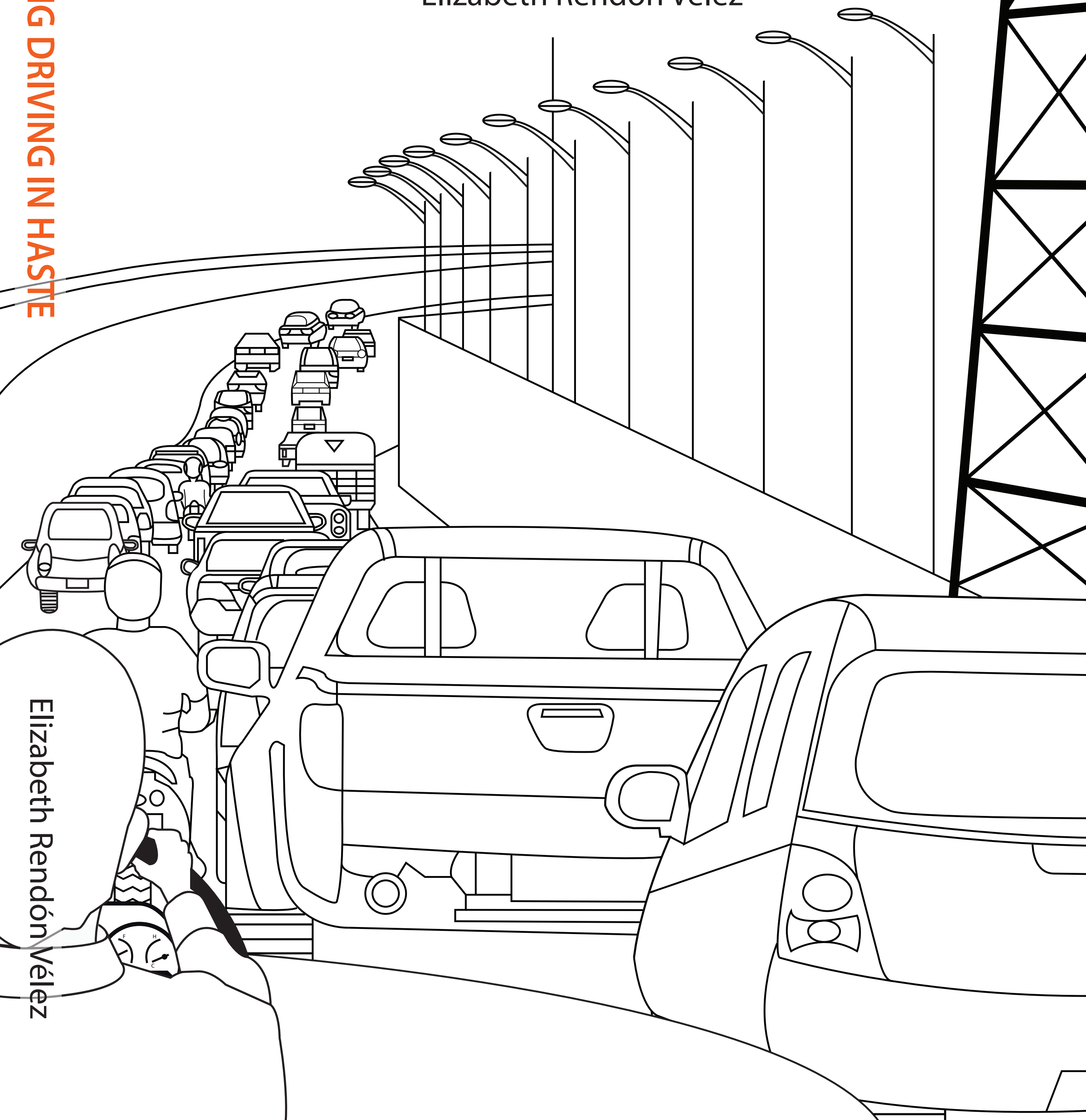
RECOGNIZING DRIVING IN HASTE

Elizabeth Rendón Vélez



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Dedicated to
Juan, Nico and Isa, and to my family
for their unconditional love

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List of abbreviations

ADAS	Advanced Driver Assistance System
ANS	Autonomous Nervous System
BVPs	Blood Volume Pulse sensor
Ci	Congruency index
COi	Correspondence index
DBQ	Driver Behavior Questionnaire
DIR	Design Inclusive Research
ECG	Electrocardiogram (also referred to as EKG)
EEG	Electroencephalography
EMG	Electromyography
EOG	Electro-Oculography
FFT	Fast Fourier Transform
FSR	Force Sensing Resistor
HCADAS	Human-Centered Advanced Driver Assistance System
HF	High Frequency (ranges >0.1Hz)
HGV	Horizontal Gaze Variance
HR	Heart Rate
HRV	Heart Rate Variability
HTP	High Time Pressure
IBI	Interbeat Interval
IR	Infrared
LED	Light Emitting Diode
LF	Low Frequency (ranges <0.1Hz)
LS	Lomb-Scargle periodogram

M	Mean
MDSI	Multidimensional Driving Style Inventory
N	Number of participants
NASA-TLX	NASA Task Load Index
NN	Normal-to-Normal beat
NTP	No Time Pressure
P_e	Pauses after expiration
P_i	Pauses after inspiration
PNS	Parasympathetic Nervous System
POR	Point Of Regard
PPG	Photoplethysmograph
PSD	Power Spectral Density
QRS	Combination of three of the graphical deflections seen on a typical electrocardiogram (ECG)
R	Point that corresponds to the peak of the R wave in the QRS complex of the ECG signal
rAMP	Respiratory Amplitude
RDC	Research in Design Context
rIBF	Respiration Interbreath Frequency
RMS	Root Mean Square
RR	Time interval between successive Rs
SD	Standard Deviation
SDNN	Standard Deviation of the Normal-to-Normal beat
SNS	Sympathetic Nervous System
T_c	Average time constraint per condition
T_e-T_c	Average time shortage
T_e	Average time under experimental condition
T_e	Expiration time
T_i	Inspiration time
T_{tot}	Duration of each respiratory cycle

VLF	Very Low Frequency
VSAT	Variable State Activation Theory
V_t	Tidal volume

Chapter 1

Introduction: The addressed research domain and objectives

1.1 Personal scientific interest

One can often hear people discussing the reasons why a road accident has happened: "He was trying to overtake the trains of cars in front of him by all means and didn't pay attention to the other car coming against", "She had to pick up her kids in the school before four o'clock and she was driving in haste and careless", "He was stressed, he wanted to reach the beginning of the football match, tried to drive faster and didn't notice the red light". In each of these statements, a single cause is identified: a driver in a haste situation and in a danger. When an accident happens, the effect of this dangerous state is profound and often irreversible. What driving in haste mainly influences are reduced risk perception and careless decision-making. These two factors play an important role in many accidents ending with injuries and damages. When people have less time for achieving their travel destination due to reasons related to road traffic, they typically become stressed and ignorant, even absent-minded. The perception of risk in a particular situation typically turns to be inaccurate and the fast and superficial decision making may lead to dangerous happenings. But, can current technology do something in this context? Is there any solution to reduce the risk in driving in haste? Can we make steps towards a driver assistant system that reduces the chance of misbehaving and fatal accidents? These were the general research questions that stimulated us to gain a better insight in this important domain of interest and to make the first steps towards the development of a smart driver assistant system.

Human beings have a natural ability to perceive dangerous behavioral and action states. They are able to recognize when a person is not in an optimal state from a broad spectrum of verbal and non-verbal modalities and, based upon their observation, they are able to take some actions that positively impact the state of the other person. The human perception of an affective state goes in too many situations beyond what science is able to understand. Skilled humans can assess these states with varying degrees of accuracy, and researchers are just beginning to make progress giving devices and products similar abilities at recognizing states. But, just imagine a device that, acting as your copilot, is able to capture your physical and mental state and help you in the situation assessment and decision-making when you are not in an optimal state for driving. Just imagine yourself driving with a virtual copilot that is aware not only of your behavioral state, but also of the situation inside and outside the vehicle[1]. A virtual copilot, playing the role of an active human passenger who is aware of your state, may be very useful to maintain a normal or controlled driving situation. However, before designers can create a device that has the capability of accurately identifying the state of mind of the person continuously and dependably, they first must understand how the driving in haste appears, how it develops, based on what symptoms it can be recognized, and how it can be eliminated or compensated for. These guiding research questions have been the drivers of doing the specific research that is reported on in this thesis.

My personal long-term objective and interest are to make a step towards the development of an accident prevention system that is able to recognize being in dangerous states of driving. I want to equip cars with the ability to recognize the state of the person in order to be able to help him in the perception, situation assessment, and risk prediction and avoidance. I truly believe that in the near future, all kind of products will be more capable of recognizing and understanding human behaviors, inferring human states and adapting their behavior to them, giving appropriate responses. The progress in the field of social-cyber-physical systems that are able to extract control information from real life processes and adapt their operation to dynamically changing situations, behaviors and context is the guarantee that we may count on these types of solutions in the near future. The technologies are already more or less available; we just have to exploit them. However, the development of successful solutions needs deeper understanding of the involved phenomena, relationships, needs, opportunities and affordances. Exactly this deeper understanding and new insights are the targeted deliverables of this promotion research work, which also tries to synthesize and built on knowledge that was acquired in past research of other researchers and developers.

1.2 Risk reduction in driving situation

With the ever-growing car usage and the more frequent occurrence of complex driving situations, the number of accidents leading to injuries and fatalities has increased dramatically in many countries. Traffic-related accidents are considered to be serious social and technological problems with global dimensions. A study made by the World Health Organization (WHO) revealed that annually as many as 50 million people are injured and over 1.2 million fatalities occur worldwide [1,2]. European commission, national governments and vehicle manufacturers have over the years promoted a number of projects and programs with the common goal of reducing the number of fatalities and injuries in road traffic accidents. Although the number of fatal traffic accidents has been reduced due to comprehensive efforts including maintenance and improvement of the traffic environment and the greater installation of vehicle safety systems, the number of traffic accidents where people are injured is still high [3]. Risk in driving is defined as

[1] Note that vehicle normally refers to a thing used for transporting people or goods, especially on land, such as a car, bus or truck. The main interest in this thesis are cars.

the probability or likelihood of a crash resulting in injury, damage or loss [4]. Since this probability can be reduced by taking preemptive actions, the understanding of risky behaviors/states (e.g. disregarding traffic signals, following too closely, being distracted, etc.) and of the influence of the road network in driving situations has become an urgent issue for the creation of a sustainable transportation society.

In order to enhance the safety of mobility (travel and transportation) and reduce this risk, a number of projects have been proposed in the last few years, ranging from enhancement of infrastructure to vehicle-based safety systems [5]. Conventional approaches to vehicle safety are mainly based on passive safety systems (e.g. airbags, seatbelts, pre-tensors, laminated windshields and collapsible steering columns), which try to minimize the severity of injuries caused in traffic accidents, rather than to prevent them.

In present-day vehicles, the above mentioned passive safety systems have been complemented by active safety systems, which are supposed to prevent and minimize the effects of a crash. These include electronic stability control, traction control and dedicated driver assistance systems, such as adaptive cruise control, lane departure warning, collision mitigation, distance following and parking assistance. For the reason that it is better to prevent accidents than just to reduce the severity of injuries, the concept of active safety systems has received attention and solutions for Advanced Driver Assistance Systems (ADASs) have gained popularity in the last years [6]. Forecasting and prevention are receiving enhanced attention in current research, together with a continuous situation assessment and real-time risk prediction. The following sections provide more concrete references to specific ADAS-related projects that help in reducing the risk of accident.

1.3 ADAS as the means for reducing the risk in driving situation

Reports on causation of road traffic crashes show that about 93% of the accidents involve human error [7]. In an attempt to reduce this amount of accidents, sensing systems that assist and warn the driver have been developed in the last few years. Specifically, Advanced Driver Assistance Systems mainly help to prevent accidents and reduce the risk in driving situations by assisting the driver in their driving task continuously. In addition, some of them also have the functionality of increasing comfort and efficiency. Unlike seatbelts and airbags that mitigate the effects of a crash, ADAS act preemptively. Instead of only decreasing injury or improving the chances of survival in an accident, some ADASs are designed to prevent an accident from happening in the first place, in some instances by taking control of the car. ADAS mainly support the driver in the three sub-processes of the driving task: the perception of the environment, the analysis and decision for a certain driving situation and the action. This support ranges from simple information presentation through advanced assisting and even taking over the driver's task in critical situations.

Examples of ADAS include: (i) the lateral control ADAS, such as the lane departure warning system and lane change collision avoidance systems. These systems improve road safety and risk reduction by prevention of unintentional lane departure or lane changes, (ii) the longitudinal control ADAS, such as Intelligent Speed Adaptation (ISA), Adaptive Cruise Control (ACC) and

Collision Avoidance Systems (CAS). These systems reduce the risk in driving by controlling the vehicle speed, providing support in keeping safe distance during vehicle following and by preventing collisions with surrounding objects in different situations, (iii) the parking and reversing aids, which mainly detect obstacles in low speed situation. These ADAS solutions do not have high impact on road safety, but enhance the driving experience, and (iv) the vision enhancement systems, such as the pedestrian detection, night vision systems, and blind spot monitoring. These systems reduce the risk in driving by helping the drivers while driving during night, driving in an unfamiliar area and by detecting non-visible objects.

1.4 Overview of the current state of the art in ADAS

As mentioned above advanced driver assistance systems mainly support the driver in driving tasks by helping him in the perception of the environment, the analysis of the situation, the evaluation of the risk and the proper action to make in a particular situation. There are two main types of ADASs: conventional ADAS and human-centered ADAS (Figure 1.1). A conventional ADAS works parallel with the driver, considering inputs only from the environment (road, pedestrian, objects, other vehicles, etc.) and the vehicle (speed, acceleration, etc.) [8]. This means that the systems perceive and analyze a situation and then take an action in the same way the driver does. There is no consideration of the driver in the loop. The system is not aware of the driver's characteristics, states, or actions. Conversely, human-centered ADAS consider the characteristics and states of the driver. They not only work parallel with the driver, but also bring him into the loop and intend to take all the important aspects into consideration. Human-centered ADASs work cooperatively with and adapting to the driver rather than letting the driver adapt to the system. In the next sections, Perception ADAS, Analysis-decision ADAS and Action ADAS that only work with vehicle and environment inputs will be presented. Due to the fact that perception errors and analysis-decision errors constitute about 90% of all human errors when driving, an emphasis is put on the Perception and Analysis-Decision ADAS [9]. For the Action ADAS, only a brief explanation of what they are is presented. Following these sections, Human-Centered ADAS are explained. In the latter section, an emphasis is placed on the driver monitoring function.

