudinal acceleration. The negative correlations of total time and the positive correlation of mean speed closely related to each other and indicated that the drivers who performed better in the real-world driving condition drove the corner faster than the drivers who performed worse in the real-world driving condition.

Lane changes as presented in TABLE 31 depended on the previous corner outcome and decision making during the preceding straight. There is a possibility to drive to the corner without waiting the cars that are coming from far ahead, as the drivers who performed better in the real-world driving condition used to do.

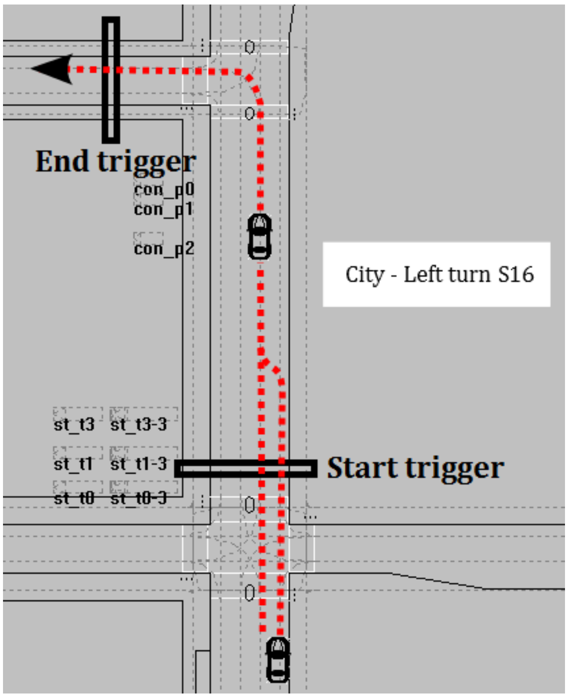


FIGURE 26 City left corner S16 driving scenario (Eepsoft Oy, 2013)

TABLE 30 City left corner S16 - Variables correlated with the driving instructor evaluation

City Left turn S16			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Total time	17	$r_s(15) = -.498$	p =.,042
Lateral acceleration standard deviation	17	$r_s(15) = .518$	$p = .033$
Mean speed	17	$r_s(15) = .491$	$p = .045$
Longitudinal acceleration minimum	17	$r_s(15) = .516$	$p = .034$

TABLE 31 City left turn S16 quantitative analysis

	lane changes	overtaking	number of cars
Overall	6.5	0	0
N	2.5	0	0
E	4	0	0
Mean	0.38	0	0

6.4.7 City left corner S20

City left corner S20 is in an intersection that precedes a two-lane one-way straight (FIGURE 27). After the previous corner (right turn S19) the participants were driving on the right lane when approaching the corner where they were instructed to turn left (TABLE 33). During the lane change, other traffic coming from behind needed to be avoided. There were also other cars standing in the intersection's left and right positions (will give way).

A Spearman's rank-order correlation test revealed that three outcomes of the driving simulator condition correlated with the results of the real-world driving condition (TABLE 32). These outcomes were the standard deviation of wheel rotation, lateral velocity, and total time. The first two correlated positively and total time negatively. These correlations indicated that the drivers who performed better in the real-world driving condition spent less time completing the scenario and had more steering wheel input as well as lateral velocity than the drivers who performed worse.

At least two things affected the driving scenario outcomes: the lane change and avoiding other cars coming from behind (mirror awareness) and how the other cars were acknowledged in the intersection (it was possible to go before them). Also it should be noticed that some drivers didn't notice or obey the traffic rules as they turned left from the wrong right lane.

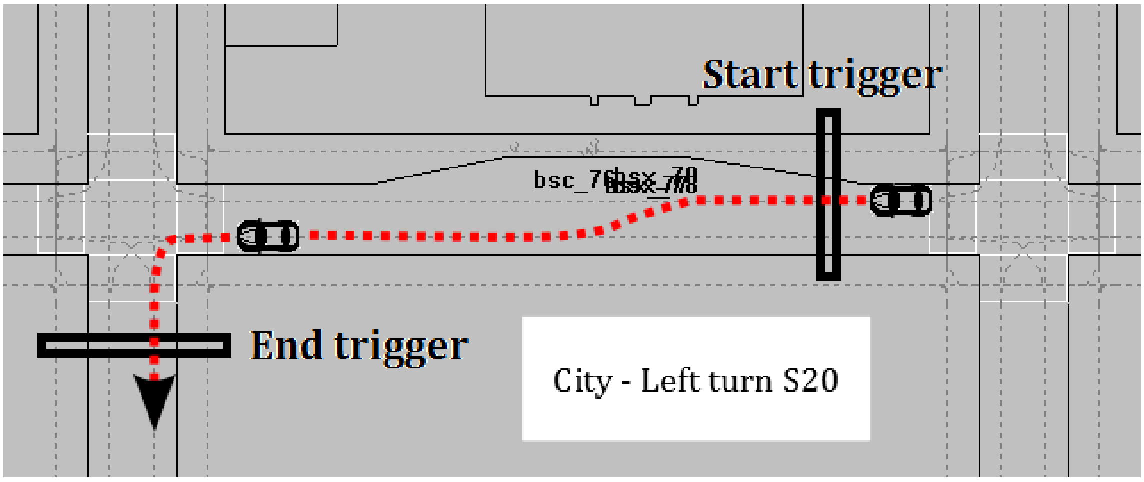


FIGURE 27 City left turn S20 driving scenario (Eepsoft Oy, 2013)

TABLE 32City left turn S20 - Variables correlated with the driving instructor evaluation

City Left turn S20			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Wheel rotation standard deviation	17	$r_s(15) = ,508$	$p = ,037$
Lateral velocity	17	$r_s(15) = ,486$	$p = ,048$
Total time	17	$r_s(15) = -,489$	$p = ,047$

TABLE 33 City left turn S20 quantitative analysis

	lane changes	overtaking	number of cars
Overall	14	0	0
N	8	0	0
E	6	0	0
Mean	0.82	0	0

6.4.8 Mlaakso merging S5

Mlaakso merging S5 was the first merging on the map. Merging was done in two stages, as the first two merging lanes joined and after that merged to motorway (FIGURE 28). The last merging to motorway was selected for the analysis. There was a little pump on the road before the two merging roads connected each other and a triangle traffic sign indicating to look out for other cars (give way sign).

A Spearman's rank-order correlation test showed that one outcome of the driving simulator condition, the minimum value of longitudinal acceleration, correlated with the results of the real-world driving condition (TABLE 34)

The positive correlation indicated that the drivers who performed better in the real-world driving condition had lower (closer to zero) longitudinal acceleration values in the driving simulator condition than the drivers who performed worse in the real-world driving condition. This finding suggests that the drivers who braked more intensively (higher deceleration), may be before the pump or the traffic sign where the two merging lanes merge, performed worse in the real-world driving condition.

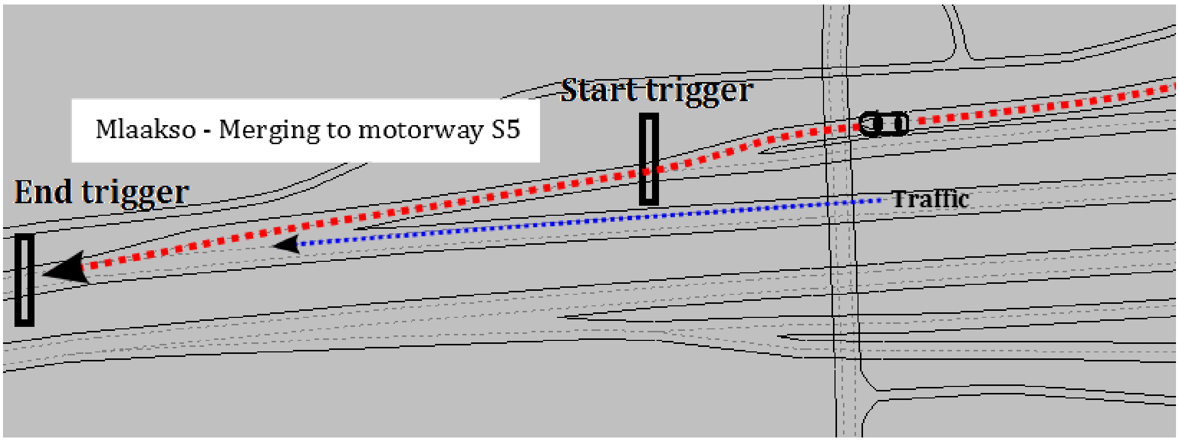


FIGURE 28 Mlaakso merging S5 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 34 Mlaakso merging S5 - Variables correlated with the driving instructor evaluation

Mlaakso motorway merging S5			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Longitudinal acceleration minimum	17	$r_s(15)$ = ,508	p = ,037

6.4.9 Mlaakso straight between corners S5 and S6

Mlaakso straight between corners S5 and S6 consist of two lane motorway road with other traffic with 80 km/h speed limit. Motorway traffic includes cars on the left lane and cars driving on the right lane while the participant is merging into the motorway. Near the end of the driving scenario, there is slow moving traffic that can form a traffic jam (FIGURE 29).

A Spearman's rank-order correlation test showed that only the lateral velocity outcome of the driving simulator condition correlated with the results of the real-world driving condition (TABLE 35).

The positive correlation indicated that the drivers who performed better in the real-world driving condition had higher lateral velocity in the driving simulator condition than the drivers who performed worse in the real-world driving condition. This finding may be explained by the fact that the traffic on the road created a need to overtake (TABLE 36) and the drivers who performed better in the real-world-driving condition behaved accordingly.

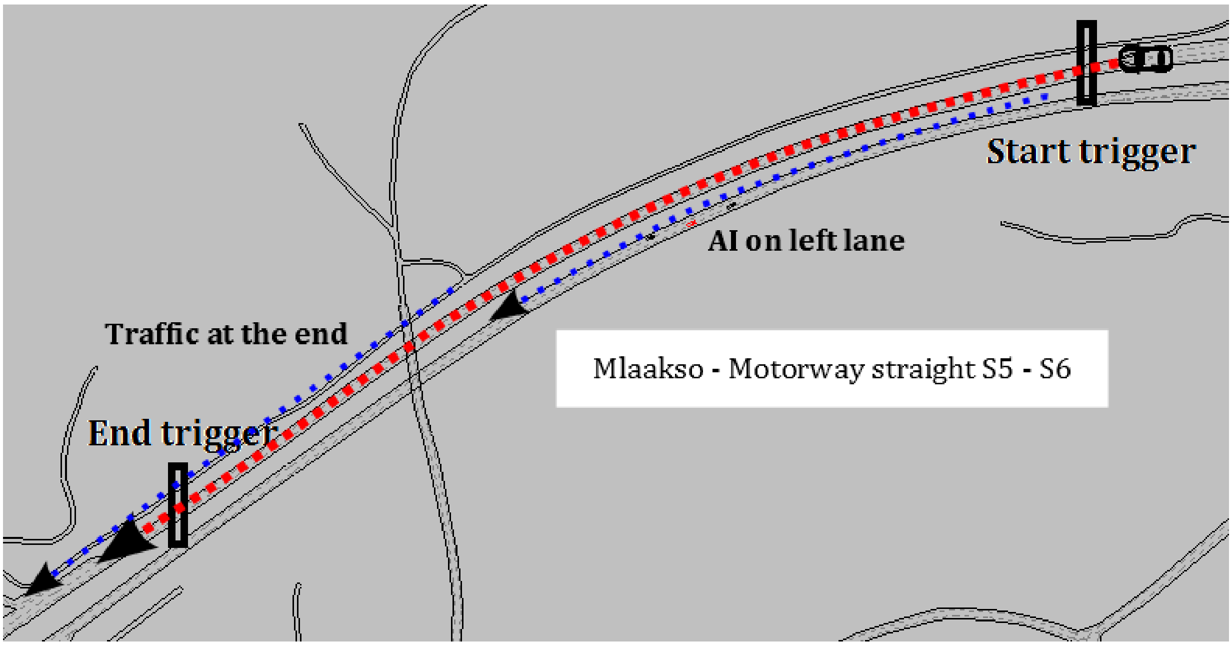


FIGURE 29 Mlaakso straight S5 - S6 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 35 Mlaakso straight S5 - S6 - Variables correlated with the driving instructor evaluation

Mlaakso motorway straight S5 - S6			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Lateral velocity	17	$r_s(15) = ,615$	$p = ,009$

TABLE 36 Mlaakso straight S5 - S6 quantitative analysis

	lane changes	overtaking	number of cars
Overall	0	13	34
N	0	4	16
E	0	9	18
Mean	0,0	0.72	1.88

6.4.10 Mlaakso straight between corners S7 and S8

Mlaakso straight between corners S7 and S8 is a two-lane motorway road with other traffic and 80 km/h speed limit (FIGURE 30). There is a possibility of slow moving traffic near the end of the straight.

A Spearman's rank-order correlation test showed that five outcomes of the driving simulator condition correlated with the results of the natural driving condition driving (TABLE 37). These outcomes were the following: lateral velocity, the standard deviation of wheel rotation, lateral acceleration, speed violations, and the number of rapid steering wheel movements. All the correlations were negative, except for the lateral velocity. Lateral velocity, the standard deviation of wheel rotation, lateral acceleration, and rapid steering wheel movements are closely related, as they all indicate the lateral movements of the car.

The negative correlations of lateral acceleration and wheel input indicated that the drivers who performed better in the real-world driving condition had lower lateral acceleration and steering wheel input values. The negative correlation of speed violations indicated fewer speed violations for the first-mentioned drivers. As TABLE 38 presents almost every driver had an overtaking situation during the straight and thus the result probably reflects the readiness for overtaking.

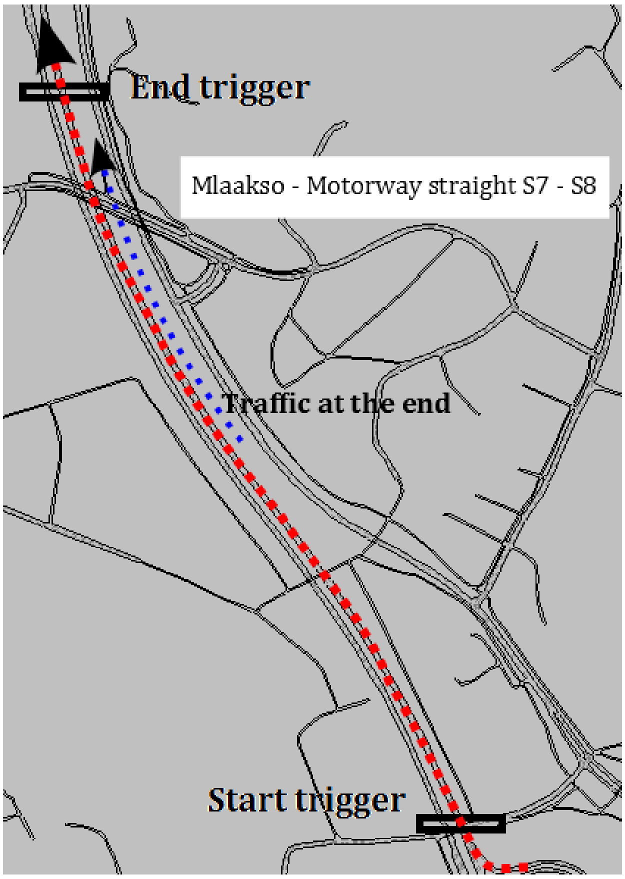


FIGURE 30 Mlaakso straight S7 - S8 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 37 Mlaakso straight S7 - S8 - Variables correlated with the driving instructor evaluation

Mlaakso motorway straight S7 - S8			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Lateral velocity	17	$r_s(15) = ,498$	$p = ,042$
Wheel rotation standard deviation	17	$r_s(15) = -,555$	$p = ,021$
Lateral acceleration	17	$r_s(15) = -,602$	$p = ,011$
Speed violations	17	$r_s(15) = -,591$	$p = ,012$
Rapid steering wheel movements	17	$r_s(15) = -,680$	$p = ,003$

TABLE 38 Mlaakso straight S7 - S8 quantitative analysis

	lane changes	overtaking**	number of cars
Overall	0	20	32
N	0	9	11
E	0	11	21
Mean	0,0	1.11	1.77

** Overall 22 overtaking were removed from the analysis as the cars crashed.

6.4.11 Mlaakso merging S11

Mlaakso merging S11 has a long merging lane and a possibility for a car in front (FIGURE 31). There are no other cars or traffic on the straight.

A Spearman's rank-order correlation test revealed that two outcomes of the driving simulator condition correlated with the results of the natural driving condition (TABLE 39). These outcomes were the standard deviation of wheel rotation and the minimum value of lateral acceleration.

The positive correlation of minimum value of the lateral acceleration indicated lower (closer to zero) longitudinal acceleration values for the drivers who performed better in the real-world driving condition. The negative correlation of the standard deviation of steering wheel rotation indicated that the drivers who performed better in the natural driving condition had less steering wheel input in the virtual driving scenario in question. TABLE 40 presents overtaking statistics.