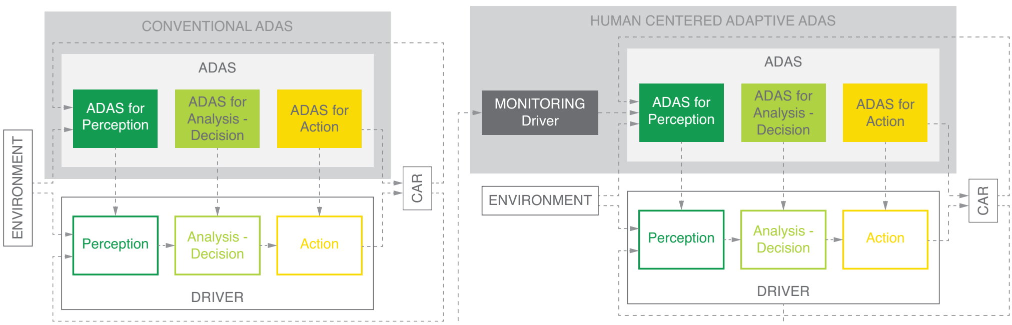

Figure 1.1. Conventional ADAS (left) and human centered ADAS (right) [10]

1.4.1 ADAS supporting driver perception

Perception ADAS take the information from the environment and present enhanced information to the driver allowing him/her to have better knowledge of the surroundings for the situation analysis process [10]. The main objective is to enhance the driver's perception of potential hazards. These systems mainly work with cameras that resemble the way the driver sense the environment but they are not limited to it. Other types of technologies used are Laser Imaging Detection And Ranging (LIDAR) and the RAdio Detection And Ranging (RADAR) systems.

Perception ADAS usually perform the sub-processes of monitoring, detection and classification of the information for the recognition of elements (objects, people, events, environmental factors) and their actual states (position, orientation, conditions). Representative systems of this group are the night enhanced vision systems, the pedestrian detection systems and the blind spot monitoring systems. The research on this area mainly focuses on the sensors (mostly cameras), the displays used for showing the information and the image processing techniques.

Sensors are mainly used for detecting the environment surrounding the ego-vehicle[2] such as the road, other vehicles, objects and/or pedestrians [11]. The sensors used can be categorized in active and passive sensors [12]. Active sensors emit electromagnetic energy. From the reflection of this energy, objects can be detected. Well-known active sensors are radar sensors, laser sensors, sonar sensors and near-infrared sensors. The main advantage of active sensors is that they have the ability to obtain measurements at any time, regardless of the time of day or the weather conditions [12]. Drawbacks of active sensors are low spatial resolution, slow scanning speed, size and costs. Passive sensors, on the other hand, detect naturally reflected or radiated energy. This means that they acquire information in a nonintrusive way. The most well-known passive sensor is the optical sensor (camera) and the far-infrared sensor. By means of a camera, moving objects (for example other vehicles or pedestrians) can be effectively tracked. The main drawback of passive sensors is that they are easily affected by illumination changes as well as by complex environments [13].

For the night enhanced vision systems, mainly two sensors are used: The near and the far infra-red sensor [11]. The near infrared systems actively illuminate the scene in the near infrared spectrum and capture the reflected radiation. The far infrared sensors generate images by passively detecting thermal emissions from objects and surfaces in the road scene. Some advantages and drawbacks have been mentioned for both far and near infrared sensor systems [14].The far infrared sensor has a larger spatial coverage than the near infrared sensor, but its image looks rather unfamiliar [15]. Although near infrared sensors present a realistic image of the environment, Tsimhoni et al. [14] compared pedestrian detection performance with both types of sensors reporting that the detection had a greater effectiveness when far infra-red sensors were used. Although there are some Perception ADAS that use active sensors, application of passive sensors is more common.

Regarding the image processing, different approaches to automatic processing have been used to improve camera output. Simple algorithms only try to reduce the glare effects or to sharpen the contrast of the image [15]. More intelligent approaches also detect and enhance specific features such the outlines of objects. In a knowledge-based categorization process this is used to detect pedestrians in the scene [16] or other vehicles. In the field of pedestrian detection, the main

[2] ego-vehicle refers to the vehicle being equipped with a safety system

challenges are [17]: (i) figure size (when pedestrians appear very small in the image due to limitations of the sensor), (ii) fast dynamics (the detection latency must be small and decisions must be obtained within few frames), (iii) heavy clutter (pedestrian detection is typically taking place at urban scenes with a lot of background noise), (iv) articulation (pedestrians are non-rigid objects, spanning high variability in appearance and cause tracking difficulties). Both, the fast dynamics and the heavy clutter challenges, require high classification precision, thus research focuses on the development of dedicated pattern classifiers.

Regarding the display technology, no industrial standards have been developed yet. The information is presented to the driver using head-down display taking the place of the conventional instrument panel, a head-up display integrated into the dashboard in front of the driver, or a head-up display using the windshield for projection (see Gish & Staplin, [18], for a detailed literature review). The information is normally presented using analogue video image which may lead to higher demands on visual and mental resources resulting in potential impairment because drivers have to search for relevant information on the display and compare it with the outside. These problems have been discussed at length (e.g. Tsimhoni and Green [19] and Rumar [20]) but, up to date, research studying them in an experimental design under real traffic conditions is limited.

1.4.2 ADAS supporting driver analysis-decision making

The Analysis-Decision ADAS are systems that help the driver in the situation assessment and risk prediction. These systems not only place an emphasis on the environment itself or on the objects in the environment, like pedestrians or other vehicles individually, but also on the relationships among the detected objects. This means that comprehension of the current situation and the projection of the future status (based on the arrangement and dynamic of the elements) must be carried out.

It is implicit that these systems also need to capture the environment through the use of sensors. With this information and a general knowledge about physical rules and behavioral patterns, the system tries to assess the risk in a situation in order to help the driver in making a decision. The situations that have been assessed by most of the systems are lane departure, over speeding on curves and collision with other vehicles or objects (forward collision, rear collision and lateral collision) [10]. Most of the systems developed until now just consider only one of these situations. The level of the precision for the recognition of a risky situation is related to the kind of algorithm used to detect that particular situation and, of course, to the number of variables considered from the environment and vehicle in the analysis of this situation.

The research on this area is mainly focused on the situation assessment algorithms. Commonly, the algorithms that have been developed are grounded in rule-based approaches where a descriptive or indicative variable is compared with a threshold value in order to determine the situation and its criticality. In situations like lane departure, the simplest variable that can be used to assess the situation and its risk is the lateral offset [21] or, in other words, the distance between the left border of the road and the center of the front bumper of the subject vehicle.

Enhanced approaches, like the one presented by Pormelau [22] use time-to-lane-crossing (TLC), which is a measure of the time remaining before a vehicle moving on a given trajectory departs the road. In general the TLC provides more time for warning than the lateral offset but sometimes this prediction can be wrong because its calculation only takes into account the vehicle's trajectory omitting other driver's behavior. Unfortunately, real-time computation of TLC is not easy due to several limitations concerning availability of vehicle state variables, vehicle trajectory prediction and lane geometry [23]. Computation time is also a limiting factor. As a result, approximate models are used. The usual one is the ratio of lateral distance to lateral speed. Although this approximation has been used in several works, this model is not valid when the lateral speed varies [24]. To tackle this problem, another approach that does not consider the lateral speed and only considers the forward speed has been developed [23]. However, it requires a long preview of vehicle path and road geometry. Besides, there is an assumption of road straight geometry which rarely happens. With the introduction of more sensors in the vehicle and the use of GPS and accurate maps, there is a better knowledge of the vehicle trajectory and a better road description, which allows for a better calculation of the TLC. Mammar et al. [23] have presented a comparison between different models for the calculation of TLC.

In situations where a collision is possible, most of the methods for determining a possible collision are based on deterministic approaches that try to predict the future states of the vehicle involved in the traffic situation and estimate the effort to avoid the accident [25]. Commonly, they try to assess only one kind of threat and they take action when that specific threat is detected [26]. To characterize the emergency level of this dynamic situation, quantitative measures such as time-to-collision (TTC) [27], predicted minimum distance, predicted time to minimum distance [28] and required deceleration are used [29]. Other approaches, generally probabilistic based approaches, try to assess more than one threat. For example, Broadhurst et al. [30] present a framework for reasoning about the future motion of multiple objects in the scene. This method is used to find threats by predicting the paths of the objects using Monte Carlo simulation. In theory, any kind of threat could be detected. Based on this framework, Eidehall et al. [31] define a new form of threat assessment with some modifications. One of the main contributions of these authors is a new way to create a more efficient use of the samples. Although probabilistic approaches seem to be a good solution for determining multiple threats, the fact that the algorithms used are computationally expensive makes these approaches still far from being implemented in commercial vehicles.

Other situation that has been commonly assessed is the speeding on curves. For the assessment of this situation, the conducted investigations compare the actual speed with the maximum authorized speed. The research effort in this situation is concentrated in the calculation of the maximum safe speed for a particular curve, which usually depends on the road geometry, the surface conditions, the skill (or tolerance for discomfort) of the driver and the rollover stability of the vehicle. The developed experimental systems vary in the different models used to calculate this speed. The simplest model considers only the curvature of the road and assumes a vehicle moving at constant speed on a circular section [32]. Other approaches, like the one presented by Pormelau [22], also consider the super-elevation of the road and the driver behavior. In recent studies, even more precise models are used. The model presented by Glaser et al. [33] considers a relatively accurate description of the road (the curvature, the super-elevation, the slope, and the maximum available friction), as well as the driver behavior.

Most of the preventive (active safety) systems developed so far are focusing only on a single slice of the road around the given vehicle (only one of the situations described above). There are only few efforts, like the PREVENT project, to develop a more integrated approach putting together different safety systems [34]. This integration does not mean that a safety zone is created as a final holistic functionality of a vehicle, but that joining different systems produces an extended safety zone.

1.4.3 ADAS supporting driver action

The Action ADAS help the driver to control the vehicle when a dangerous situation happens [8]. In order to be able to do this, a system should be aware of the environment and it should have analyzed the situation so as to know the type of action to be performed. This implies the execution of the first two cognitive tasks performed by the driver: perception and analysis. The action performed is, indeed, linked to the situation analyzed. For example, if the system was preventing a lane departure, the action would be to steer the car into a position where the departure is avoided.

Most of the systems that can be classified as Action-Systems are preventing or minimizing a collision such as (i) collision mitigation systems, which usually intervene when a collision is unavoidable and actuate (e.g. the brake system in order to reduce the consequences of a collision by reducing the impact speed), and (ii) collision avoidance systems, in which the trajectory of the involved vehicle(s) is changed in order to avoid an impact. In the first case, once the system has been established that a collision is unavoidable, autonomous emergency braking is activated to reduce the collision speed. In the second case, when the system establishes that a collision is imminent, the autonomous steering function is activated in order to avoid such collision. These types of systems work mostly in the same way as the Analysis-Decision ADAS. The only difference is that, instead of issuing warnings or providing information to the drivers, a control function is used in order to control the vehicle by steering or braking. Therefore, the inputs for these systems and most of the critical factors are the same as the inputs and the critical factors for the analysis and decision support systems.

1.4.4 Human centered ADAS

Although conventional ADAS offer good service for preventing accidents, there is no adaptation to the driver. The physical characteristics, activities or mental state of the driver are not fully taken into account [10]. If we think in ADAS as a human co-pilot, to be of any help, the co-pilot should not only be aware of what is happening outside the car (e.g., how is the road turning?, are there any pedestrian crossing the road?, etc.) but he should also be aware of what is happening inside the car (i.e., the driver's responses or intentions such as braking or changing lanes; the driver's state such as fatigue, intoxication, angriness; and driver's limitations such as visual acuity, reaction time, etc.). A co-pilot should intervene if he realizes that the driver failed to notice an upcoming situation. That means, the co-pilot, based on the driver's situation inside the car, analyzes the outside situation and provides a warning only when it is necessary. We are talking about "Human-Centered Advanced Driver Assistance Systems (HCADAS)" or, in other words, systems that are adaptive to the driver and, thus, take the driver's characteristics into account in order to better understand the situation and provide help without exasperating false alarms or incorrect information. HCADAS are not standalone systems, but rather systems that work cooperatively with the driver.

Research in this area is mainly focusing in the driver monitoring function and in how to blend drivers' state information with the situation assessment and risk prediction. Due to the fact that the driver monitoring function is vital in these type of systems and that it is what makes the difference between conventional ADAS and Human centered ADAS, in the next sections efforts are concentrated in reviewing the state of drivers that contribute to traffic accidents and in listing the ones that been detected by using technology.

1.5 States of the driver that contribute to traffic accidents

As mentioned before, the most prominent factor contributing to the vast majority of traffic accidents is the behavior of drivers when they are under certain psychological, physical or physiological state. According to various studies in Europe, USA and Asia, over 90% of car accidents can be traced back to some degree of driver misbehavior combined with equipment failure, improper roadway design, or poor roadway maintenance [7,35-37]. Misbehavior of drivers may take many forms (e.g., running red lights, tailgating, etc.). Many of them appear when drivers are distracted, fatigued, or when they drive under the influence of alcohol, under time pressure, or in any other medical conditions. The European Project TRACE presents statistics of the causes of road traffic accidents in Europe provided by 21 institutes from different countries [38,39]. Due to the different coding and classifications in the databases, this project classified their results into more general factors. Specifically, the contribution of the: (i) inattention factor to traffic accidents was found to be up to 40%, (ii) distraction factor up to 37.7%, (iii) careless, reckless or thoughtless factor up to 39%, (iv) being in a hurry factor up to 23%, (v) fatigue factor up to 17.4%, (vi) aggressive driving factor up to 10.3%, (vii) falling asleep factor up to 5%, (viii) acute medical conditions like loss of consciousness, sudden illness or faintness up to nearly 5% and (ix) different moods (e.g., anger, pre-occupation, etc.) up to 3.9%. Note that these values correspond to the highest result presented among the databases included for each factor.

A Japanese study also found that the most frequent mental and physical state of the drivers immediately before the incidents were, in descending order, haste – "being in a hurry" (28%), lowered concentration (25%), and drowsiness (8%). The top position of haste in the results matches the results of the investigation of driver mental and physical states immediately before accidents conducted by Maruyama [40]. In the USA, according to the Unsafe Driving Actions (UDA) study and the Indiana University Tri-Level study, the principal human direct causes of crashes were also (i) attention errors contributing up to 47.9%, (ii) excessive speed/"being in a hurry" contributing up to 20.1% of the crashes, (iii) alcohol/drug impairment contributing up to 5.2%, (iv) fatigue contributing up to 1.7%, and (v) emotional upset contributing up to 1.2% of the crashes [41].

From all these dangerous states, the ones that have been more studied are fatigue, distraction, emotions and drug impairment, all of which are at the top position of accident causation statistics. Currently, there are many researchers focusing on the understanding of these phenomena in the context of driving a car. Psychologists concentrate their efforts particularly on the causes, symptoms and counter-measures in order to reduce the number of traffic accidents triggered by these conditions around the world. Engineers are using psychological studies in order to develop solutions for monitoring these particular states and warn the driver or alert other driver support systems when needed. The introduction of these driver's states in the analysis of a dangerous situation has been reported in studies of collision and lane departure warning [42,43].

However, from the variety of dangerous states present in the driving context, some of those mentioned above have not been considerably explored such as driving in haste, or under any medical condition. Specifically driving in haste or in a hurry is at the top position of the most common causes of traffic accidents according to the abovementioned studies. Although several studies claim that the effects of being in haste usually contribute to risky behaviors in driving, most of the papers do not address the manifestations of haste (i.e. physiological reactions, behavioral changes, etc.) [44]. To our best knowledge, the understanding of this phenomenon is still at a low level. This research will be particularly focusing on this phenomenon of driving in haste. In the following sections the phenomenon will be explained and forerunning research will be presented.

1.6 Forerunning research in studying driving in haste

In general haste, or the state of being in a hurry (or being rushed), has been recognized as a phenomenon that often has negative effects on the well-being of the drivers [45,46]. Feelings of being rushed are prevalent across society causing concern for how this experience of hurriedness impacts upon the well-being of individuals and family [47]. The complex phenomenon of haste arises from several different factors, of which the most important ones are: (i) physiological factors, (ii) social pressure, (iii) motivational states, and (iv) time-related factors. Typical physiological factors are physical urges or instinctive impulses such as the need to drink, eat, urinate and defecate. In the case of social pressure, people rush because they are obliged to maintain cultural norms for speedy behavior or because they are in an environment where there are social consequences for slowness [48]. The motivational state of the person refers to a predisposition to hurry - time-urgent personality [49] or to operate in certain states (e.g., irritability, angriness, etc.), or to circumstances where the person attempts to perform multiple tasks at once or has trouble relaxing/getting work off his mind [50,51]. Time-related factors signify a shortage of time to perform a task, i.e., being late in meeting a dead-line or being late for an appointment [52].

All these different factors, which can be defined as stressors, place a demand on the person inducing some feelings of stress [53]. Based on Lazarus and Folkman's Transactional Model of Stress and Coping, these stressors (or potentially stressful events) trigger an appraisal process in which the person assesses the degree of threat that this stressor imposes on his/her wellbeing and determines the ability to manage or cope this threat with the resources he/she has available [54]. This form of stress, triggered by any of the above mentioned factors, experienced as a feeling of hurry, and in which the first coping mechanism that comes to mind is acceleration of actions, is what is referred to in this research as *haste* (Figure 1.2).

Although haste is commonly associated with the physical condition of rapidly executing actions, when the execution of rapid actions is not feasible, haste is manifested by other behavioral changes that are also result of this feeling of hurry. In order to understand this other behavioral changes, literature on driving in haste has to be further studied. Some forerunning research focuses on identifying causal factors for driving in a hurry. Specifically, they focus on people that are prone to show risky behaviors when driving in this state and the situational factors that may elicit or exacerbates this feeling. Other researchers concentrate on the relation of this phenomenon with risky behaviors and its relation to other risky states.

The studies that identify factors that influence driving in a hurry/haste[3] are scarce. To the author's knowledge, little is known about the factors that trigger or aggravate driving in a hurry. Only very recent questionnaire-based studies address this gap. In a recent study, predominantly itinerant professionals and people of working age were identified as the people more prone to drive in this state [55]. Additionally, in the study presented by Obermair [56], it was also found that older people drive less often under time pressure and perform less aggressive behaviors compared to younger people. One of the reasons suggested for this behavior is the generalized decrease in activity in daily life as age increases. Moreover, these studies did not find any difference between male and female. The non-significant result was probably due to participants' denial of either the frequency and intensity, or the level of social representation and individual experience.

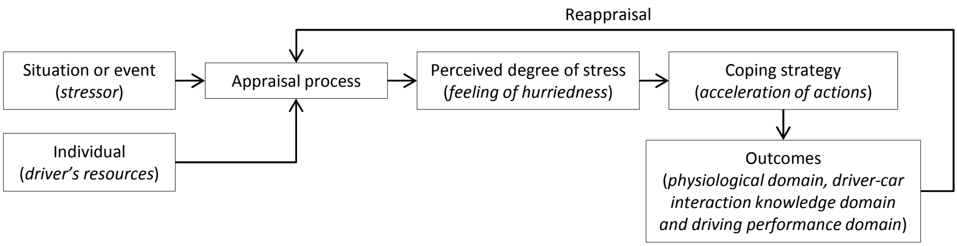

Figure 1.2. Definition of haste based on the Transactional Model of Stress and Coping [54]

Regarding situational factors, frustrating road situation (e.g., stopping behind a car that does not move) and traffic congestion on roads were referred to as the main factors that trigger or intensify driving in a hurry and other emotional states connected to it such as anger [57]. Fuller and Tarko [58,59] suggested that the emotions of impatience and frustration could occur when traffic congestion forced drivers to travel more slowly than they wanted to. This would lead them to select routes and speeds that they believed would shorten their travel time and, thus, would result in an increase in the level of haste. Drivers' impatience during frustrating situations was found to be a function of haste (time pressure), where when haste (time pressure) increases, impatience, arousal and negative valence also increase [60].

Additionally, Beck et al. [50] confirmed that the higher levels of frustration and impatience presented by hurried drivers with respect to other drivers on the road indicated that they had difficulty in withstanding or coping with negative psychological states when driving. This inability to cope with negative emotional states and with aversive conditions (such as congested traffic) is what, according to them, led the driver to perform risky behaviors. This confirmed that frustrating on-road events can act as a trigger to aggressive behaviors [61]. The result of these studies gives a useful basis for the identification of the people prone to this state and for the understanding of the influence of situational factors in the feeling of haste. However, the results are still exploratory

[3] The concepts hurry and haste are used indistinctively along this document

and based on questionnaires. More objective studies performed in driving simulators or in actual roads are needed. Additionally, little is known about the individual characteristics that modulate haste. In this area, the studies fail to provide data about the driving style of the person and potentially relevant personality traits of the participants, such as type A/B personality, sensation seeking, and driving trait-anxiety.

In addition to the studies mentioned above, the study of the relation between being in haste and other risky states and emotions, as well as its effects in terms of risky behaviors, has gained importance in the last few years. Questionnaire-based studies have reported a high relation between being a hurry and other motivational states or negative emotions such as anger [56]. Cœugnet et al. [55] believe that the negative emotion emerges (fear, anger/aggressiveness) when the driver does not have enough resources to cope with the demand that causes him/her to drive in a hurry and his/her evaluation regarding the performance is unfavorable. However, these authors also believe that a positive emotion may arise when the person has coping responses for the optimal performance of the task. This often happens for moderate levels of haste because the individual is able to perform optimally [62]. To the author's knowledge, there is no research addressing the mechanisms behind the relation of haste with emotions. Currently, it is still not clear when or how haste produces negative or positive/neutral emotions. Researchers do not know whether the level of haste felt by the drivers is what explains the emotional feelings or whether negative emotions are explained by the characteristics of the driver or previous emotional states. Further research is needed to clarify this.

In addition to a relation with emotional states, hurried drivers were also found to be related to a variety of risky driving behaviors, including more extreme levels of aggressive behaviors on roads (e.g., fast acceleration, horn honking, weaving, etc.), driving after drinking and being ticketed for a moving violation [63]. Emotion-focused coping and avoidance-focused coping of hurried drivers have been established as the cause of deterioration in driving performance and the appearance of aggressive behaviors [64]. From the risky behaviors performed by hurried drivers, speeding was the most often reported in the different questionnaire-based studies. According to Gabany et al. [65], who developed a speed perception inventory, driving in haste due to time shortage is one of the five factors contributing to the speedy behavior. According to McKenna et al. [66], who surveyed 9470 drivers, the choice to exceed speed limit is influenced by the level of haste felt by the driver: the higher the level of haste, the higher the willingness to exceed the limit. The results of these questionnaire-based studies were confirmed by a driving simulator study were participants driving in a hurry, due to a lack of time to arrive at a destination, drove faster and felt more activation than participants driving to the same destination under normal conditions, that is without a time constraint [67]. This last study did not test the presence of any other risky behaviors besides speed. These results have led researchers to conclude that drivers driving in haste place themselves (and others) at risk, as one of the main causes of motor vehicle crashes is excessive speed. However, although speed is an obvious symptom of hurried drivers, it is not the only one.

Other symptoms extracted from an analysis on fatal road accidents showed that driving in a hurry results in individual distraction, reduced attention and short distance between cars [68]. The presence of other aggressive behaviors, such as horn honking or passing on hard shoulders, were also investigated by an observational study in which a strong linear association was found between driving in a hurry in congested roads and the frequency of aggressive behaviors [69]. Even more, the subjective appraisal of a situation (i.e. congested road), as suggested by Cœugnet et al. [70], besides generating other types of emotions and aggressive behaviors may also produce a cognitive distortion that may lead the hurried driver to compulsively look at the sources of speed and time information at the expense of their road-directed attention, generating a more risky behavior. Although, these previous studies offer a useful basis from which predictions can be made, further testing with more sophisticated approaches, such as experiments performed with driving simulators or in natural environment, are needed. There are a lot of subjective questionnaire-based studies but a lack of empirical experimentation showing specific manifestations of drivers in a hurry. This knowledge is critical in order to develop effective safe driving prevention systems and intervention programs.

A different trend can be observed in the field of engineering-rooted studies, where system-oriented investigations have been completed and various safety improvement-oriented solutions have been proposed. Few engineering studies in which the behavior of the driver when feeling hurried is compared to his/her driving behavior under normal conditions have been executed using driving simulators or instrumented vehicles in naturalistic environments. In the naturalistic driving studies, special attention has been placed on acceleration data demonstrating that drivers accelerate to a greater degree when feeling hurried relative to normal states [71]. Some posterior studies analyzed the time headway and the longitudinal acceleration concluding that compared to normal driving, the mean value and standard deviation of the time headway is smaller and that the number of pedal operations, which result in high levels of acceleration or deceleration, is higher [72]. Practically, the study of driving behavior (in a hurried state) has been focused on vehicle data, such as acceleration, time headway, and host vehicle velocity in all the previous investigations.

To our best knowledge, there is only one driving simulator study published that attempts to characterize hurried driving behavior based on metrics that are not derived only from vehicle data [73]. This study proposed a method to characterize hurried driving from the viewpoint of attention allocation (gaze position) and collision risk. However, the method only works to characterize hurried drivers when overtaking another car.

In all these previous studies, the sample used is small in number. The driving simulator study conducted by Wada et al. [73] used nine subjects and the naturalistic driving studies performed by Hotta et al. [71], Raksincharoensak et al. [72] and Khaisongkram et al. [74] used 3, 4 and 1 participant respectively. Additionally, these studies did not provide proof of the participants' feelings of haste. In these studies it is unclear if the manipulation they used to create the condition of hurry is indeed resulting in the desired state.

Concluding remarks

Several studies claim that the effects of driving in haste usually contribute to risky behaviors. However, most of the papers do not address the specific manifestations of driving in haste. They limit to the most obvious risky behaviors such as speeding, short distance between cars and high acceleration. Besides, most of the studies are based on questionnaires using videos or images about driving situations in which the questioned drivers have to judge whether they are supposed to be in a hurry or not and what their reaction would be. Although the answers given to these questionnaires by participants may in general be true, some participants' responses may not be honest and leave room for bias. The proneness of respondents to produce fake answers is well-documented by Furnham et al. [75]. The results of questionnaire-based studies have to be carefully considered and verified using more objective approaches such as driving simulator studies or naturalistic observation. Using questionnaires for deriving hypotheses and driving simulators for testing them seems to be effective for an a priori confirmation of indicators of driving in haste.

Although engineering-rooted studies have used driving simulators to identify specific manifestations of haste and to predict this dangerous state, their studies do not go beyond vehicle information (e.g., speed, acceleration, etc.) for the characterization of this state. Considering that in the overall process of driving a car, the behavior of the driver is transferred to the car through the driver interaction and the behavior of the car and its interaction with the environment is already a reaction to the driver behavior, vehicle information alone is not sufficient to predict a dangerous state of the driver. It is reasonable to think that indirect driving parameters have to be combined with direct driver-related measures (i.e., indicators related to the driver physiology and driver-car interaction knowledge domains) in order to have a better discriminative power and a better prediction of the risky state. Additionally, although some studies of driving in a hurry give a useful basis for the understanding of causal factors that may elicit or exacerbate the feeling of haste, the results are still exploratory and subject to the drivers' opinion about these factors. Little is known about the individual characteristics that moderate driving in haste. More empirical studies, evaluating the relation between driving style and driving in haste, are needed for further understanding of the impact of these characteristics in the manifestations of haste.

1.7 Specification of the research problems

From the previously reviewed literature, the first impression and assumption is that in the future more human centered ADAS will be needed. In this type of systems the driver monitoring function will become crucial for detecting the driver intention and state and for judging a particular dangerous situation. Therefore, it seems necessary to study all possible driver states and activities of the driver that may cause driving accidents. From the dangerous states that contribute to traffic accidents, driving in haste has been considered at the top position of the results of the investigations of driver mental and physical states immediately before accidents. In this research, it is assumed that the development of a system for the detection of driving in a hurry will contribute to reduce traffic accidents. The understanding of the phenomenon, in terms of how it is developed and its manifestations, is necessary for the development of a technical support system. The knowledge derived by psychologists and engineers about driving in haste needs to be combined in order to get a comprehensive understanding of the phenomenon and to explore optimal detection possibilities, even if the current trends in the literature do not indicate an effort in this direction.

Assuming that being in a hurry can be conceived as a form of stress induced by a particular stressor, it could be expected that the driver will normally respond to this type of stressors, in a similar manner as he/she does to other types of stressors (such as heat, noise, etc.), through extraordinary mental or physical effort or by exhibiting changes in performance. These stressors will possibly affect the way the driver performs (behavioral), the way he/she feels (emotional) and the way the bodily functions respond (physiological). Therefore, it can be assumed that driving in haste produces some recognizable symptoms in the driver's physiology and his/her interaction with the vehicle. Our main assumption has been that the behavior of the driver in a hurry is different from his/her usual behavior in a normal driving situation and that the emerging changes in the behavior propagate from the driver through the car towards the environment. However, until now, researchers have focused only on the detection of driving in a hurry using only few vehicle behaviors which are the most obvious symptoms. The methods based on these behaviors are attempting to detect the driver state in an indirect way or, in other words, using the behavior of the vehicle, which is just a propagation of the driver's actions.

This research focuses on the problem of recognizing driving in haste based not only on information about the vehicle behavior but also on information about the driver's physiology and his/her interaction with the car. More specifically the problem lies in identifying the effects of driving in haste on the physiology of the driver, his/her interaction with the car and the driving performance. In order to study the phenomenon of driving in haste we need to recreate this situation. However, it is difficult to study the phenomenon in real life since there are too many triggering factors and too many variables that cannot be controlled. Besides, intentionally inducing haste in drivers on the road can lead to unsafe situations and is therefore unethical. Reproducing haste in a laboratory setting appears to be the most feasible alternative approach. Assuming that the phenomenon of driving in haste can be generated in an artificial environment, this research also faces the issue of reproducing driving in haste in a driving simulator.

1.8 Overall research objective

The overall objective of this PhD research is to identify indicators with sufficient discriminative power for the recognition of driving in haste that could eventually be used in the development of algorithms for the detection of this state in real driving conditions. Recognizing this state will allow to take countermeasures and thus to prevent a considerable number of traffic accidents around the world.

More specifically, the aim is to further understand the phenomenon of haste in order to: (i) induce this state for the execution of a study using a driving simulator, as well as to (ii) identify, based on studies reported by other authors and knowledge derived from experts in the fields of driving, behavioral psychology and human medicine, via focus group studies, possible observable manifestations or indicators of driving in haste, and finally (iii) empirically assess the discriminative power of the indicators identified for the recognition of driving in haste by means of the design and execution of an experiment using a driving simulator.

1.9 Hypotheses and assumptions

The main assumption for the current study is that the behavior of the driver in a haste situation would be different from his/her usual behavior in a normal driving situation and that the resulting changes in the behavior would propagate from the driver through the car towards the environment. That is, the behavioral state of the driver would be reflected not only on the human body, but it would also have observable influences on the behavior of the car, the interaction of the driver with the car, and the interaction of the car with the environment.

Moreover, the **first hypothesis** for the current study is that **there exists at least one indicator that is completely independent from the driving context and completely**

insensitive to differences between drivers. In other words, it is believed that it will be possible to find one indicator that will have sufficient discriminative power for the recognition of driving in haste independent of whether the driver is one or another, and whether he/she is driving on a freeway or approaching an intersection with traffic crossing ahead.