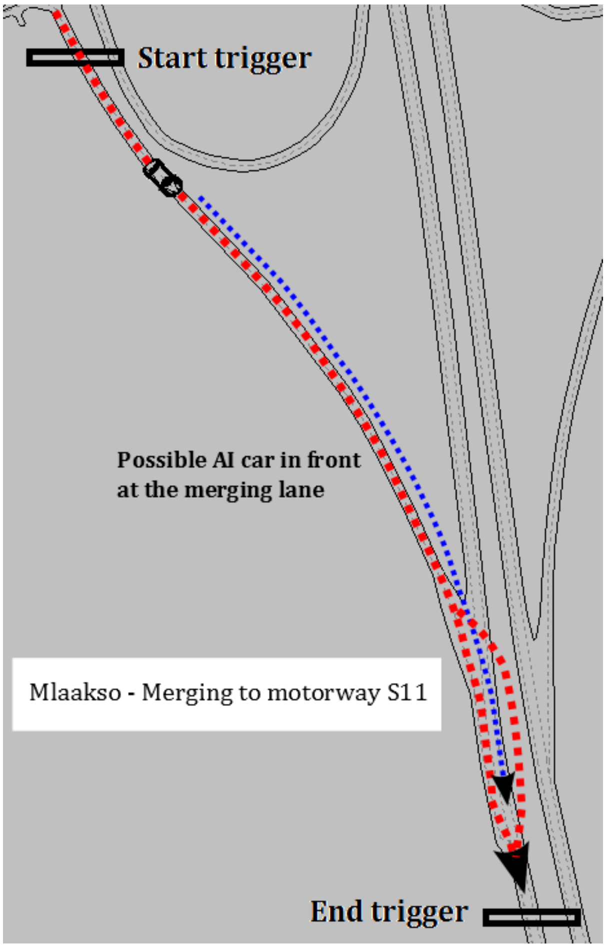


FIGURE 31 Mlaakso merging S11 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 39 Mlaakso merging S11 - Variables correlated with the driving instructor evaluation

Mlaakso motorway merging S11			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Wheel rotation standard deviation	18	$r_s(x) = -,552$	$p = ,018$
Lateral acceleration minimum	18	$r_s(x) = ,540$	$p = ,021$

TABLE 40 Mlaakso merging S11 quantitative analysis

	lane changes	overtaking	number of cars
Overall	0	8	8
N	0	5	5
E	0	3	3
Mean	0,0	0.44	0.44

6.4.12 Mlaakso straight between corners S11 and S12

Mlaakso straight between corners S11 and S12 is a two-lane motorway road with other traffic and 80 km/h speed limit (FIGURE 32). There is also a possibility of a car on the left lane.

A Spearman's rank-order correlation test showed that two outcomes of the driving simulator condition correlated with the results of the real-world driving condition (TABLE 41). These outcomes were the minimum value of longitudinal acceleration and the maximum value of lateral acceleration.

The positive correlation of the minimum value of longitudinal acceleration and the negative correlation of the maximum value of lateral acceleration indicated that the drivers who performed better in the real-world driving condition decelerated and moved the car sideways more carefully than the drivers who performed worse in the real-world driving condition. As TABLE 42 indicates overtaking was necessary for almost every participant: only two participants chose not to overtake.

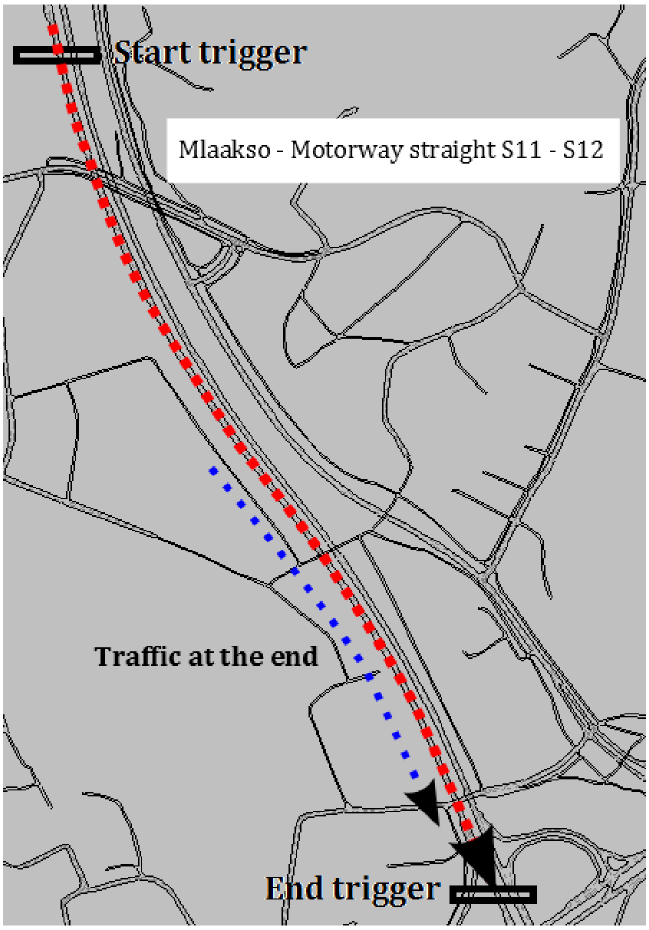


FIGURE 32 Mlaakso straight S11 - S12 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 41 Mlaakso straight S11 - S12 - Variables correlated with the driving instructor evaluation

Mlaakso motorway straight S11 - S12			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Longitudinal acceleration minimum	18	$r_s(16)$ = ,487	p = ,040
Lateral acceleration maximum	18	$r_s(16)$ = −,538	p = ,021

TABLE 42 Mlaakso straight S11 - S12 quantitative analysis

	lane changes	overtaking	number of cars
Overall	0	28	53
N	0	14	25
E	0	14	28
Mean	0	1.55	2.94

6.4.13 Mlaakso straight between corners S13 and S16

Mlaakso straight between corners S13 and S16 is a two-lane motorway road with other traffic and 80 km/h speed limit (FIGURE 33). There is no merging lane in the previous corner so acceleration occurs mostly during the straight.

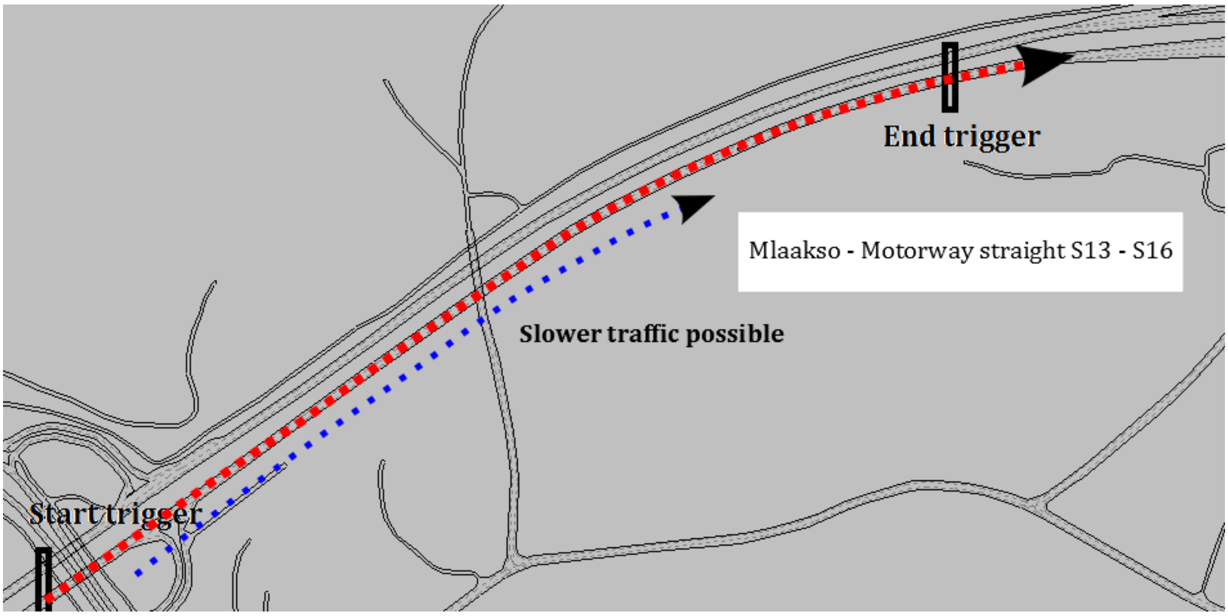


FIGURE 33 Mlaakso straight S13 - S16 driving scenario (Eepsoft Oy, 2013; also National Land Survey of Finland, 2012)

TABLE 43 Mlaakso straight S13 - S16 - Variables correlated with the driving instructor evaluation

Mlaakso motorway straight S13 - S16			
Variable	**N**	**Spearman's rho**	**Sig. (2-tailed)**
Wheel rotation standard deviation	18	$r_s(16) = -,511$	p = ,030

TABLE 44 Mlaakso straight S13 - S16 quantitative analysis

	lane change	overtaking	numb of cars
Overall	0	17	22
N	0	8	12
E	0	9	10
Mean	0,0	0.94	1.22

A Spearman's rank-order correlation test revealed that only one outcome of the driving simulator condition, the standard deviation of steering wheel rotation correlated with the results of the real-world driving condition (TABLE 43). The correlation was negative, indicating that the drivers who performed better in the real-world condition steered the car more cautiously.

6.5 Driver's performance prediction – regression analysis

The next step was to find out to what extent the results of driving simulator performance explained the differences in the real-world traffic evaluations between the drivers. The large amount of data and variables collected in the driving simulator offers possibilities for various regression models and the model presented below is only one example of these.

The linear regression model presented in this report included the following explanatory factors: rapid steering wheel movements in the City left turn S8, the standard deviation of steering wheel rotation in the City right turn S6 and the standard deviation of steering wheel rotation in the Mlaakso motorway straight between corners S13 and S16.