A **second hypothesis** for the current study is derived from the fact that, in the overall process of driving a car, the behavior of the car (i.e., vehicle information such as speed, acceleration, etc.) is a reaction to the drivers' behavior and, thus, indirect driving parameters are responses to direct driver-related actions. Consequently, since both indirect and direct measures provide similar information, it is expected that **indicators closer to the source, that is indicators coming from the physiology of the driver and his/her interaction with the vehicle controls, are best for identifying driving in haste**. In fact, it is initially expected that indicators closer to the source alone are already enough for the intended purpose.

A third hypothesis is related to the induction of haste in drivers in a laboratory setting using a driving simulator. The premise is that **driving in haste, with the stressor being time-related, can be induced using the time pressure construct defined as a time constraint plus a motivation to perform the driving task in the given time.** In other words, it is expected that haste resulting from a time-related stressor can be intentionally prompted by reducing the time available to complete the task as long as the participant is motivated to do so.

1.10 Methodological framing of the research

In order to recognize when a driver is in a hurry, it is necessary to synthesize bodies of knowledge from behavioral science and engineering science. However, collecting and merging information and research data from multiple fields introduces a complexity in the research. In order to handle this inherent complexity a multi-methodological framing was applied to set up the research design. The whole PhD research was broken down into four interrelated research cycles, as shown in Figure 1.3. Each cycle has specific objectives and methodological framing. For this purpose, the methodological framing theory proposed by Horváth [76] has been applied. The first three research cycles, which aim at gathering knowledge about the indicators present when driving in haste situations and about the induction of haste in a driving simulator, have been methodologically framed as research in design context (RDC). The fourth cycle, which deals with the selection of indicators, their combination, and their association with measurement technologies, has been framed as design inclusive research (DIR).

The use of this methodological framing is explained by the fact that the first three research cycles aim at gathering insights and understanding the phenomenon in a specified context (i.e., driving a car), whereas in the fourth research cycle an experimental arrangement is used for detecting and testing the indicators and this also serves as an evolving research tool.

The specific objective of the first two cycles of the research project was to synthesize an explanatory theory about recognizable behavioral indicators in the discussed context. We investigated which phenomena are strongly associated with the state of driving in haste, and how indicators can describe the various manifestations of these phenomena. In the research cycle three, due to the fact that it is difficult to study the phenomenon of "driving in haste" in real life since there are too many triggering factors and too many variables that must be controlled, we investigated how to induce an emotional state in subjects in such a way that we could be certain that subjects actually experience haste. In the fourth research cycle, the indicators were further studied and refined in order to identify those with the higher discriminative power for recognizing the state of driving in haste.

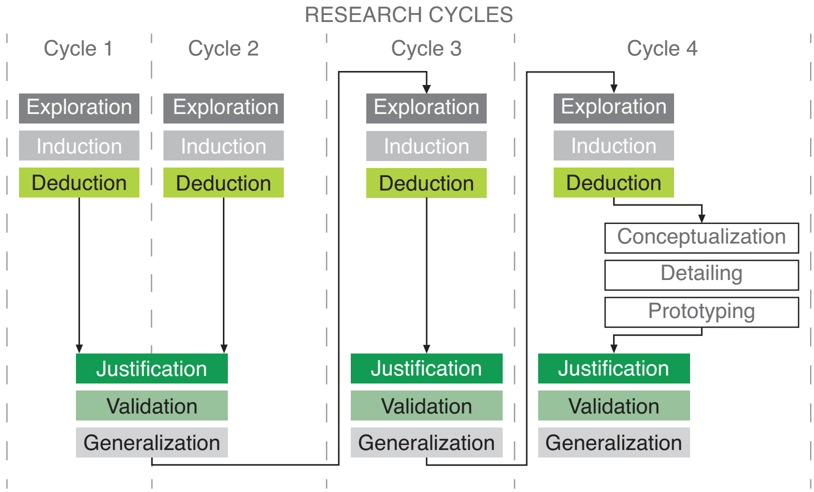

Figure 1.3. Organization of the research cycles

The use of this methodology allows achieving a higher level of rigor by decomposing the research project into less complex procedural units (i.e., procedural structuring) and by applying a framing methodology to each procedural unit. This facilitates the obtainment of a proper combination of design (creative and integrative) and research (analytic and reductive) activities.

1.11 Structure of the thesis

From a structural point of view, the thesis book has been compiled into seven chapters, which present the work and results in the sequence of the completed research cycles: In the current chapter, as you just read, a general overview of the research problems, the overall objective, hypotheses and the methodological framing of the research were given. Chapter 2 provides an overview of the different manifestations of driving in haste that have been identified by other researchers. This chapter reports on the research work and results achieved in research cycle 1. Afterwards, Chapter 3 presents the research carried out in research cycle 2. It presents the behaviors and actions that professional drivers, psychologists and traffic policemen believe to be connected to the phenomenon of driving in haste. Chapter 4 covers the results of research cycle 3, in which we establish how the phenomenon of haste when driving can be reproduced in a driving simulator. Chapter 5 includes further exploration of indicators associated to haste due to a time constraint, as well as the set of hypotheses to be tested. This chapter also presents the design of the full-scale experiment and the results of the pilot study conducted to recognize possible adverse events related to the experimental procedure used. Chapter 6 reports on the results and analysis of the full-scale experiment performed to determine the most discriminative indicators of driving in haste. Chapters 5 and 6 present the outcomes of research cycle 4. Finally, Chapter 7 presents the conclusions of the complete PhD research.

1.12 Forerunning publications

During the PhD project, parts of the research work and results, reported in this thesis, have been published in conference proceedings and one journal. Publications were made on the topic of each research cycle:

- Rendon-Velez, E., Horváth, I. and Opiyo, E. Progress with situation assessment and risk prediction in Advanced Driver Assistance Systems: A survey. Proceedings of the 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services, Vol. 5, pp. 3832-3848, September 21-25, 2009.

- Rendon-Velez, E. Classification and overview of Advanced Driver Assistance Systems according to the driving process. Proceedings of ASME 2010 Design Engineering Technology Conferences and Computers in Information and Engineering Conference, Vol. 3, pp. 687-695.

- Rendon-Velez, E. Horváth, I., Van der Vegte, W. Identifying indicators of driving in a hurry. Proceedings of the ASME International Mechanical Engineering Congress & Exposition 2011, Vol. 9, pp. 111-125.

- Rendon-Velez, E., Horváth, I., van der Vegte, W. A pilot study to investigate time pressure as a surrogate of being in haste. Proceedings of the Ninth International Symposium on Tools and Methods of Competitive Engineering - TCME-2012, Vol. 1, pp. 393 – 406.

- Rendon-Velez, E., Horváth, I., van der Vegte, W. Motivating subjects to drive in haste using time pressure in a simulated environment. Special Issue on: "Virtual Reality and Ergonomics Enablers for Product Development" (in Press).

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Chapter 2

Research cycle 1: Observable manifestations of driving in haste

2.1 Introduction

There is a movement in vehicular technology towards developing on-board systems for cars that are able to detect the drivers' emotion, behavior and attitudinal characteristics. In this context, we can talk about 'affective intelligent vehicles', which are able to recognize emotional states of the driver and respond to them in an adaptive manner. In order to appear socially intelligent, the car computer has to recognize their driver's emotional state and respond to that state adequately. In order to do this recognition it is necessary to understand how this emotional state of the driver is developed and what the symptoms of this state are. The particular state we are targeting in this research is driving in haste. In this chapter, efforts are concentrated on attaining an understanding of what the manifestations of driving in haste are. That is, manifestations in the driver physiology, in the driver interaction with the car, car behavior and the driving performance.

2.1.1 Objective of the research cycle

The objective of this research cycle is to synthesize, based on a systematic literature review of reports and journals, general observable manifestations of driving in haste associated to driver physiology, driver interaction with the car, car behavior and driving performance. This, in order to gather a first set of observations to be used in a posterior research cycle for the identification of detectable behavioral indicators for the recognition of driving in haste.

Specifically, as will be explained in more detail in the following section, the aim is to collect information related to manifestations of driving in haste by using an internet-based literature study, which will then be triangulated with knowledge obtained in focus group studies to consolidate a set of relevant indicators.

2.1.2 Methodological approach

In order to fulfill this research objective we applied a two-cycle research framework. This framework helped us to maintain the coherence among the specific research activities. For this methodological framing, the theory proposed in Horváth [1] has been applied. Each research cycle is a logically ordered set of research actions, which have been supported by various methods (Figure 2.1). These two research cycles have been methodologically framed as research in design context (RDC). RDC supports getting insights about the phenomena studied and results in explanatory theories for knowing. Each RDC cycle involves six phases of activities, which have their specific objectives, namely: (i) knowledge exploration and aggregation in context (E), (ii) inductive statement of knowledge problems, research questions, and research hypothesis (I), (iii) deductive generation of descriptive, explanatory and/or predictive theories (D), (iv) rational and empirical justification of theories and models (J), (v) validation of the methods, conducts and/or findings (V), and (vi) generalization of the findings and the propositions (G) (see Figure 2.1). Starting out from the fact that fused knowledge is expected as an outcome, the objective of the first two research cycles has been defined to be practically the same. For this reason, the explorative parts (i.e., the exploration, induction, and deduction phases) were conducted separately, and with the support of different methods, but the confirmative parts (i.e., the justification, validation and generalization phases) have been merged into one stream of research actions, driven by the strategy of data and methodological triangulation. We explain this below.

In the first research cycle, internet-based literature study was used as a method for knowledge exploration. Information and data about manifestations (symptoms) of driving in haste were aggregated by means of structured lists of keywords and cited references. In the second phase, the data carried by the written text were interpreted and assumptions were made in an inductive way.

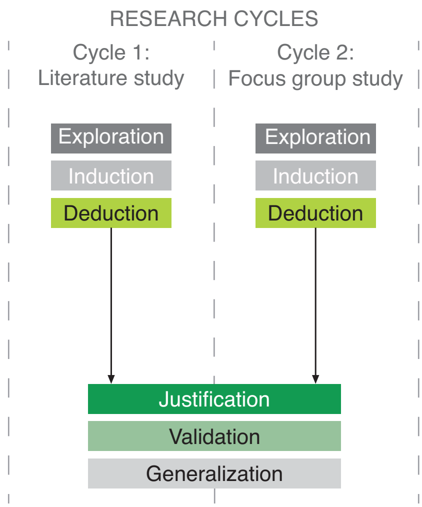

Figure 2.1. Combination of research cycles 1 and 2

Our main assumption has been that the behavior of the driver in a haste situation is different from his/her usual behavior in a normal driving situation and that the emerging changes in the behavior propagate from the driver through the car towards the environment. That is, the behavioral state of the driver is reflected not only on the human body, but it has observable influence also on the behavior of the car, the interaction of the driver with the car, and the interaction of the car with the environment. Based on this assumption a reasoning model was devised. This reasoning model was used as a support mean for a deductive generation of a theory that explains the nature, the relevance, strength and appearance of indicators, and allow us to classify them in a non-taxonomical way.

In terms of the execution of the confirmative parts of research cycle one and two, we identified two objectives: (i) to merge the bodies of knowledge generated in the explorative parts of research cycle one and two, and (ii) to test and justify the resultant knowledge from multiple aspects. To achieve these goals, we brought together the knowledge obtained about the possible observations concerning driving in haste from the literature study with the knowledge obtained in the focus group studies. This research strategy is commonly referred to as 'triangulation' in the literature. Triangulation, allowed us to investigate the semantic relations and the relative contribution of the partial bodies of knowledge (i.e., the two sets of observations) to the consolidated theory about a set of dominantly relevant indicators. According to our reasoning, if there is high congruency between the two sets of observations it gives us evidence to believe that they are relevant, or even true.

We also investigated the correspondence of the two sets of observations, based on how frequently they were mentioned as relevant in the literature study and the focus group sessions, respectively. The frequency is expressed in terms of the number of people that agree that a possible observation or symptom is associated with the studied phenomenon. Given the fact that the knowledge generation process is contextualized and influenced by human decisions, we need to consider the validation of the results of the research actions. Both internal and external validations play an important role in testing if the obtained body of knowledge is proper and relevant. For testing internal validity, we considered source validity, and investigator validity. However, since the obtained knowledge will not be used outside the context of our research, we do not make effort to test its external validity. Otherwise in testing external validity aspects, such as reliability, sensibility and usefulness of the data could be considered.

2.2 Reasoning model and structure of the literature study

Having the objective of exploring and synthesizing knowledge about the possible observations (manifestations) of driving in haste, the first research cycle concentrated on the works and results reported in the literature. The investigation covered journals, proceedings and academic reports published in English before 2013. The literature study was carried out digitally, using Google Scholar, Scopus, IEEE Xplore Digital Library and Transport databases.

As a first step, information about the proposed possible observations of driving in haste was collected by keyword-based searches and then this was complemented by the retrieval and study of the relevant articles included in the reference lists. The terms used in the search were constructed as combinations of the following words: ‘driver’, or ‘monitoring’, or ‘hurry’, or ‘driving’, or ‘symptoms’, or ‘aggressive’, or ‘time-pressure’, or ‘rushing’, or ‘state’ or ‘stress’, or ‘haste’, or ‘detection’, or ‘behavior’, or ‘assessment’ (e.g., ‘hurry driving’, ‘monitoring driver stress when in a hurry’, ‘stress assessment when in a hurry’, etc.). After gathering a large pool of literature items and interpreting their contents, we devised a reasoning model to support a structured further processing of the results. This reasoning model arranges the knowledge elements in a framework that helps finding facts and developing a theory for the research problem at hand. As pointed out in the previous section, the fundamental assumption behind the reasoning model is that the behavior of the driver in a haste state is different from his/her behavior in a normal driving state. Furthermore, this change propagates from the driver through the car to the environment. Our null hypothesis has been that indicators can characterize this.

As shown in Figure 2.2, we have identified five potential source domains of indicators in the reasoning model. Namely, they are: (i) the driver, (ii) the interaction of the driver with the car, (iii) the car, (iv) the interaction of the car with the environment, and (v) the environment.

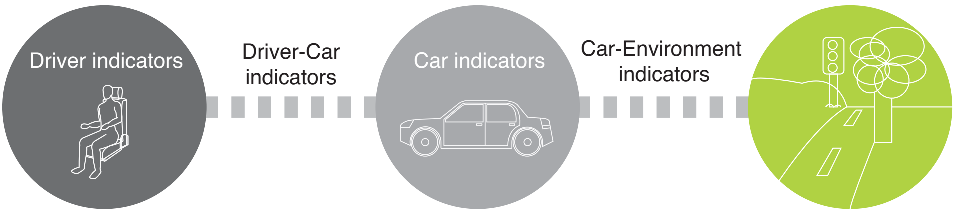

Figure 2.2. Reasoning model

The first source domain of indicators is related to human behavior. The indicators in this domain originate in the physiology of the driver (e.g., heart rate, muscle tension, etc.), or the body actions (e.g., hand movement, leg movement, etc.). The second source domain of indicators is the driver-car interaction. In this domain, we are looking for indicators that are associated with the way the driver interacts with the vehicle (e.g., gas pedal pressure, steering angle, etc.). The third domain provides indicators that are closely related to the operation and behavior of the car. These indicators can be detected and measured relative to the state of the car (e.g., velocity, acceleration, engine rotational speed, etc.). The fourth domain is the origin of indicators that are related to the interaction of the car with the surrounding environment. This domain provides indicators that can typically be observed in the car position in traffic flow (e.g., following distance, relative lane position, etc.). The fifth possible source domain of indicators has not been considered in our investigation for the reason that, though there are detectable changes in the environment due to driving in a haste situation (such as increased CO_2 accumulation, damage in objects, etc.), the recognition and measurement of these, generally, needs to be done outside the car. Additionally, the detection of the indicators in the remaining four domains is expected to provide sufficient information about all significant manifestations of driving in a hurry.

2.3 Literature study

Below we present the main findings of the literature study, clustered according to their source domain using the reasoning model presented in Figure 2.2. For a specific list of the main findings of this literature study, please refer to Appendix A.

2.3.1 Overview of literature concerning human behavior in haste

We have found reports and papers that discuss various forms of human behaviors that can be associated with driving in a hurry or haste. However, these phenomena have not been extensively studied in the context of situation improvement. A number of studies report on relationships between driving in a hurry and other psycho-physiological state of drivers such as mental stress and anger/aggression. However, these studies focus more on particular manifestations of mental stress and anger than on specific possible observations of driving in haste.

Empirical research has shown that being in a hurry and having to keep a strict time schedule exacerbates the feeling of mental stress [2]. Drivers acting according to high urgency scenarios (running late) have shown higher stress level than drivers in low urgency scenarios (being on time) [3]. Additionally, when driving in a hurry is combined with situational factors such as traffic congestion, researchers indicate that the level of frustration and irritation increases, resulting in negative moods, such as anger [4]. These findings reported in the context of driving, are also consistent with general studies on aggression and with the so-called frustration-aggression theory, which argues that "aggression is always a consequence of frustration" [5,6]. Beck et al. [7] also suggest that drivers in a hurry lack the ability to cope with aversive conditions and have difficulty in withstanding or coping with negative psychological states.

From the literature reviewed, it is clear that driving in haste can produce other psychological states. However, until the date on which this literature was reviewed, there were no studies addressing the specific manifestations of driving in haste on the human physiology or body actions. Throughout the following paragraphs, manifestations of anger and mental stress on human physiology will be presented. Although these manifestations may be representative of haste, the author recommends that no generalization be made without prior empirical testing.

The state of anger has been associated with both overt behavior (observable actions) and physiological responses. Following from the overt behaviors, rude gestures, swearing or yelling at others, and facial expressions have been identified as manifestations of anger [8,9]. These manifestations have already been used for the detection of anger in emotional recognition systems. Yelling or angriness of voice have been detected based on certain features of the voice, for instance, the pitch and sound pressure [10]. Although these two indicators were efficient for detecting angriness of the voice in controlled environments (e.g. driving simulators), according to some studies the heavy noise of real environments can significantly increase the difficulty of detecting these phenomena [11]. Angry facial expressions have been recognized based on extracting face features by evaluating their descriptive parameters. Although face features-based recognition has been effective, the existing methods are capable to handle only deliberate and exaggerated expressions of emotion [12].

Additionally, in the driving context, illumination variance might pose some problems for the recognition system. In terms of physiological characteristics, muscle activity, heart rate and skin temperature have been associated with anger. Researchers found that the activity of the corrugator supercilii (muscles above the brow, used in frowning) [13], the heart rate [14] and the skin temperature [15] increase when experiencing negative feelings compared to positive emotions. However, in some studies, when anger was compared with neutral emotions in empirical research, there was no substantial difference in the pattern of heart rate. Similarly, Sinha et al. [15] reported that changes in skin temperature were not significantly different from those typical for neutral conditions.

A strong correlation has been found between mental stress and physiological responses. High levels of stress have been shown to result in a substantial increase in blood pressure. It was reported that drivers displayed greater systolic blood pressure in a hurry and under high stress than under normal conditions [16]. This was consistent with the results of the study in which high stress in offices was related to high blood pressure [17]. Also higher heart rate, skin conductivity (sweating) and skin temperature were found to be associated with stress [18,19]. However, De Waard [20] reported that skin conductivity was affected by respiration, temperature, humidity, age, time of day and season. He suggested that this indicator was not the most appropriate for detecting this state in cars. Other physiological variables that were also correlated with high level of stress are the increase of muscle tension and respiration frequency [20,21]. However, according to other studies, the respiration frequency had no clear correlation with stress levels due to the inter-individual differences [18,22].

2.3.2 Overview of literature concerning driver interaction with car

According to several research studies, there are observable changes in the interaction of the driver with the car in a haste situation. Researchers have dealt with these changes from two perspectives: (i) psychological research focused on risky behaviors and their causes, and (ii) engineering research concentrated on finding working principles for the development of detection systems.

Psychology-rooted studies considered various forms of risky behaviors, such as horn honking and flashing headlights [8,9,23]. In these studies, which typically used questionnaires, it was found that driving in a hurry was the most frequent cause of the two above-mentioned risky behaviors. Horn honking and flashing headlights were described as behaviors that help the driver to overcome frustrating obstacles formed by other drivers [8]. What is common in the findings of the above studies is that these behaviors do not happen without a cause. On the contrary, they are usually the result of impatience and frustration on the road due to situational factors, such as a congested road. Furthermore, it has to be mentioned that these behaviors are also conditioned by gender [23] and/or culture [24]. Frequent horn honking both by men and women was reported, but it was found to be somewhat more pronounced among women and in countries with hot climate.

The studies conducted from an engineering perspective investigated phenomena such as manipulation of the pedals and the steering wheel [25-27]. It was found, in a naturalistic study, that when drivers were in a hurry, they changed from braking to pushing the gas pedal faster in order to accelerate the car [27]. It was also found that drivers have a tendency to delay activation of the brake, which results in heavier braking [25]. The findings in these studies were congruent with the findings of an experiment completed in a driving simulator, where it was found that the driver made more intensive use of the brake pedal under frustrating conditions on roads than under normal conditions [28].

Canale and Malan [29] also observed that, in addition to an intensive use of the pedals, drivers applied pressure more strongly and suddenly resulting in a large throttle opening and more fuel consumption. Regarding the usage of the steering wheel, it was found that when drivers drove under high levels of anger and under irritating conditions in a driving simulator, they made larger steering wheel movements [26]. These experiments indicated that drivers have poorer control abilities when in anger than in a calmed state. These findings are in line with studies on the effects of time pressure on using general device interfaces [30,31]. In these studies it was found that time urgency tends to increase the stiffness of a person's limbs, which explains why actions are performed with relatively higher force.

2.3.3 Overview of literature concerning car behavior in non-regular situations

Several psychological studies concluded that high speed is one of the most prominent possible observations of driving in a hurry [32-36]. In questionnaire-based studies, drivers agreed that the most prevalent reason for fast driving and speeding was time pressure, also referred to by the people as "being late for a meeting or an appointment" [37,38]. In studies, where the drivers were caught speeding, they also indicated to be influenced by time pressure [39,40]. Furthermore, in detailed descriptions of rollovers, field investigators also identified that being in a hurry was a factor that led to misjudgment of the speed at which a particular curve could be safely negotiated [41]. The above findings were in line with the results of a driving simulator-based study in which participants who were instructed to drive under time constrains felt more activated and more aroused, and they drove faster than the drivers without the time constraints [42].

High speed driving was also observed in cases in which haste provoked anger in drivers [43,44]. It was found, by questionnaire-based studies, that respondents drove faster when they were angry than when they were in any other emotional state [45,46]. The intensity of angry/threatening expressions showed a significant correlation with this higher speed. The findings of these field studies were similar to the results of the studies completed using driving simulators. Drivers with high anger maintained a higher average speed than drivers with low anger levels [47]. These conclusions were also confirmed by a naturalistic study in which anger was continuously measured during driving [48]. In this study, participants who reported anger in certain parts of the route drove faster and exceeded the speed limit more often than participants who were not experiencing anger. Complementing the above findings, Musselwhite [33] found in a questionnaire-based study, that speeding always occurs in combination with other behaviors such as accelerating and braking hard. Therefore, he suggested that speeding should be addressed along with these other dangerous behaviors.

The majority of the reviewed engineering studies used acceleration and velocity as an indicator for detecting haste. It was found, in some naturalistic studies, that the acceleration and velocity of the car were higher when the driver was feeling hurried relative to a normal mental state [27,49]. Similarly, in a subsequent study, acceleration and deceleration were used to classify the driver's style, specifically the aggressive style which was highly related to driving in haste [50]. In this study, aggressive maneuvers were identified through the rate of change in acceleration or deceleration.

2.3.4 Overview of the literature concerning car-environment interaction

The majority of the studies found in this domain reported on psychology-oriented rather than on system-development-oriented investigations. Psychology-rooted research mainly focused on understanding risky behaviors, such as running red lights and tailgating [23,51,52]. According to these studies, risky behaviors occur when drivers have to arrive timely but they are late. It was demonstrated by a survey study that a large number of drivers who were in a rush and wanted to save time were willing to speed up to run an upcoming red light [51]. These findings were also confirmed by a later study which found that drivers were more prone to show this behavior when they were driving alone [52]. Tailgating was also mentioned as a form of behavior that happens when driving in a hurry, as well as under particular traffic conditions, such as heavy traffic on busy narrow roads during rush hour [23].

Stern [53] found that the frequency of these responses to traffic congestion had a positive relation with the level of haste. This means, that the more hurried the driver, the more tailgating, overtaking or, in general, the more aggressive behaviors on road were present. In a field study, the drivers who were stopped because of driving too close to the car in front also mentioned haste as a reason for their behavior [54]. These findings were also confirmed in driving simulators under specific experimental conditions (i.e., congestion on road) [47]. The general observation was that, in traffic congestion, a high-anger driver drove faster and had a shorter time and distance to other cars. Researchers also mentioned the existence of other possible forms of misbehaviors when driving in a hurry: weaving in and out of traffic, neglecting stop signs, failing to yield pedestrians, and "cutting" in front of other drivers [8,9]. According to these researchers, all these behaviors appear all together and not separately. For example, Musselwhite [33] reported that frequent switching of lanes and a series of forced overtaking are accompanied by intense speeding. However, we could not find enough studies reporting on empirical evidence.

The engineering-oriented studies concerning the real-time detection of hurried driving mainly focused on tailgating [27,49,55]. As an indicator of this behavior, the headway has been considered. This is expressed as a distance or time between cars following each other. However, although the average value and the standard deviation over all drivers tend to be smaller than for normal driving, time-headway was reported to differ among different drivers and road sections.

2.4 Implications of the findings

The preceding subsections provided a concise overview of the current state of the art about the possible observations of driving in a hurry. As can be noticed throughout the current chapter, psychologically-based studies have mainly focused on the study of the phenomenon of haste and its manifestations via the use of questionnaires. Engineering-based studies, contrarily, have focused not on the understanding of this phenomenon but on its detection in order to prevent accidents on the road. Both types of studies as conducted in this particular area, however, have significant limitations. The studies based solely on questionnaires are often biased due to the proneness of respondents to produce fake answers. The engineering-based studies have focused on the detection of driving in a hurry by using only a few vehicle behaviors, which are the most obvious symptoms. Furthermore, in addition to having a scope limited to a single domain, these engineering studies have been conducted with small samples and are, thus, limited in validity. These findings reveal a need to combine the knowledge derived from psychologists and engineers about driving in haste in order to get a comprehensive understanding of the phenomenon and to explore optimal detection possibilities. Also, although these previous studies offer a useful basis from which predictions can be made, further testing with more sophisticated approaches, such as experiments performed in driving simulators/natural environments with larger samples, are needed.

Below, we will discuss the findings from two perspectives: (i) appropriateness of our reasoning model for processing the data gathered by the literature study and (ii) reflection on the methods which were used in the studies for collecting information about driving in haste state. Our discussion follows this order.

The first thing to consider is the appropriateness of the constructed reasoning model. The model proved to be appropriate to gather data and it provided sufficient assistance to a systematic exploration of the related knowledge domains. It provided us not only with a structured review, but also with new insights in certain relationships. Knowledge exploration according to the reasoning model casted light on the fact that, actually, there is a set of observable manifestations of driving in haste that can be considered for the implementation of a detection system. We could find observable manifestations for all the four domains included in the reasoning model. This suggests that the assumption mentioned in Section 2.1.2 is valid and, thus, it means that we can find indicators of equal importance in all the four domains (related to the human body, the interaction with the car, the behavior of the car, and the relation of the car with the environment.)

The majority of the reviewed literature studies were not specifically dedicated to our objective: the recognition of driving in haste. A large part of them were dealing with particular risky behaviors (e.g., speeding, horn honking, fast acceleration of the car, negative emotions, etc.) and their causes (i.e., being in hurry) rather than with driving in a hurry and its effects. However, all these studies pointed at the fact that "being in a hurry", or the related conditions "being under stress" and "being in anger", are among the major reasons for such risky behaviors. While it is natural to assume that people in haste situations will show these indicators, the assumption needs to be verified with further studies. So, in order to recognize hurried drivers, it is necessary to study drivers under a particular setup in which haste is induced in a driving task. However, it is believed that the observable manifestations presented in this exploratory literature study offer a useful basis from which predictions can be made prior to further testing with more sophisticated approaches such as experiments performed in driving simulators or studies using naturalistic driving.

According to the literature study, there were three methods used for gathering data about driver behavior: (i) questionnaire-based studies, (ii) driving simulator-based studies, and (iii) naturalistic-based studies. The majority of the research projects used questionnaires for collecting data. Although the answers given to these questionnaires by participants may in general be true, some participants' responses may not be honest and leave room for bias [56]. However, it was recognized by some qualitative researchers that using questionnaires is generally a suitable methodology for studying human characteristics, and that questionnaires represent an inexpensive and relatively quick way of collecting large amount of data [57]. The latter may explain the reason why using objective questionnaires is extremely prevalent in most areas of the social sciences, and has been frequently used in the studies reviewed in this chapter. Besides, as suggested by Pope [58], this method may be used as an starting point for generating hypotheses in a domain where little research has been carried out.

Another method used for collecting information is naturalistic observation, in which the researcher carefully observes and records a particular behavior or phenomenon in its natural setting over a longer period of time, while interfering as less as possible with the subjects. According to the reviewed studies, this method could yield a vast amount of data in the context of everyday driving. However, some researchers argue that the reduction and analysis of such large amounts of data tend to make this method time-consuming and expensive [59]. Furthermore, compared with other approaches, naturalistic driving studies show other disadvantages, such as lack of strict control over the situation and potential confounding variables, and more complex project setup and management [60]. This may explain the scarcity of naturalistic studies in the literature. Nevertheless, it is recognized that naturalistic driving studies offer a unique way to observe driver behavior in everyday life. This is important because, according to some researchers, the nature of risky driver behavior cannot be revealed in controlled study settings [60]. Consequently, when money and time is available for the research, it is desirable to use naturalistic studies as a basis for developing recognition systems that work in real driving situations.

Using driving simulators has been another way of gathering data in the reviewed studies. Working in a controlled environment gives the opportunity to experiment with drivers under extreme conditions and to consider multiple-car scenarios. However, some researchers argue that the responses of subjects to driving events, which occur in a safe environment (simulator), may be rather different from those in real conditions [60]. Nevertheless, high-fidelity driving simulators are becoming increasingly attractive due to the ease of data collection, higher safety for the subjects, lower cost compared with real traffic experiments, and last but not least, the rapid technological developments [61]. Besides, simulators have been used successfully to derive indicators of other psycho-physiological states of drivers such as fatigue and distraction [62]. Consequently, high-fidelity driving simulators are a viable option for recognizing and testing, in a controlled way, indicators of driving in haste.