The selected explanatory variables were not correlated with each other and there was independence of residuals, as assessed by a Durbin-Watson statistic of 2.077. In TABLE 45 below is displayed the non-standardized regression coefficients (B), the standard error of the coefficient and intercept, the standard error of the coefficient and the standardized regression coefficients (beta). Regression coefficients and standard errors can be found in TABLE 45 below.

Two of the variables contributed significantly to prediction of the real-world traffic evaluations: rapid steering wheel movements (City S8) (beta = –.616) and Wheel rotation standard deviation (Mlaakso S13 – S16) (beta = –.547) as $p < .05$. Variable wheel rotation standard deviation (City S6) was not statistically significant for the prediction (beta = .235) ($p > .05$).

The assumptions of linearity, independence of errors, homoscedasticity, unusual points and normality of residuals were met. These variables statistically significantly predicted the driving instructor's evaluations in the real-world traffic ($F(3, 14) = 11.168$, $p = .001$, R (.840), R^2 (.705) and adj. $R2^2$ adjusted =(.642559). For summary, 64.2% of the variability in real-world traffic evaluations was predicted by the three variables of the driving simulator condition. Two of the variables added significantly to the prediction, $p < .05$. For one of the variables, the standard deviation of the steering wheel movements in the Mlaakso environment (S13-S16 section), the level of significance remained lower ($p = .155$).

TABLE 45 Summary of multiple regression analysis

Variable	*B*	*SE (b)*	*β*
Intercept	25,358	6,864	
Rapid steering wheel movements (City S8)	– 0,347	0,089	– 0,616*
Steering wheel rotation standard deviation (City S6)	29,564	19,671	0,235
Steering wheel rotation standard deviation (Mlaakso S13 - S16)	– 461,07	130,814	– 0,547*

Notes: **p* < 0.05; *B* = unstandardized regression coefficient; SE(b) = Standard error of the coefficient; *β* = standardized coefficient

6.6 Self-reported workload and performance quality

6.6.1 NASA-TLX - Workload

A Mann-Whitney test showed that the novice and experienced drivers did not differ from each other in their NASA-TLX scores in real-world traffic task (novice drivers: *Mdn* = 38.3, experienced drivers: *Mdn* = 39.2; $U = 41.5$, $z = .088$, $p = .930$) (FIGURE 34) or in the virtual city environment (novice drivers: *Mdn* = 33.3, experienced drivers: *Mdn* = 45.0, $U = 57.5$, $z = 1.503$, $p = .133$) (FIGURE 35), or in the virtual motorway environment (novice drivers: *Mdn* = 26.6, experienced drivers: *Mdn* = 34.2, $U = 52.5$, $z = 1.061$, $p = .289$) (FIGURE 36).

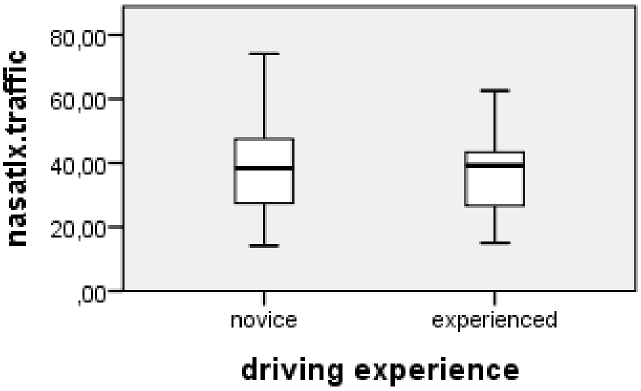


FIGURE 34 Novice and experienced drivers NASA-TLX scores in natural driving environment.

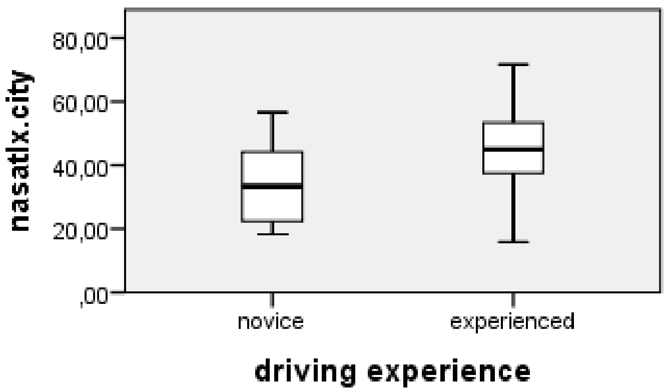


FIGURE 35 Novice and experienced drivers NASA-TLX scores in the virtual city environment.

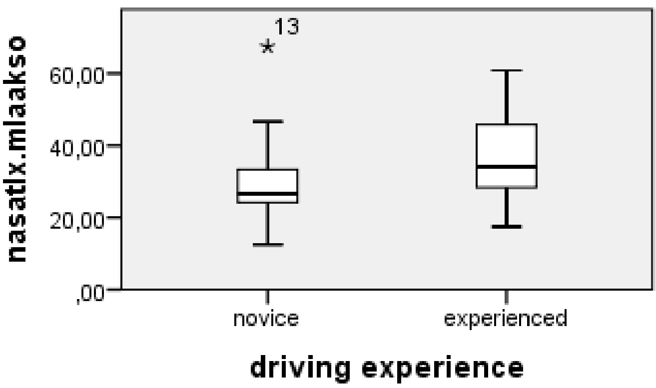


FIGURE 36 Novice and experienced drivers NASA-TLX scores in the virtual motorway environment.

A Wilcoxon Signed-Rank test was run to determine if there were differences in the workload between the two driving simulator tasks and the real-world traffic task. Between the real-world traffic (*Mdn* = 39.2) and the driving simulator city task (*Mdn* = 37.5) there was no statistically significant differences,

z = .142, p = .887, one participant showed no workload difference between either of the tasks. There were also no statistically significant differences between the driving simulator mlaakso task and the real-world traffic, z = −1.394, p = .163. Between the two driving simulator tasks of mlaakso (*Mdn* = 32.5) and city (*Mdn* = 37.5) the statistical significance was closing to significant as z = 1.765 and p = .078, twelve participants reported higher workload in the simulator city task; however the results were only suggestive.

6.6.2 Visual Analogue Scale

A Mann-Whitney test was run to determine if there were differences in the VAS self-report between novice and experienced drivers. There were no statistically significant differences in the real-world traffic task VAS score between the novice (*Mdn* = 6.5) and experienced (*Mdn* = 6.0) drivers, U = 44.5, z = −.354, p = .724 (FIGURE 39). Also no statistical differences were found from the driving simulator city driving task between the novice (*Mdn* = 6.1) and experienced (*Mdn* = 6.2), U = 40.5, z = .000, p = 1.00 (FIGURE 37) and in the mlaakso map between the novice (*Mdn* = 6.3) and experienced (*Mdn* = 5.5), U = 25, z = −1.369, p = .171 (FIGURE 38).

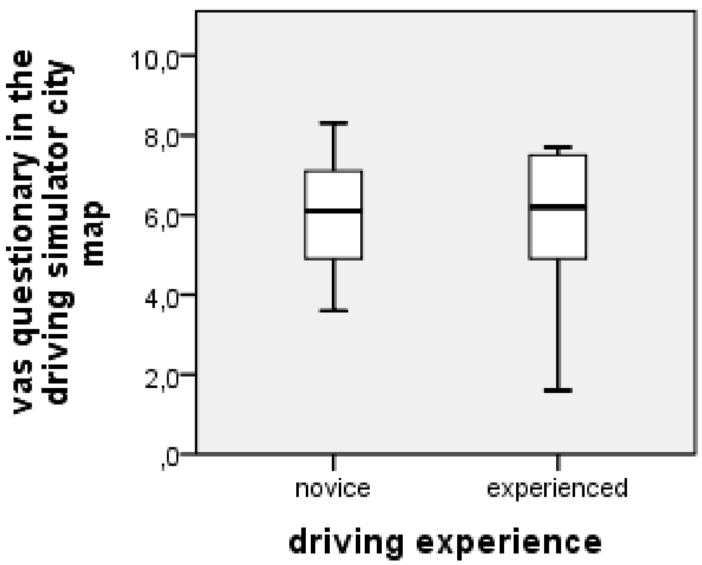


FIGURE 37 VAS self-report differences between novice and experienced drivers in the virtual city environment.

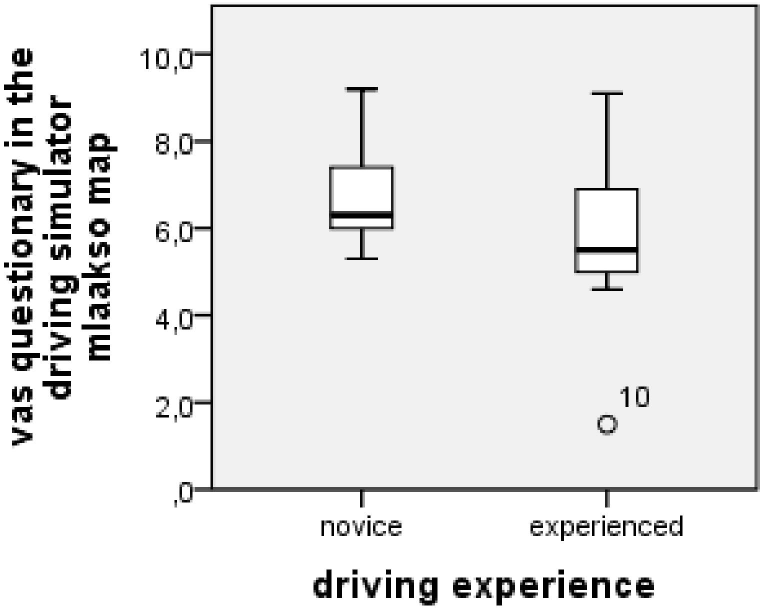


FIGURE 38 VAS self-report differences between novice and experienced drivers in the virtual motorway environment.

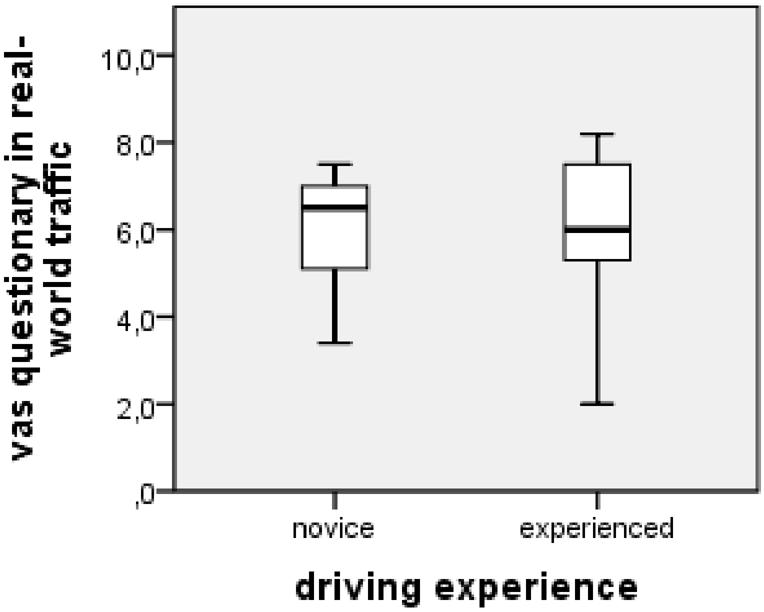


FIGURE 39 VAS self-report differences between novice and experienced drivers in natural driving environment.

7 CONCLUSIONS

The first part of this chapter summarizes the topics of a driving task and individual differences (Chapter 2), modeling of driver behavior (Chapter 3) and assessing of driving simulator validity (Chapter 4). The second part of the chapter concludes the main findings of the empirical part of the thesis described in chapter five "method" and presented in chapter six "results".

7.1 Summary of literature review

The literature review part of the thesis presented driving as a complex task that requires cognitive, perceptual and motor abilities from the driver controlling the car in a continuously changing environment, challenging driver capabilities and skills referred to as driver performance. Former research on individual differences on driving was presented. Driving research historical trends concentrated more on driver performance as driving was seen as a skill based task. The search for accident causation and individual differences resulted not only in driver behavior research of attitude, motivation, personality and other factors but also for theories that aimed to describe and model driver behavior.

Chapter three discussed driver behavior and introduced the most influential models. Three motivational models that describe driving as a self-paced task were presented in more detail: the zero-risk theory, the risk homeostasis theory and the Task-Capability Interface (TCI) model. The zero-risk and risk homeostasis theory discuss how drivers perceives risk. The risk homeostasis theory suggests that drivers constantly varies the level of risk as the zero-risk theory argues that risk is experienced only after certain threshold is exceeded.

The TCI model proposes that a driver has a certain capability that is rather constant and biologically static, influenced by psychological and physiological factors. The capability is challenged by constantly changing task demands; when hazardous situation are not met, task demands do not exceed the driver's capability and the driver is not put to the maximum test.

Drivers' experience of risk has also been questioned on driving simulator research as the concept of simulation realism is a concern. Evans (1991) questions whether driver behavior can be truly researched in the simulator. On the other hand empirical evidence of driver performance validity is presented by Wang et al. (2010). Driving simulator validity is commonly divided into physical and behavioral validity with physical validity being a correspondence to real-world components; behavioral validity reflects the comparison of performance in virtual and natural driving conditions. This comparison leads to two categories of behavioral validity: absolute and relative validity. Absolute validity refers to how accurately simulator numerical values represent those measured in natural conditions. Relative validity is determined by to which degree those measures have the same direction and have the similar magnitude.

7.2 A review and conclusions of the empirical findings

The aim of this thesis was to research driving simulator validity by comparing novice and experienced drivers' driving performance results in simulated and natural driving conditions. The study was conducted in a fixed-base driving simulator and all the participants (N = 18) drove one separate practice run before the experiments to familiarize with the simulator environment.

Validity was approached from two perspectives; firstly by evaluating the difference between the two driving groups in natural and virtual driving conditions and secondly, how strongly the two driving conditions were associated with each other. There were three main findings in the empirical part of the thesis.

The first finding is that there were no differences between novice and experienced drivers' driving performance results or self-estimations neither in the virtual nor in the natural driving conditions. Secondly, there were 31 outcomes of driving performance measures in virtual driving that were associated with the quality of driving in the natural environment. Thirdly, three driving performance variables from different virtual driving scenarios were selected that significantly explained (64%) the observed interindividual driving quality in the on-road environment.

8 DISCUSSION

There are two main contributions for this thesis to be further discussed; the validity of a driving simulator and its relationship to driver performance and driver behavior. The two previous topics are further discussed and reflected in the previously mentioned literature. There are also several issues in this study which must be taken into account as the limitations of the study are discussed. Follow-up and future suggestions for research are also discussed along the way.

The concept of behavioral validity that is further divided into relative and absolute validity is used as previous driving simulator studies have adopted the use of the vocabulary. Because of the evaluation method, driving performance assessed by the driving instructor in the natural environment, the qualitative analysis of relative validity is used when evaluating the driving performance results. Similarly, because of the evaluation method used in the real-world, it is concluded that the quantitative absolute validity cannot be measured as no data is extracted from the natural conditions. Criticism and concern over different concepts of validity such as measurement, internal and external validity (Blana, 1996; Reimer et al., 2006) is noticed but not further discussed within the limits of this study.

It can be concluded that the study results support relative validity of the fixed-base driving simulator used in the experiments with certain limitations discussed later in this chapter. Driving performance measures in virtual driving presented a similar degree of direction and magnitude as the quality of driving results measured on-road in 12 different scenarios that generated 31 different outcomes.

The results presented three interesting findings. The first somewhat surprising finding was that there were no differences in driving performance results or self-estimations between the two driving groups of experienced and novice drivers neither in virtual nor natural driving conditions. Secondly, three simulator driving scenarios highlighted the results as four left turn corners in the city environment and four straights and two merging scenarios in the motorway environment were most strongly associated with the driving quality in natural conditions. Thirdly, the outcome variables most strongly associated with the natural driving conditions were steering wheel input (number of rapid steering wheel movements and wheel rotation standard deviation) and vehicle lateral acceleration.

8.1 Discussion on driver performance and driver behavior

It can be discussed whether the three previously introduced scenarios (city left turns and motorway straights and merging) were such high task demands, for example demanding traffic environment and other road users, that differences in driving performances were mostly related to the level of driver skill. But then would this have meant that the more experienced drivers, with higher driver performance through practice, would have performed better? The relationship between driving experience and driver performance remains under debate, for example findings such as Sagberg and Bjornskau (2006) suggesting that the driving experience does not always relate to better hazard perception and reaction times, although some decrease in reaction times was observed. The results also presented statistically significant differences in the Driver Behavior Questionnaire as experienced drivers had higher mean values on aggressive and ordinary violations than novice drivers. The DBQ results were only preliminary and needed to be analyzed further.

An alternative approach is discussed as Näätänen and Summala (1976) states that the task demands are not seen to have any fixed degree but rather a function of the driver's choice; it is the driver who sets the demands for himself in different traffic situations. A similar perspective as Näätänen and Summala, Evans (1991) continues and refers to driver performance as what the driver can do and driver behavior as what the driver actually does or attempts to do with their skills. Therefore individual differences in driver behavior may offer an explanation. The previous research findings on trait differences, such as accident involvement between extraversion and introversion personalities (Linnankoski & Ollila (1988) referring to Venables, 1956; Fine, 1963; Greenshield & Platt, 1967), driver tendency to sensation seeking (or avoiding) (Heino et al., 1996) and also the need for developing psychological tests to evaluate these aspects (McKenna, 1982) should be considered more closely.