In order to have ecologically valid data, it is also necessary to study the driver in real traffic situations. Using findings from naturalistic studies brings us closer to the implementation of a detection and intervention system that indeed works under real driving situations. However, due to the risk associated to the studied phenomenon and the high cost incurred when performing naturalistic studies, we believe that using questionnaires for deriving hypotheses and driving simulators for testing them can be effective for the a priori confirmation of indicators of haste.

2.5 Concluding remarks

The objective of this chapter was to identify observable manifestations based on previous literature and associated to the four source domains: driver physiology, driver interaction with the car, car behavior and car-environment interaction (driving performance).

The manifestations of driving in haste associated to driver's physiology comprehended measurements associated with other emotional states such as anger and mental stress. In particular, the manifestations found included changes in cardiovascular activity (heart rate, blood pressure), respiratory activity (respiration frequency), other body reactions such as variations in skin temperature and conductivity (sweating) and muscle tension, as well as overt behaviors such as rude gestures, facial expressions (frowning), swearing and yelling. Moreover, in terms of the driver's interaction with the car, the observable manifestations were related to the intensity in operation of controls such as force exerted on the gearstick, force exerted on the pedals (brake, throttle, clutch), large movements of the steering wheel, force exerted on the steering wheel and velocity in switching between pedals. Operation of warning-related controls such as horn honking and flashing headlights was also mentioned in some studies. Furthermore, in the vehicle behavior domain, the observable manifestations included: velocity, acceleration and deceleration. Finally, the observable manifestations related to driving performance included risky behaviors such as running yellow/red lights, disobeying traffic signals, short distance between cars, overtaking dangerously and cutting others off in a lane. Additionally, failing to yield to pedestrians and frequently changing lanes were also reported in the literature.

2.6 References

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Chapter 3

Research cycle 2: Observable manifestations of driving in haste

3.1 Introduction

In the previous chapter, several observable manifestations and indicators of driving in haste were obtained based on the investigation of the related literature. However, most of the findings originate from studies that did not have the objective and were not specifically tailored to recognizing the state of driving in haste. Dominantly, the studies were orientated to post-event analysis, and focused more on the happenings and the implications, than on the influential factors, cause-effect relationships, and the non-obvious reasons and causalities. The manifestations and indicators were mainly gathered based on reports of traffic accidents or questionnaire-based studies, in which the goal was to establish why drivers were involved in risky behaviors. The literature study revealed that people who drive in haste are prone to show dangerous behaviors and that these behaviors are even exacerbated in certain traffic situations. It also showed that detection of those non-normal behaviors is not the only way of recognizing that a person is driving in haste.

This is important to note because, in the context of our research, detecting an already developed and performed risky behavior might be too late to prevent an accident, or even to apply some sort of vehicle control measures. For this reason, we decided to conduct a specifically tailored interrogative study in the second research cycle to collect information about a wide spectrum of human behaviors that possibly appear in the state of driving in haste under various circumstances and contexts. The interrogative study was based on five focus group sessions that were conducted in predesigned set-ups relying on the same procedural protocol, but with different participants. Professional itinerants, traffic policemen, psychologists and medical doctors have been invited to the focus group sessions, and have been asked to present their opinions on the phenomenon of driving in a hurry, its manifestations under different circumstances, and the signs of it that can be observed in various contexts. As will be explained throughout the following paragraphs, we were interested in all kinds of signs and indicators of the phenomenon that could be observed and/or detected as an effect on the body of the driver, on the interaction of the driver with the car, on the behavior of the car on the road, and on the effects on the traffic environment. Below, we summarize the objective of the reported research cycle, the research design, and the findings and results of this study.

3.1.1 Objectives of the research cycle

The objective of this research cycle is to synthesize, based on knowledge derived from drivers and experts in the fields of driving, behavioral psychology and human medicine, general observable manifestations of driving in haste associated to driver physiology, driver interaction with the car, car behavior and driving performance. The purpose of this is to extend the set of observations found during the previous research cycle for the identification of detectable behavioral indicators for the recognition of driving in haste.

More specifically, to further refine and consolidate the set of relevant indicators, this chapter merges the bodies of knowledge generated from the literature review (presented in Chapter 2) and from the focus group sessions (presented in the current chapter).

3.1.2 Methodological approach

In this cycle focus groups methodology is used as a qualitative approach to gather data about driving in haste. The participants, in each of the five focus group sessions conducted, were asked to express their opinions about the attitudes, behaviors, actions, etc. of drivers being in haste with the help of open-ended, semi-structured discussion forums.

Because our generic assumption was not falsified by the forerunning literature study, each phase of this research cycle was guided by the same objective and assumptions. In order to be able to derive relevant technically rooted indicators, we analyzed the obtained data from the focus group sessions in several steps. First, we grouped the sentences referring to the same possible observation of driving in haste. Then, we identified the background phenomenon for each group and derived some specific indicators. Afterwards, we sorted the indicators according to the reasoning model used for the literature (Section 2.2) and we made an assessment of them in order to derive the most relevant indicators.

3.2 Focus group sessions

3.2.1 Conduct of the focus group sessions

In all conducted sessions, a questionnaire and visual material were used to stimulate discussions, and to maximize the amount of the elicited knowledge. Additionally, a specific procedure was elaborated for conducting the sessions. Four days before a focus group session took place, the participants received a visual dictionary to familiarize themselves with the driving-related terminology that was used in the session.

Five focus group sessions were conducted in Colombia, South America. The first four sessions were organized with people who used cars for professional purposes. The fifth session was conducted with experts who had different backgrounds and were active in different fields. These sessions were spread over five weeks. Each session was structured as follows: at the start, each participant received the socio-demographic data form and the image-based questionnaire (Figure 3.1). Actually, the first half hour was spent in for preparation. All participants were asked to complete the above-mentioned data form, which requested the participants to provide information about age, gender, driving experience, and education. Then the participants were asked to watch a video with traffic situations with the aim of bringing them into the context of the session. After this, they were asked to provide answers to the questions of the image-based questionnaire concerning possible manifestations of driving in haste. During the following hour, a female moderator (M.Sc.-level researcher) moderated a group discussion on the specific questions. The same moderator was present in all sessions. All sessions were video and audio recorded, and later transcribed. The data from the transcriptions was pruned and analyzed in order to arrive at a set of relevant indicators of being in a hurry while driving a car.

3.2.2 Sampling of groups and subjects

Four of the five Colombian focus groups were composed of participants who used cars for professional purposes at different companies (n =12, n=10, n=9 and n=8). The fifth group (n=10) was composed of experts with backgrounds in medicine (n=3), transportation (n=3) and psychology (n=4). In the stage of data analysis, the outcomes of the former sessions were compared with those of the latter sessions.

The number of participants in each of the groups was based on Krueger's [1] recommendation. This author suggested that groups consisting of 8-10 participants per session are most efficient. Anticipating cancellations and no-show ups, we over-recruited each group by inviting 12 people. The number of focus groups was decided based on Nyamathi and Shuler [2], who suggested that four focus groups are adequate to reach sufficient saturation, which is the point where no new information emerges from additional groups.

To select the non-experts, purposive sampling was applied. This allowed us to obtain a diverse sample of about 48 individuals (n=48) who drive a car on a daily basis (i.e., who were experienced at driving a car). Purposive sampling was entirely based on the researcher's judgment. To select the participants, the following set of criteria was applied: (i) being at least 20 years of age, (ii) having a valid driving license, (iii) having a minimum of 3 years of drive experience, and (iv) traveling at least 150 km per week for professional purposes. Based on this set of criteria, a list of eligible candidates (n=118) was compiled. The Human Resource Management departments of five companies provided the list of possible participants. There were twenty subjects (n=20) on this list who worked for a taxicab company. Due to the fact that they had a different socioeconomic status than the other subjects, and in order to maintain homogeneity inside the groups, these subjects were considered as possible participants of one focus group session. Each of them received our invitation and the group was actually formed from the first twelve volunteers.

From the other subjects whose names remained on the list (n=98), a total of seventy eligible people (n=70) were randomly chosen for the other focus group sessions. They received invitation to participate and were randomly sorted into three focus group sessions. Each of these sessions

Table 3.1. Socio-demographic characteristics of the focus group participants

	Non-experts (n=12,10,9,8)				Experts (n=10)
Characteristic	**1 (%)**	**2 (%)**	**3 (%)**	**4 (%)**	5 (%)
Age at time of					
25-35	75	90	78	25	60
36-45	17	10	11	25	40
More than 46	8	0	11	50	0
Gender					
Male	75	70	33	100	60
Female	25	30	67	0	40
Highest education					
Primary school	0	0	0	0	0
High school	0	10	11	88	0
Some college	8	10	22	13	0
College degree	33	20	33	0	60
Postgraduate degree	59	60	33	0	40
Driving experience					
Less than 5	8	20	22	13	50
5-10	17	30	33	0	10
10-15	50	30	11	13	20
More than 15	25	20	33	75	20

involved twelve participants, who were selected from the first 36 volunteers. For setting up the expert group, we specifically used snowball sampling by contacting three doctors (one psychiatrist, and two internists), four psychologists (three behavioral psychologists, one neuropsychologist) and three traffic policemen (with a minimum of three years of experience). These people are representatives of experts who most often come across with people being in haste. The socio-demographic characteristics of the participants in the sessions are shown in Table 3.1.

3.2.3 Content development for focus group sessions

To facilitate a focused discussion, and to record all the comments of the participants in the focus group sessions, we developed (i) a visual dictionary, (ii) a video with traffic situations, and (iii) an image-based questionnaire (Figure 3.1). The visual dictionary explained the general objective of the focus group sessions and presented visual images of the elements of the car and traffic, together with their names. The video presented different traffic situations (e.g., roundabouts, traffic lights, etc.) and showed the driver's interaction with the controls of the car (e.g., accelerating, braking, etc.). The aim of these preparatory actions was to clarify the context of the research and to prepare the subjects for answering the questionnaire. The four domains of the reasoning model, presented in Section 2.2, have all been considered for the development of the image-based questionnaire. There was a set of questions related to each of the domains. Additionally, a complete guide was developed for the moderator in order to support the conduct of the sessions. The guide included greetings to the participants, an introduction to the sessions, an explanation of the interrogative elements used in the focus groups (questionnaire and video), information on the timing and guidelines for the discussion, a set of technical questions and an acknowledgement for the participation.

The developed informative contents (visual dictionary, video and questionnaire) and the guide for the focus group sessions were pre-tested. This was done in order to ensure that quality data could be obtained in the different sessions. The participants for this pre-test were selected based on convenience sampling of drivers.

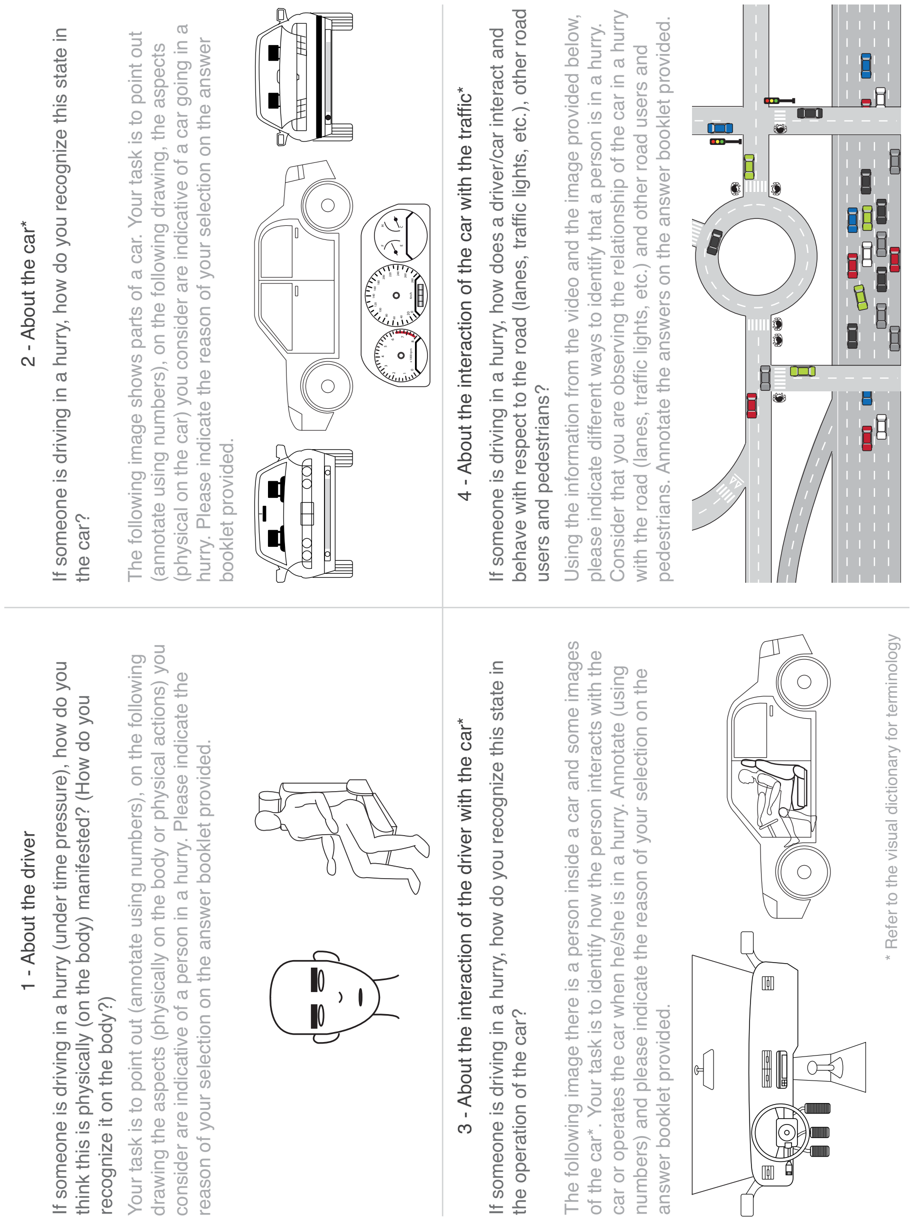

Figure 3.1. Image-based questionnaire for the focus group sessions

In the course of the pre-testing, we checked: (i) the formulation of the questions, (ii) the understanding and usefulness of the visual elements, and (iii) the data obtained by using the developed informative contents and the guide. This was done in order to see if they were useful with respect to our goal. The intention was to guarantee that: (i) participants understood what the questions meant, (ii) the visual dictionary and the video were useful for completing the questions, and (iii) the questions produced useful results for the research study. The informative contents were pre-tested with the involvement of five participants, who did not participate in the main study. Based on their feedback, the questions and the informative contents provided to participants were updated. The moderation of the sessions and the usefulness of the data gathered using the informative contents and the guide were tested in a pilot study with the involvement of other six participants, who did not participate in the main study. After conducting this pilot session, the participants were asked by the moderator to explain how they experienced the session. In addition, the results of this try-out session were also analyzed intuitively in order to check whether the answers were useful for the rest of the research. The comments of the participants did not indicate the need for any change in the setup or in the conduct. Consequently, the actual focus group sessions were completed by using a textually enhanced guide.

3.2.4 General workflow for processing the gathered data

After each focus group session, the recordings were transcribed. The information provided by the participants and the notes taken by the moderator on paper were typed. The data gathered in the different sessions were combined in a single file. These raw data were pruned and semantically analyzed. Considerable effort was put into data pruning in order to make the large amount of recorded material and writings manageable, and to develop a comprehensive set of relevant indicators of driving in a haste situation.

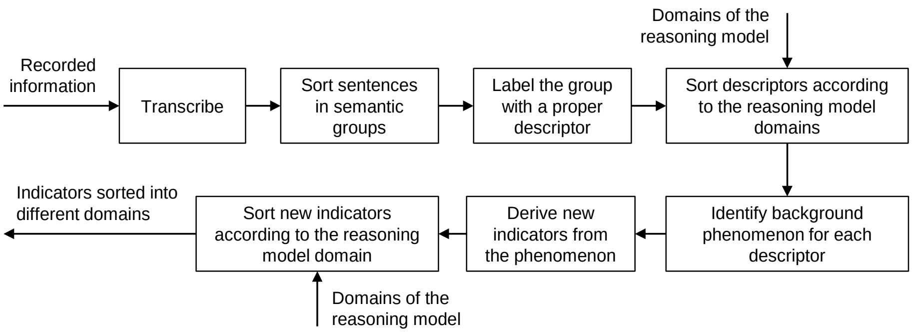

Figure 3.2. Graph of the general workflow for processing the gathered data

Data analysis involved the following main actions (Figure 3.2): (i) arranging the gathered raw data (verbal expressions) in groups according to their meaning (semantic groups) and characterizing each group by an expressive textual descriptor, (ii) sorting the descriptors (possible observations regarding the haste state) according to the reasoning model presented in Section 2.2 in order to compare it with the literature, (iii) identifying the background phenomena based on the consideration of the descriptors, (iv) deriving indicators from each phenomenon, and (v) sorting these indicators according to the different domains of the reasoning model (Section 2.2) and making an assessment of these indicators.

3.3 Methods and results of data processing

The following sections contain the analysis and results of the four focus group sessions conducted. The information is presented according to the process described in Figure 3.2.

3.3.1 Filtering the data and sorting them into semantic groups

After completing all the five focus group sessions and transcribing the outcomes into text, the transcripts of the recordings were analyzed by two members of the research team and the irrelevant textual parts were removed. The resulting processed text was actually the basis for sorting the data into groups that referred to the same possible observation (semantic groups). The criterion used in sorting into semantic groups was whether the transcribed data element was related to the same possible observation mentioned by the participants or not. Each semantic group referred to one particular observation mentioned by the participants. The semantic groups were created by the researchers in an inductive way. While browsing through the transcripts, a group was created every time a new observation of driving in a hurry was found. One data element (sentence or phrase) mentioned by a participant referring to one possible observation was selected as the starting point for the creation of each group. Then textually and/or semantically congruent, or similar, data elements in the transcript were gathered in a group (the first semantic group). The search was done using synonyms or similar expressions.

Afterwards, another data element, referring to a different possible observation and that had not been grouped yet, was selected and the same procedure was applied in order to form a new semantic group. The procedure was repeated until all data elements were grouped. This means, until all semantic groups had been formed. Then, expressive descriptors were assigned to each group. In several cases, the most characteristic (transcribed) verbal expression was used as the descriptor in each group. For example, people mentioned statements like “the driver is waving his hands quickly”, “the driver is making movements of the hands faster”, and “the driver moves his arms aggressively”. All these statements were gathered in one group and the descriptor used was “the driver is moving hands and arms abruptly”. Table 1 contains a list with examples of the semantic groups referring to possible observations of driving in a hurry. In this list, the frequency with which participants mentioned each statement in the focus group sessions was reported.

3.3.2 Identifying background phenomena to derive indicators

After completing the list of semantic groups, the researchers came together and compiled the lists in one file. Then, for each semantic group, the background phenomenon was inductively derived using rational reasoning. The phenomenon was a generalization of the possible observation mentioned by the participants. The goal of this generalization was to find other possible indicators that were not mentioned by the participants in the focus group sessions. So, each phenomenon was taken and a deductive reasoning was applied in order to derive all possible indicators of the phenomenon. The word indicator refers to a testable research variable that is related to one aspect of the phenomenon. This derivation was done by searching for different implications of the phenomenon in the driving system: Driver-Car-Environment. For example, the background phenomenon derived for: "the driver is moving the hands and arms abruptly" was "tendency to have a dynamic interaction with the car". For this phenomenon the following indicators were deduced: (i) force exerted on the pedals (brake, clutch, gas), (ii) force exerted on the steering wheel, (iii) force exerted on the gearstick, (iv) speed when switching between pedals, (v) acceleration of the body of the car, etc. All of these indicators are implied by this general phenomenon. The list of background phenomena and indicators can be seen in Table 1.

3.3.3 Categorization and rational assessment of indicators

The list of relevant indicators was categorized according to the different knowledge domains to which they semantically belong. Each of the indicators was allocated to the one domain in which it can be dominantly observed and measured. In order to consistently assign the indicators to these knowledge domains, unambiguous definitions were provided for each domain. This assured that each researcher over time or multiple researchers independently would arrive at the same results when sorting the indicators. For example, "heart rate" was allocated to the driver knowledge domain, "force exerted on pedals (brake, gas, and clutch)" was allocated to the driver-car interaction knowledge domain, "longitudinal acceleration" was allocated to the car knowledge domain and "time headway" was allocated to the car-environment interaction knowledge domain. Table 1 contains the list of sorted indicators.

After sorting the indicators into the different knowledge domains, a preliminary filter was applied to the indicators in order to select those that belonged to the domains where the manifestations of driving in a hurry are first noticed. Assuming that (i) the driver's behavior under the condition of driving in a hurry defines everything which is observable (physiological, motor, perception, cognition changes), (ii) the driver's behavior is transferred to the car through the driver-car interaction, (iii) the behavior of the car is already a reaction to the driver's behavior, and (iv) the car-environment interaction is a "distant" (indirect) reflection of the driver's behavior; the indicators selected were the ones that belonged to the driver and driver-car domains because they are the first domains where the changes induced by driving in a hurry occur. The rest of the indicators were filtered out because they were just propagations of the human behavior (indirect driving behaviors) which occurred later in time. Besides, thinking in terms of recognition systems, using indirect indicators like the ones coming from the car behavior and car-environment interaction requires a system that can cope with larger changes in the characteristics of the roadway, road quality and lighting.

Additionally, some of the indicators highly depend on the vehicle type, driving experience and age. Indirect measures from driving behavior are more difficult to interpret. They may not be specific to only driving in a hurry but also to other states of the driver (e.g., fatigue, distraction, etc.). The collection and the correct interpretation of indirect measures require knowledge about the surrounding environment. For example, for calculating the frequency of changing lanes, lane markings have to be assessed by sensors. Also steering activities can only be interpreted correctly if influencing factors from the environment (e.g. driving through curves) or driving maneuvers (e.g. turning, lane changing) are considered.

Table 3.2. Derived indicators related to driving in haste

Driver domain, **Driver – car interaction related knowledge domain,** Car related knowledge domain , Car – environment

Statements of the people	#	Background Phenomena	Derived indicators
The driver argues and self-complains a lot	28	Intense drive for immediate aggressive verbal communication	*Pressure of voice -* ***Pitch of the voice*** *- Number of aggressive words*
The driver swears at others or yells (verbal aggression)	26		
The driver makes gestures with the hands or mouth	13	Intense drive for immediate non-verbal (gestural) communication	*Presence of change in the facial expression - Presence of frowning (activity in the corrugator supercillii) - Presence of aggressive gesture with the hand - Presence of mouth movement to complain - Making gestures indicating other people to move.*
The driver changes the facial expression (serious or upset)	10		
The driver frowns	23		
The driver moves the hands - arms frequently (conscious to operate controls of the car or unconscious like nervous movements)	21	Intense drive for unconscious motion of a body part (nervous movements)	*Frequency of hands / arms motion - Frequency of legs / feet motion - Frequency of head motion - Frequency of eye movements - Frequency of moving the trunk of the body -* **Pressure distribution on the seat - Frequency of the driver checking the time -** *Presence of frowning (activity in the corrugator supercillii) - Frequency of touching the head .*
The driver moves the feet - legs frequently (conscious to operate controls of the car or unconscious like nervous movements)	14		
The driver frowns	23		
The driver leans the body forward.	21		
The driver moves the hands and arms in an abrupt way (fast and sudden/aggressive - jerky movements)	14	Proliferating impatience in action	*Speed of hands / arms movement - Speed of feet / legs movement - Acceleration of hands / arms movement - Acceleration of feet / legs movement - Acceleration of head / neck movement - Frequency of hands / arms motion - Frequency of legs / feet motion - Frequency of head motion - Frequency of eye movements - Frequency of moving the trunk of the body - Speed of head movement - Speed of eyes movement -* **Time the hands remain on the gearstick - Time the foot remains pressing the clutch -** Frequency of stepping on the lane line - Frequency of failing to yield a pedestrian – Distance between cars/headway (Tailgaiting) - **Frequency of horn honking** - Frequency of moving the steering wheel
The driver moves the feet and legs in an abrupt way (fast and sudden/aggressive - jerky movements)	11		
The driver moves the head in an abrupt and fast way.	21		
The car weaves in and out of the traffic (weaving from lane to lane)	44		
The car fails to yield pedestrians	25		
The car fails to yield the right of way preventing other drivers from passing	10		
The car passes on the road shoulder or sidewalks	9		
The driver drives too closely behind another car (sticking to the car in front)	24		
The driver moves the eyes frequently (looking at the mirrors, instruments, traffic)	22		
Checking the time constantly / looking at the car's clock often	14		
The driver makes mistakes often	15		
The driver moves the head in an abrupt and fast way.	21	Tendency to gather information necessary for fast decision making	**Frequency of checking mirrors - Frequency of moving head to check the mirrors or to check other traffic - Frequency of moving the eyes to the check the mirrors - Presence of checking the traffic situation in the radio**
The driver moves the head frequently to check the traffic in order to change lanes	21		
The driver moves the eyes frequently (Looking at the mirrors, instruments, traffic)	22		
The body of the driver is tensioned (the posture is rigid – neck rigidity)	16	Observable physiological change (primitive physiological reflex that puts the body on guard for danger)	*Breathing rate - Heart rate - Muscle tension (jaw, back, neck) - Blood pressure - Skin conductivity - Presence of adrenaline*
The breathing quickens	5		
The heart is accelerated (stronger heart beats) – The heart is pumping faster	14		
The driver sweats	26		
The body temperature risens	7		
The driver makes mistakes often	15	Tendency to commit mistakes	**Frequency of errors when operating the gearstick - Frequency of not pressing the clutch pedal properly - Frequency of accidentally pressing the horn - Frequency of riding the** [illegible]
The driver drives in the wrong way	5		
The driver has a narrow field of vision	4	Lack of attention	*Presence of distraction (cognitive/visual) - Mental overload*
The driver loses concentration	15		

Table 3.2. (Continued)

Driver domain, **Driver – car interaction related knowledge domain,** Car related knowledge domain ,Car – environment

Statements of the people	#	Background Phenomena	Derived indicators
The driver flashes the headlight	28	Tendency to influence other people	**Frequency of horn honking - Frequency of flashing headlights to other people -** Distance between cars/headway (Tailgaiting) - *Making gestures indicating other people to move - Swearing at other people to move.*
The driver uses the horn frequently	46		
The driver makes gestures with hand/mouth	13		
The driver swears at others or yells (verbal aggression)	26		
The driver presses the pedals harder	22	Tendency to make dynamic interaction with the vehicle	**Force exerted on the pedals - Force exerted on the gas pedal - Force exerted on the brake pedal - Force exerted on the clutch pedal - Force exerted on the steering wheel - Speed of switching between pedals - Speed of moving the steering wheel - Speed of moving the gearstick - Force exerted on the gearstick - Force exerted on the steering wheel - Force exerted on the horn - Pressure exerted on the steering wheel-** Acceleration of the body of the car
The driver presses the pedals faster	18		
The driver switches between pedals faster	7		
The driver shifts the gears harder	24		
The driver moves faster the gearstick	22		
The driver makes sudden movements of the steering wheel (turning the steering wheel harder)	9		
Gripping the steering wheel too tightly	9		
The car weaves in and out of the traffic (weaving from lane to lane)	44		
The driver uses the clutch frequently	7	Tendency to operate frequently the vehicle.	**Frequency of using clutch pedal - Frequency of pressing brakes - Frequency of using the steering wheel - Frequency of pressing gas pedal - Frequency of shifting gears - Frequency of horn honking**
The driver uses the gearstick frequently (Moving the gearstick frequently in order to shift up to the next gear as soon as possible to change velocity.)	15		
Sudden movements of steering wheel	19		
The driver uses the horn frequently	46		
The gas pedal is pressed up to the maximum position	12	Tendency to overuse the capabilities of the vehicle.	**Displacement of the accelerator pedal (displacement of the accelerator pedal to the max position) -** Engine rpm - Acceleration of the body of the car - Speed of the wheels - Rate of fuel consumption - Rate of change of the fuel level gauge - Rate of deceleration - Sound level of the engine - Rate of temperature change in the engine - Acceleration of the car - Speed of the car - Tire wear rate - Speed value shown by the speedometer - RPM show by the tachometer - Rate of change of the odometer - Amount of emissions - Temperature on the brakes disk - Temperature on the engine - Vibrations of the engine (Cyclic amplitude of the vibration) - Position of the brake pedal (displacement of the brake pedal to the max position) - **Frequency of turning the lights on and off -** Presence of screeching tires.
The speed average is higher than normal	34		
The speed is high for the type of road (higher speed on curves)	1		
The car is more accelerated (changing frequently the velocity in order to go faster)	31		
The car brakes harder (higher deceleration)	10		
The wheels are moving faster	5		
The sound of the car revving up	11		
Brake light of the car frequently turns on/off	20		
The fuel consumption is higher	9		
The fuel gauge is showing lower level	6		
The tires wear faster than normal	3		
Sharp movements of the bodywork	5		
The sound of the horn	4		
There is a smell of burn brakes especially when you are going down on hill.	5		
The car speed average higher than normal	34	Tendency to underestimate the risk	Frequency running red lights - Frequency running stop signs - Speed near a stop sign - Speed on the speed bumps - Frequency and duration the driver goes the wrong way - Frequency of disobeying traffic signs - Frequency of dangerous overtaking - Distance between cars - Speed on curves.
The car speed is high for the type of road (higher speed on curves)	1		
The car runs the red lights or drives through the yellow lights	35		
The driver does not come to a full and complete stop at a stop sign	22		
The driver drives in the wrong way	5		
The driver ignores the speed bumps / driving fast over speed bumps	10		
The driver disobeys the general traffic signals	28		
The driver drives too closely behind another car (sticking to the car in front)	24		
The car stops at a crosswalk (stop even in the middle of a crosswalk)	12		
The car overtakes other cars dangerously (wrong lanes / in curves)	20		

Moreover, the methods relying on these indicators are not attempting to detect the driver's state per se, but the effect of changes in the driver's state that are significant for road safety. It is our belief that indirect driving parameters will never be suitable to be used as single measures alone for the detection of driving in a hurry as it was proved to be for other states such drowsiness and distraction [3]. They always have to be combined with direct driver-related measures (i.e. indicators related to the driver and driver-car interaction knowledge domains). Indicators coming from the driver and from his/her interaction with the car are inevitable and are expected to explain the highest amount of variance within a combined algorithm. A system based on driver related measurement will achieve the best accuracy in terms of driver's state detection due to the fact that they measure directly on the human which is the source of the emotional state.