The above-mentioned individual differences and the strong association of steering wheel input and vehicle lateral acceleration may also reflect drivers' behavior. Häkkinen (1958) in his early work described that a driver’s impulsivity, rushing and a kind of motor hypersensitivity worsened the performance especially when there was an increase in the task demands. Driving performance described as unhurried but fluid, flexible, certain and controlled movements were described as an accident avoider. Further discoveries could also be found from the additional driving performance data collected in the study: eye tracking measures as well as lane and speed errors.

The TCI model of driver behavior discusses how the driver perceives the workload described as task demands (Fuller, 2005 refers to Kahneman, 1973). In this study there were no significant findings on driver workload. Future research on driver mental workload reflecting the task difficulty, could offer interesting findings. A possible approach could be comparing the drivers' subjective workload in virtual and natural environments between driver groups who performed below and above average in the driving instructor's on-road evaluation. Although Summala (1986) presents driving as a mostly automatized task and Fuller (2005) continues that when the driver exceeds their capability, driving does not immediately collapse or lead to error but its more fragile to errors. Therefore individual differences in the driver workload may not be measurable.

When summarizing the discussion on driving performance differences and its relation to driver behavior, the suggestion of Michon (1985) on Janssen (1979) should be noticed; what driver problem solving task we are reviewing? On the three levels of skills and control (strategic, maneuvering and control), the automatic action patterns of the control level are most often described in research (Blana, 1996), which is also the case in this study. A question for future research is how the level of automatic actions resembles the human individual differences (such as personality) on complex tasks such as driving.

8.2 Limitations of the study

Several limitations of the study need to be mentioned when evaluating the results. The study sample was limited (N = 18) and further research with larger number of participants is encouraged. There is also a possibility for self-elimination of volunteers that consider their driving performance insufficient and vice versa, over presentation for example of novice drivers with higher driving experience. The effect of simulator sickness also needs to be reviewed. This study report does not include the Simulator Sickness Questionnaire (SSQ) results which need to be analyzed to gain knowledge whether participants experienced motion sickness symptoms that could affect the study results.

The similarity between the virtual and natural driving condition routes should also to be considered. Blaauw (1982) recalls that the simulator and the real-world driving scenarios should be as equal as possible. In this study, the simulator city and the motorway sections were designed to resemble the real-world driving as closely as possible but the true similarity would require identical correspondence.

When compared to previous research on driving simulator validity the special feature of this study was the real-world evaluation assessed by the driving instructor; an instrumented vehicle was not used and therefore no data extracted. The evaluation time of one hour was completed for each driver and an overall assessment of the driving was conducted according to the Finnish Transport Safety Agency Trafi's regulations. Therefore a longer period of driving or concentration on similar driving scenarios than presented in the simulation might have changed the evaluation results. These limitations are addressed by Allen et al. (1991) and also Blana (1996) who highlights the question whether genuine behavior can be observed in artificial experiment conditions. Evans (1991) states, that real driver behavior cannot be achieved in simulator conditions.

8.3 Final words

Individual differences in driver behavior such as trait differences in personality provide a possible explanation why there were no differences in driving performance results or self-estimations between novice and experienced drivers. Further research is encouraged as the results are only to be speculated in this study.

Summala (1986) prompts to research different subtasks of driving to gain knowledge on driver behavior mechanisms. The study results suggest that the subtasks of driving might be different environmental situations that reflect the drivers' individual differences on driving performance results, offering a possible glance on the human personality and driver behavior.

There is still uncertainty regarding the methodologies and vocabulary used in the driving simulator validation studies and how to combine performance and behavior measures of validity. Future research is needed to measure validity and to compare parameters to gain advancement between real-world driving and driving simulators. Modeling driver behavior as well as development and validation of driving simulators will benefit both research fields.

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APPENDIX 1 AJOSIMULAATTORIIN TUTUSTUMINEN

1) Ennen koetta
   - Ratin ja polkimien ruuvit auki
   - Käynnistä koneet ja lataa ohjelmistot valmiiksi (kartta: Mlaakso, perustila)
   - Lomakkeet valmiiksi
2) Koehenkilön saapuessa
   - Matkapuhelin pois päältä tai äänettömälle
   - Kysy meikin käytöstä tai mahdollisista piilolinsseistä (laitteiston mahdollisten häiriöiden vuoksi).
   - Esittele tutkimus lyhyesti.
   - Pyydä lukemaan ja allekirjoittaman nimenselvennyksellä tutkimuksen esittelypaperi. Mainitse kolmesta ajokerrasta.
   - KYSYMYKSET ENNEN KOETTA:
     I. Ikä?
     II. Kuinka monta kilometriä olet ajanut (noin arvio vko:ssa/kk:ssa, sataa tai tuhatta kilometriä)?
     III. Kuinka monta vuotta/kk sinulla on ollut ajokortti (autokolun II-vaiheen suoritusaika)?
     IV. Oletko ajanut ajosimulaattorilla aikaisemmin (Agoran simulaattori, muut simulaattorit, kuinka usein)?
3) Siirtyminen simulaattorille ja ohjeistus ennen ajoa
   - Tyynyillä ajoasennon säätö.
   - Ensimmäinen ajo, tarkoitus tutustua simulaattoriin.
   - Aja kuten normaalista ajaisit tieliikenteessä liikennesääntöjä noudattaen.
   - Autossa automaattivaihteet, vain kaasu ja jarru käytössä.
4) Silmänliikelaitteiston kalibrointi ja käyttö
   - Taustoita silmänliikelaitteiston käyttöä ja toimintaa koehenkilölle.
   - SMI HEADin valmistelu
     i. Dynamic asetus pois päältä
     ii. Scene kameran ikkunan säätö kokonaan näkyväksi.
     iii. Scene view ja eyelence säätö samaan aikaan (akselin mukainen säätö)
     iv. Pyydä koehenkilöä näyttämään katseen keskipiste sormella. Aseta Scene kamera kuvaamaan mieluummin hieman ylemmäksi.
     v. Pupil threshold + Corneal reflection säätö.
     vi. Osoita laserilla etunäkymään ja pyydä seuraamaan katseella. Tee tarvittava hienosäätö asetuksiin.
   - Kalibrointi

   i. Pyydä koehenkilöä ottamaan ajoasento
   ii. Pyydä koehenkilöä pitämään pää paikallaan liikkumatta ja seuraamaan punaista laserosoitinta pelkällä katseella.
   iii. Aloita iViewissä kalibrointi
   iv. Punaisen ristin ympärille ilmestyvät sakarat kun laite tunnistaa fiksaation. Säädä kalibrointipisteitä mikäli tarvetta.
   v. Hyväksy kohdistus space näppäimellä.
   vi. Pyydä koehenkilöä rentoutumaan kun kalibrointi on suoritettu. Kerro, että hän voi jatkossa liikuttaa päätään vapaasti.

5) Harjoitusajon suorittaminen
   - Paina iViewin REC nappia.
   - Ajoaika 30 minuuttia.
   - Ohjeistus:
     i. Tarkoitus on tutustua simulaattorilla ajamiseen. Ajoreitin voi valita vapaasti
     ii. Liikennesääntöjä noudattaen, nopeusrajoitusten mukaan.
     iii. Voit kysyä ajon aikana jos kysymyksiä.
     iv. Tarvittaessa neuvon reittiä (moottoritiellä ajo ainakin kerran)
     v. Voit keskeyttää ajamisen koska tahansa haluat.
     vi. Nyt kysyttävää?

6) Harjoitusajon jälkeen
   - Tallenna ajo iViewistä

7) Lopuksi
   - KYSYMYKSET KOKEEN JÄLKEEN:
     I. Minkälainen ajotuntuma/ajokokemus simulaattorista jäi?
     II. Kuinka vertaisit ajotuntumaa oikeaan autoon?
     III. Miltä silmänliikekypärä tuntui?
     IV. * a) Arvioi koehenkilön suoritus
     * b) merkitse fysiologiset tuntemukset, esim. huono-olo, huimaus, päänsärky mikäli koehenkilö mainitsee niistä kokeen tai haastattelun aikana/jälkeen.
   - Seuraavan ajokerran ajan sopiminen. Vahvistetaan vielä sähköpostilla tai puhelimitse -> yhteystietojen tarkastaminen.

APPENDIX 2 AJOSIMULAATTORISSA AJO

1) Ennen koetta
    - Ratin ja polkimien ruuvit auki
    - Käynnistä koneet ja lataa ohjelmistot valmiiksi.
        - Starter: Season: ″winter″, recording options
    - Merkitse koehenkilön tehtäväjärjestys (liite 8) ja laita kyselyt valmiiksi

2) Koehenkilön saapuessa
    - Matkapuhelin pois päältä tai äänettömälle
    - Kysy meikin käytöstä tai mahdollisista piilolinsseistä (laitteiston mahdollisten häiriöiden vuoksi).
    - Esittele ajokerran kulku lyhyesti: lyhyt alkuharjoitus, silmänliikelaitteiston kalibrointi, kaksi n. 15 minuutin ajoa sekä kyselyt välissä ja lopussa.
    - KYSELYT ENNEN KOETTA (vain ensimmäisessä ajossa!)
        - Ajokysely (liite 4)
        - DriveBehaviourQuestionary (liite 5)

3) Ajosimulaattorilla
    - Ajoasennon säätäminen ja silmänliikekypärän säätäminen.
    - Lyhyt harjoitusajo: City-kentässä, muutama minuutti, kysytään koska koehenkilö saa ajotuntumaa tarpeeksi.
    - Silmänliikelaitteiston kalibrointi tehdään liitteen 1 mukaan. (HUOM! Ei koehenkilöille jotka eivät halunneet käyttää ajaessa)

4) Ohjeistus ennen ajoa
    - Tehtävänäsi on:
        - Ajaa ennalta määrättyä reittiä. Ennen risteystä kuulet suomenkieliset ajo-opaste äänet ja näet vihreän kääntymissuuntamerkin etunäytöllä (kuten autonavigaattorissa).
        - Ajo kestää n. 15 minuuttia.
        - Tarvittaessa voit pyytää kokeen pitäjää toistamaan suunnan tai kysymään jos jotain epäselvää. Muuten keskustelua vältetään ajon aikana.

   - Kaupungissa oikeaa reittiä näyttävät lisäksi myös siniset ”REITTI”-ajo-opastekyltit.
- Ajo tapahtuu liikennesääntöjä noudattaen ja nopeusrajoitusten mukaan. Taajamassa ajonopeus on 40 km/h ja taajaman ulkopuolella 80 km/h (huom! max. nopeudet!). Ei ole kiire, aikaa ei mitata. Säädä ajonopeutta tilanteen mukaan.
- Edellä olevan auton/autot saa ohittaa nopeusrajoituksia noudattaen.
- Voit keskeyttää ajamisen koska tahansa haluat.
- Nyt kysyttävää?

5) Ajojen suorittaminen.

Ennen ajoa:

a. Käynnistä videokameran nauhoitus.
b. Lataa kartta (winter) city tai mlaakso (kts. liite 8, taulukko 2)
c. Paina iViewin REC nappia.

Ajon aikana:

d. Merkitse ajolokiin tapahtumat (virheet ja konfliktit)

Ajon jälkeen:

e. TALLENNA ajo simulaattorista (Replay ->)
f. TALLENNA ajo iViewistä
g. KYSELYT:
   I. Visual Analog Scale (liite 6)
   II. NASA TLX (liite 7)
   III. Viimeinen: Simulaattoripahoinvointi –kysely (liite 10)

6) Lopuksi

- Seuraavan ajokerta ajan sopiminen.

APPENDIX 3 LIIKENTEESSÄ AJO

1) Ennen koetta
    - Kyselyt valmiiksi.
    - Tarkasta koehenkilön esitiedot (tutustumiskysymykset).
2) Koehenkilön saapuessa
    - Matkapuhelin pois päältä tai äänettömälle
    - Kysy meikin käytöstä tai mahdollisista piilolinsseistä (laitteiston mahdollisten häiriöiden vuoksi).
    - <u>Esittele ajokerran kulku lyhyesti</u>: silmänliikelaitteiston kalibrointi, ajon kesto, suoritetaan liikenneopettajan johdolla sekä kyselyt.
    - <u>KYSELYT ENNEN KOETTA</u> (vain ensimmäisessä ajossa!)
        - Ajokysely (liite 4)
        - DriveBehaviourQuestionary (liite 5)
        - Trafi E101: ”Oman ajotaidon arviointi ennen ajokoetta”
3) Autossa ennen koetta
    - **Tutkija:** Kalibrointi etäisyyden mittaaminen.
    - **Koehenkilö**: Kypärä ja ajoasennon säätäminen huolella (näkyvyyden tarkastaminen ja kypärän käyttö kysyttävä!)
    - <u>Silmänliikelaitteiston kalibrointi</u> tehdään liitteen 1 mukaan. (HUOM! Ei koehenkilöille jotka eivät halunneet käyttää ajaessa)
        i. Kalibrointi paikan sijainti ja etäisyys sama
        ii. Kalibrointi osoitinlaserilla seinää vasten
4) Ohjeistus ennen ajoa (Liikenneopettaja ohjeistaa)
    - <u>Tehtävänäsi on: Ajaa liikenneopettajan ohjeiden mukaan</u>
    - Liikennesääntöjä noudattaen, olet vastuullinen kuljettaja ajokortin haltijana.
5) Ajon suorittaminen
    a. Paina iViewin REC nappia.
    b. TALLENNA ajo iViewistä
    c. <u>KYSELYT ajon jälkeen</u>:
        I. Visual Analog Scale (liite 6)
        II. NASA TLX (liite 7)
        III. (Liikenneopettajan arviointi ajosta E101-lomakkeelle)
6) Lopuksi
    - Liikenneopettajan palaute ajosta koehenkilölle.
    - Seuraavan ajokerta ajan sopiminen.
    - Keksiä ja pillimehua.

APPENDIX 4 AJOKYSELY

AJOKYSELY – participant:

Opinnot: **Ammatti:**

1) Kuinka usein ajat autoa?

1. Harvemmin kuin kerran kuussa
2. Harvemmin kuin kerran viikossa
3. 1-2 päivänä viikossa
4. 3-5 päivänä viikossa
5. Päivittäin tai lähes päivittäin

2) Missä ajat?

a) Kaupungissa

1. Harvemmin kuin kerran kuussa
2. Harvemmin kuin kerran viikossa
3. 1-2 päivänä viikossa
4. 3-5 päivänä viikossa
5. Päivittäin tai lähes päivittäin

b) Moottoriteillä

1. Harvemmin kuin kerran kuussa
2. Harvemmin kuin kerran viikossa
3. 1-2 päivänä viikossa
4. 3-5 päivänä viikossa
5. Päivittäin tai lähes päivittäin

c) Maanteillä

1. Harvemmin kuin kerran kuussa
2. Harvemmin kuin kerran viikossa
3. 1-2 päivänä viikossa
4. 3-5 päivänä viikossa
5. Päivittäin tai lähes päivittäin

d) Kyläteillä

1. Harvemmin kuin kerran kuussa
2. Harvemmin kuin kerran viikossa
3. 1-2 päivänä viikossa
4. 3-5 päivänä viikossa
5. Päivittäin tai lähes päivittäin

3) Ajoväsymys

a) Oletko ajaessasi ollut lähellä nukahtamista?

1. En koskaan/ harvoin
2. Joskus
3. Usein

b) Oletko ajaessasi nukahtanut rattiin?

1. En koskaan/ harvoin
2. Joskus
3. Usein

4) Onko sinulle sattunut kolareita?

a) Kuinka monta?

b) Miten pitkä aika siitä/niistä on?

c) Millainen/millaisia kolareita?

1. Yhden auton kolari (ulosajo, törmäys)
2. Kolari jalankulkijan/pyöräilijän kanssa
3. Kolari toisen/toisten autojen kanssa

d) Missä?

1. Kaupungissa
2. Pihassa/Parkkipaikalla
3. Moottoritiellä
4. Maantiellä
5. Kylä-/metsätiellä

e) Mihin aikaan?

1. Vuodenaika?
2. Vuorokaudenaika?

f) Millainen sää oli?

g) Oliko kyydissäsi matkustajia?

h) Olitko itse matkustajana?

i) Koitko ajoväsymystä kolaria ennen?

j) Kuvaile omin sanoin mitä kolarissa tapahtui

Lisäkysymykset tätä ajokoetta varten

a) kuinka kauan nukuit edellisen yön ja päivän aikana? ___ h klo

b) käytitkö kofeiinituotteita?

c) oletko käyttänyt lääkeaineita?

APPENDIX 5 DRIVER BEHAVIOUR QUESTIONARY

Kuinka usein teille on tapahtunut seuraavia asioita liikenteessä?

Seuraavassa on lueteltu asioita, joita voi tapahtua liikenteessä. KUINKA USEIN teille on tapahtunut kyseisiä asioita **viimeisen vuoden aikana**? Vastausvaihtoehdot (0-5) ovat:

0=ei koskaan 1=hyvin harvoin 2=joskus 3=melko usein 4=usein 5=hyvin usein

	0	1	2	3	4	5
Peruuttaessanne olette osunut johonkin esineeseen, joka jäi huomaamatta	☐	☐	☐	☐	☐	☐
Aikoessanne ajaa kohteeseen A olette yllättäen huomannut erehdyksessä valinneenne kohteeseen B johtavan reitin (esim. siksi että B on tyypillisempi määränpäänne)	☐	☐	☐	☐	☐	☐
Ajanut autolla vaikka olette epäillyt nauttineenne alkoholia yli sallitun määrän	☐	☐	☐	☐	☐	☐
Valinnut väärän kaistan lähestyessänne risteystä	☐	☐	☐	☐	☐	☐
Päätielle kääntyessänne olette kiinnittänyt kaiken huomion risteävään liikenteeseen niin, että olette lähes ajanut edellä olevan auton perään	☐	☐	☐	☐	☐	☐
Kääntyessänne pääkadulta sivukadulle teiltä on jäänyt huomaamatta katua ylittävä jalankulkija	☐	☐	☐	☐	☐	☐
Soittanut auton äänitorvea ilmaistaksenne ärtymystä toista autoilijaa kohtaan	☐	☐	☐	☐	☐	☐
Unohtanut katsoa taustapeiliin esim. vaihtaessanne kaistaa tai ohittaessanne	☐	☐	☐	☐	☐	☐
Jarruttanut liian voimakkaasti liukkaalla tiellä ja menettänyt auton hallinnan	☐	☐	☐	☐	☐	☐
Ajanut "kolmion takaa" risteykseen niin pitkälle, että etuajo-oikeutetulla tiellä ajava kuljettaja on joutunut pysähtymään ja antamaan teille tietä	☐	☐	☐	☐	☐	☐
Rikkonut nopeusrajoitusta taajamassa	☐	☐	☐	☐	☐	☐
Erehdyksessä laittanut päälle väärän hallintalaitteen, esim. kaukovalot tuulilasinpyyhkimien sijasta	☐	☐	☐	☐	☐	☐
Kääntyessänne oikealle lähes törmännyt samalla kaistalla oikealla puolellanne ajavaan polkupyöräilijään	☐	☐	☐	☐	☐	☐
Jättänyt huomaamatta kärkikolmion, minkä seurauksena lähes joutunut kolariin etuoikeutetulla tiellä ajavan kanssa	☐	☐	☐	☐	☐	☐
Yrittänyt lähteä liikennevaloista liian suurella vaihteella	☐	☐	☐	☐	☐	☐
Yrittänyt ohittaa vasemmalle kääntyvän auton, koska ette huomannut auton suuntamerkkiä	☐	☐	☐	☐	☐	☐
Suuttunut toiselle kuljettajalle niin paljon, että olette osoittanut ärtymystänne seuraamalla kyseistä autoa hyvin lähellä jonkin aikaa	☐	☐	☐	☐	☐	☐
Tarkoituksella ajanut päättyvällä kaistalla niin pitkälle, että olette viime hetkellä kiilannut toiselle kaistalle lähes väkisin	☐	☐	☐	☐	☐	☐
Unohtanut minne olitte pysäköinyt autonne	☐	☐	☐	☐	☐	☐
Ohittanut hitaan ajoneuvon väärältä puolelta	☐	☐	☐	☐	☐	☐

0=ei koskaan 1=hyvin harvoin 2=joskus 3=melko usein 4=usein 5=hyvin usein

	0	1	2	3	4	5
Kiihdyttänyt liikennevaloista tarkoituksena voittaa viereisellä kaistalla oleva auto	☐	☐	☐	☐	☐	☐
Lukenut liikenneopasteen väärin liittymässä ja kääntynyt väärälle tielle	☐	☐	☐	☐	☐	☐
Ajanut niin lähellä edellä ajavaa, että pysähtyminen olisi ollut vaikeaa hätätilanteessa.	☐	☐	☐	☐	☐	☐
Ajanut liikennevalojen läpi vaikka valot olivat jo vaihtuneet punaisiksi	☐	☐	☐	☐	☐	☐
Raivostunut toiselle kuljettajalle ja näyttänyt suuttumuksenne kaikin mahdollisin keinoin	☐	☐	☐	☐	☐	☐
Huomannut olleenne jonkin aikaa niin ajatuksissanne ettei teillä ole selvää muistikuvaa tiestä, jota olitte juuri ajanut	☐	☐	☐	☐	☐	☐
Ohittaessanne aliarvioinut lähestyvän ajoneuvon nopeuden	☐	☐	☐	☐	☐	☐
Rikkonut nopeusrajoitusta moottoritiellä	☐	☐	☐	☐	☐	☐

Pitävätkö seuraavat liikennettä koskevat väitteet mielestänne paikkansa?

Seuraavassa on esitetty liikennettä koskevia väitteitä. Arvioikaa missä määrin väitteet pitävät mielestänne paikkansa laittamalla rasti oikean vastausvaihtoehdon kohdalla olevaan ruutuun. Vastausvaihtoehdot (1-5) ovat:

1=ei pidä lainkaan paikkaansa 2=ei pidä juuri lainkaan paikkaansa 3=siltä väliltä 4=pitää jokseenkin paikkansa 5=pitää täysin paikkansa

	1	2	3	4	5
Jos toinen kuljettaja käyttäytyy vihamielisesti minua kohtaa, minulla on oikeus maksaa samalla mitalla takaisin	☐	☐	☐	☐	☐
Joidenkin ihmisten luonne muuttuu kun he ajavat autolla	☐	☐	☐	☐	☐
Jos joku tekee vaarallisen virheen liikenteessä tai ajaa holtittomasti, minun pitäisi huomauttaa häntä siitä esim. vilkuttamalla auton valoja tai äänimerkillä	☐	☐	☐	☐	☐
Vihamielinen käyttäytyminen liikenteessä johtuu pääasiassa liikenneolosuhteista	☐	☐	☐	☐	☐
Joskus suutun ajaessani niin paljon, että minun on yksikertaisesti purettava kiukkuni toiseen kuljettajaan	☐	☐	☐	☐	☐
Poliisi ei kiinnitä tarpeeksi huomiota vihamieliseen käyttäytymiseen liikenteessä	☐	☐	☐	☐	☐

Miten suhtaudutte autolla ajamiseen?

Pelkään ajamista ja yritän välttää sitä	☐
En pidä ajamisesta, mutten myöskään pelkää sitä	☐
Ajaminen on minulle vain paikasta toiseen siirtymistä	☐
Pidän ajamisesta	☐
Pidän ajamisesta hyvin paljon ja ajan mielelläni	☐

APPENDIX 6 VISUAL ANALOGUE SCALE (VAS)

Kuinka hyvin mielestäsi suoriuduit ajotehtävästä?

Merkitse alhaalla olevalle poikittaisviivalle yksi pystyviiva, joka mielestäsi kuvaa ajotehtävässä suoriutumistasi.

Huonosti Erinomaisesti

APPENDIX 7 NASA-TLX

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX 8 AJOJEN TASAPAINOTTAMINEN

Kokemattomat (N) / Kokeneet (E)	1	2	3
N1 / E1	Tutustuminen	Ajosimulaattori	Liikenne
N2 / E2	Tutustuminen	Liikenne	Ajosimulaattori
N3 / E3	Tutustuminen	Ajosimulaattori	Liikenne
N4 / E4	Tutustuminen	Liikenne	Ajosimulaattori
N5 / E5	Tutustuminen	Ajosimulaattori	Liikenne
N6/ E6	Tutustuminen	Liikenne	Ajosimulaattori
N7 / E7	Tutustuminen	Ajosimulaattori	Liikenne
N8 / E8	Tutustuminen	Liikenne	Ajosimulaattori
N9 / E9	Tutustuminen	Ajosimulaattori	Liikenne
N10 / E10	Tutustuminen	Liikenne	Ajosimulaattori

Taulukko 1 Ajojärjestyksen tasapainottaminen koehenkilöiden välillä.

Kokemattomat (N) / Kokeneet (E)	1	2	3
N1 / E1	harjoitusajo (city)	city	mlaakso
N2 / E2	harjoitusajo (city)	mlaakso	city
N3 / E3	harjoitusajo (city)	city	mlaakso
N4 / E4	harjoitusajo (city)	mlaakso	city
N5 / E5	harjoitusajo (city)	city	mlaakso
N6/ E6	harjoitusajo (city)	mlaakso	city
N7 / E7	harjoitusajo (city)	city	mlaakso
N8 / E8	harjoitusajo (city)	mlaakso	city
N9 / E9	harjoitusajo (city)	city	mlaakso
N10 / E10	harjoitusajo (city)	mlaakso	city

Taulukko 2 Simulaattoriajon ajojärjestyksen tasapainotus.

APPENDIX 9 AJOLOKI - SIMULAATTORI AJOTAPAHTUMAT

Ratti-projekti 12.12.2012

Ajosuorituksen tapahtumat kh: pvm:

City _____ajo

Ajoaika	Tapahtuma

Mlaakso _____ajo

Ajoaika	Tapahtuma

APPENDIX 10 – SIMULAATTORIPAHOINVOINTI – KYSELY

Koitko jotain seuraavista oireista ajon aikana?

Merkitse rasti (x) yhteen ruutuun per kysymys: Ei, Lievää, Kohtalaista tai Voimakasta.

	Ei	Lievää	Kohtalaista	Voimakasta
1) Epämukavuutta?				
2) Väsymystä?				
3) Päänsärkyä?				
4) Silmien rasitusta?				
5) Vaikeuksia tarkentaa katsetta?				
6) Syljenerityksen lisääntymistä?				
7) Hikoilua?				
8) Pahoinvointia?				
9) Keskittymisvaikeuksia?				
10) Painetta päässä?				
11) Näkökentän sumentumista?				
12) Huimausta (silmät auki)?				
13) Huimausta (silmät kiinni)?				
14) Tasapainottomuutta?				
15) Vatsaoireita?				
16) Röyhtäilyä?				