3.4 Justification of the theory about deriving relevant indicators

In order to provide evidence that justifies the properness of the theory about deriving the relevant indicators of being in haste, presented in Sections 3.3.1-3.3.3, we carried out two logic-based analyses, namely, (i) congruency analysis, and (ii) correspondence analysis. For conducting these analyses, the frequency of mentioning observable manifestations of driving in haste relative to each of the four domains was determined for the literature review and for each of the focus group sessions. This data is available in Appendix A.

3.4.1 Congruency analysis

In general, a congruency analysis concentrates on how much various bodies of knowledge from different sources overlap semantically (logically) and/or how much they complement each other. The main considerations of our congruency analysis are discussed below. Due to the limited resources and time, it was not realistic to strive for an exhaustive collection of statements about possible observations concerning being in haste. Obviously this meant that the obtained set of statements mentioned by the participants of the different focus group sessions and the literature could give us just a limited approximation of the ideal knowledge. By ideal knowledge, we mean the exhaustive collection of statements that hint all indicators of being in haste and that would guarantee the strongest basis for deriving indicators.

The sets of statements about possible observations collected from the different focus group sessions and literature represent just a part of this ideal knowledge. However, it can be considered as a proper assumption that the aggregation of the different sets of statements obtained in various focus group sessions and literature can provide us with a good approximation of this ideal knowledge. Obviously, if the set of statements coming from the different sources (i.e., different focus group sessions or literature) would define completely disjoint (i.e., non-overlapping) sets of statements, the ideal knowledge formed by these sets of statements would be questionable. This implies the need for a congruency analysis with the objective to show how much the statements from the different sources overlap with each other semantically, and how much they complement each other towards the sought for ideal knowledge.

To evaluate whether the amount of data available was enough to perform the congruency analysis, a saturation test was performed. Saturation means, and is reached, when no significant new statements emerge from the subsequent focus group sessions. Note that saturation cannot be considered without taking into account the minimal number of focus groups that are needed for a successful experimentation. The larger the number of focus groups, the larger the chance to have differing statements. On the other hand, a clear indication that saturation is achieved with the involved sample of population is when no new statements are obtained from the subsequent focus group sessions (i.e., the participants of the subsequent focus group are just repeating what was mentioned by the participants of the preceding focus group sessions). The saturation test showed that even the group of experts did not significantly extend the results obtained from the four non-experts groups. Though five groups may sound few in number, the decision on the requested number of focus groups sessions was based on the work of Nyamathi and Shuler [2], who suggested that four sessions should be sufficient to reach saturation. The research design of the focus group sessions in this study seems to reconfirm this theory. Although extending the saturation test to the literature study would be ideal, the fact that new publication mainly refer to new knowledge makes the comparison difficult and, even if comparable data were available, decades would be needed.

The congruency analysis was applied on the set of statements about possible observations concerning driving in haste, which were available in the time period of conducting the literature study. This means that a below-saturation set of statements was used in the congruency study. In order to assess the degree of congruency of the data, a measure called congruency index, C_i was introduced. The congruency index C_i is a measure of how much the statements gathered from the focus group sessions and the literature study semantically overlap and/or complement each other. Eventually, this index also informs about the proportional contribution of the focus group sessions and the literature study to the aggregated knowledge. The congruency index has been formally defined as

$C_i = I_i / T$,

where: $i = \{G1, G2, G3, G4, GN, GE, L, GN \cap GE, G \cap L\}$,

- G1 is Non-experts group 1,
- G2 is Non-experts group 2,
- G3 is Non-experts group 3,
- G4 is Non-experts group 4,
- GN is All non-expert groups (G1+G2+G3+G4), GE is Expert group,
- G is All groups (GN + GE),
- L is Literature,
- $GN \cap GE$ is Intersection of Non-experts and Experts,
- $G \cap L$ is Intersection of all groups and the literature
- I_i = amount of observations mentioned by a source
- T = total number of statements mentioned by all sources

T can be considered as an approximation of the ideal knowledge or, in other words, the “relative truth”. In the rest of this chapter, this will be called “aggregated knowledge”. The congruency indexes were calculated for each of the four knowledge domains by considering the actual aggregated knowledge (Table 3.3).

Table 3.3. Results for the congruency analysis

Indicators domains	C_{G1}	C_{G2}	C_{G3}	C_{G4}	C_{Nexp}	C_E	C_G	C_L	$C_{Nexp \cap E}$	$C_{G \cap L}$
Driver	0.80	0.70	0.70	0.60	0.80	0.95	0.95	0.45	0.80	0.40
Car	0.96	0.72	0.60	0.32	1.00	0.80	1.00	0.14	0.80	0.14
Driver-Car	0.91	0.96	0.96	0.70	1.00	1.00	1.00	0.40	1.00	0.40
Car-Environment	1.00	1.00	0.93	0.60	1.00	0.93	1.00	0.53	0.90	0.53

In the driver-related knowledge domain, the non-expert groups approached up to 80% of the aggregated knowledge, while the experts up to 95% and the literature up to 45%. To our surprise, the literature did not contribute to a large number of observations. All observable manifestations mentioned by the non-experts group were also indicated by the experts group. Even more, the experts contributed with additional possible observable manifestations not mentioned at all by the non-experts. The literature offered only a single new observation, but mentioned up to 40% of the observations brought up by the groups together.

In the driver-car related knowledge domain, the non-experts and the experts brought up 100% of the observable manifestations while in the literature only 40% of the aggregated knowledge was mentioned. This means that all the statements of the non-experts were confirmed by the experts. Surprisingly, the literature did not offer new observation beyond the ones mentioned by the participants of the focus group sessions.

In the car-related knowledge domain, the non-experts brought about 100% of the observable manifestations, while the experts mentioned 80%, and the literature included only 14%. All the observations related to this domain were mentioned by the non-experts. To our surprise, some of the observations in this domain were not mentioned at all by the experts. An explanation for this can be that the current study did not have experts in this field and only one expert session was conducted. The literature did not contribute to any new observable manifestations.

Relative to the car-environment knowledge domain, the non-experts again mentioned 100% of the aggregated knowledge while the experts mentioned 93% of it, and the literature only 53%. Consequently, 93% of the possible observations mentioned by the non-expert groups were confirmed by the experts. The literature, however, did not contribute to any new observation concerning the interaction of the car with the traffic environment.

In general, the contribution of the particular focus group sessions to the aggregated knowledge was high for each knowledge domain. The majority of the observable manifestations were mentioned in the focus group sessions with non-experts. The literature only contributed with one new statement in the driver-related knowledge domain and this can be considered as a good mirror of the advancements, and the maturity of this field of interest. For the driver-car, car related and car-environment knowledge domains, the saturation was reached in the non-expert focus group sessions. No information about other possible significant observations emerged in the follow up expert session. Notice that the highest contribution of the literature is in the car-environment knowledge domain which indicates that researchers have mainly focused on the study of drivers' risky behaviors that can be seen from outside the vehicle (indirect measures of driving in haste) and not on the drivers' condition inside the vehicle (direct measures). For the driver-related knowledge domain, the saturation is not so dominant. There were some differences in the amount of possible observable manifestations mentioned by the various groups. For example, in the session conducted with cab drivers (G4), only 32% of the possible observations were mentioned with respect to the car-related knowledge domain. An explanation of this may be the lower level of specialized education among the participants.

3.4.2 Correspondence analysis

In general, a correspondence analysis intends to make visible how much and what kind of bodies of knowledge underpin the aggregated knowledge. It is claimed that if a given piece of knowledge was mentioned by multiple sources (participants in the focus group sessions and publications), it gives a stronger underpinning of the aggregated knowledge than a piece of knowledge (possible observation) mentioned by one or just a very few people. Actually, a larger number of mentions indicates that people agree on the content and significance of a given observation. In other words, the mentioning frequency reflects the relevancy of the statement towards describing the phenomenon of driving in haste. If correspondence is expressed in terms of a measure, then its higher value can indicate higher relevance. To express the measure of correspondence, a correspondence index CO_i is defined. This can be applied to quantify the correspondence of the statements about observations, so as[4]:

$CO_i = F_i / T_i$,

where: $i = \{G, L\}$,

F_i = Frequency with which a statement is mentioned by a source

T_i = Total number of people taking part in the focus groups sessions or conducted studies in the literature

This correspondence index was calculated for the outcome of the focus group sessions and the literature study in each of the four domains (Table 3.4).

Regarding the driver-related knowledge domain, the observable manifestations that have the highest correspondence to aggregated knowledge about the haste state in all the focus group sessions are swearing at others (57%), sweating (53%), frowning (47%), moving the eyes frequently (45%), turning the head and moving the hands frequently (43%), and inclining the body forward (43%). In the literature study, the highest correspondences showed for heart rate (45%), arterial blood pressure (25%), body temperature (25%), swearing at others (20%), sweating, changes in facial expression (15%) and breathing frequency (15%). Both, the group sessions and the literature study, agree that swearing and sweating are observable manifestations that mostly correspond to driving in haste.

[4] Please refer to the nomenclature of the congruency analysis in Section 3.4.1.

In the driver-car knowledge domain, the possible observable manifestations with the highest correspondence index in all the focus group sessions are horn honking (94%), checking the mirrors frequently (76%), flashing headlights (57%), and pressing pedals hard (45%). In the literature study, the highest correspondences showed for horn honking (36%), flashing headlights (18%), pressing pedals hard (18%), switching between pedals faster (9%), gripping hard the steering wheel and turning the steering wheel harder (9%). Both focus group sessions and the literature study agree

Table 3.4. Results for the correspondence analysis

Human Behavior observable facts	CO_G	CO_L
Frequency of swearing / Voice pitch-sound pressure	0.57	0.20
Skin conductivity - Amount of sweating	0.53	0.15
Presence of frowning	0.47	0.05
Frequency of movement of the eyes	0.45	0.00
Degree of inclination of the body	0.43	0.00
Turning the head frequently	0.43	0.00
Frequency of hand movement	0.43	0.00
Muscle tension	0.33	0.10
Heart rate	0.29	0.45
The hand velocity	0.29	0.00
Frequency of the feet movement	0.29	0.00
Number of rude gestures	0.27	0.00
Feet velocity	0.22	0.00
Change in facial expression	0.20	0.15
Body temperature	0.14	0.25
Breathing frequency	0.10	0.15
Presence of narrow field of vision (focused vision)	0.08	0.00
Presence of dilated pupils	0.06	0.00
Amount of blinking	0.02	0.00
Arterial blood pressure	0.00	0.25

Car – Environment observable facts	CO_G	CO_L
Frequency changing lanes	0.90	0.14
Frequency running yellow lights / red lights	0.71	0.29
Number of times disobeying traffic signals	0.57	0.14
Frequency of failing to yield to a pedestrian	0.51	0.14
Distance between cars	0.49	0.64
Velocity near the stop sign	0.45	0.07
Overtaking dangerously (wrong lane / in curves)	0.41	0.07
Frequency stepping on the lane line	0.31	0.00
Number of times stopping on a crosswalk	0.24	0.00
Cutting other off in a lane	0.22	0.14
Frequency of failing to yield the right of way	0.20	0.00
Velocity on the speed bumps	0.20	0.00
Frequency in passing road shoulder or sidewalk	0.18	0.00
Time the car remains in the left lane	0.18	0.00
Number of times driver goes the wrong way	0.10	0.00

Driver – Car observable facts	CO_G	CO_L
Frequency of horn honking	0.94	0.36
Frequency checking mirrors	0.76	0.00
Frequency flashing headlights	0.57	0.18
Frequency of use of turn signals	0.55	0.00
Force exerted on the gearstick	0.49	0.09
Velocity in the movement of the gearstick	0.45	0.00
Force exerted on accelerator pedal	0.45	0.18
Force exerted on brake pedal	0.43	0.18
Velocity on the steering wheel	0.39	0.00
Force exerted on clutch pedal	0.39	0.09
Velocity pressing pedals	0.37	0.00
Frequency in the movement of gearstick	0.31	0.00
Frequency checking the time	0.29	0.00
Frequency pressing brakes	0.27	0.00
Time the hand remains on the gearstick	0.24	0.00
Displacement of the accelerator pedal	0.24	0.00
Gripping force of the steering wheel	0.18	0.09
Deviation of the steering wheel (from left to right)	0.18	0.09
Presence of pounding on the steering wheel	0.18	0.00
Distribution of the pressure on the seat	0.14	0.00
Velocity in switching pedals	0.14	0.09
Frequency using clutch pedal	0.14	0.00
Time the foot remains pressing the clutch	0.10	0.00

Car observable facts	CO_G	CO_L
Velocity value for the road	0.69	0.79
Engine RPM value	0.65	0.00
Acceleration value	0.63	0.21
Number of times the brake lights turn on/off	0.41	0.00
Screeching of the wheels (jackrabbit start)	0.39	0.00
Velocity measure in the speedometer	0.37	0.00
Rate of temperature change in the engine	0.31	0.00
RPM measurement in the tachometer	0.22	0.00
Sound level of the engine	0.22	0.00
Number of times the headlights turn on/off	0.22	0.00
Deceleration value	0.20	0.13
Amount of fuel consumption	0.18	0.00
Presence of smoke from the wheels	0.12	0.00
Level of the fuel gauge	0.12	0.00
Amount of emissions	0.12	0.00
Smell of burnt brakes	0.10	0.00
Acceleration/ Velocity of the wheels	0.10	0.00
Acceleration of the chassis	0.10	0.00
Wheels moving from one side to the other	0.08	0.00
Number of times the horn is on	0.08	0.00
Tire wear	0.06	0.00
Rate of change of the odometer	0.02	0.00

on the fact that horn honking, flashing headlights and pressing pedals hard are the most frequently observable manifestations of driving in haste.

In the car-related knowledge domain, high speed (69%), revving up the engine (65%) and hard acceleration (63%) were claimed to be the most frequent manifestations of being in haste. In the literature study, the higher correspondence indexes were for high speed (79%), high acceleration (21%) and high deceleration (13%). Both the focus group sessions and the literature study agree that speed and acceleration are the most significant observable manifestations of a change in normal behavior.

Regarding the car-environment related knowledge domain, changing lanes frequently (90%), running red/yellow lights (71%), disobeying traffic signals (57%), failing to yield pedestrians (51%) and tailgating (49%) showed the highest correspondence index values in the results of focus group sessions. In the literature study, the highest correspondence indices were for tailgating (64%), running red/yellow lights (29%), changing lanes frequently (14%), disobeying traffic signals (14%), failing to yield pedestrians (14%) and cutting others off (14%). Both, the focus group sessions and the literature study agree that, in this domain, tailgating, changing lanes frequently and running red/yellow lights are the most important possible observable manifestations for driving in haste.

Since in the literature study driving in a hurry was found to be correlated with changes in physiological behavior, it is not a real surprise that a large number of observable manifestations were mentioned related to the human body and to its physiological operation. As in other similar states, such as being in stress (which highly correlates with haste according to other researchers), the most often mentioned driver physiological observable manifestations included sweating, muscle tension, breathing frequency and heart rate. Overt behaviors, such as the change in facial expression, particular eye movements, and the intensity of body movements when operating the controls of the car, were also frequently mentioned as observable facts of driving in a hurry. This suggests that our hypothesis "in the context of driving, cardiovascular activity, breathing behavior, visual behavior, intensity of the body movements and intensity in the operation of the car controls are enough indications to recognize when a person is driving in a hurry" is valid for testing in a posterior research cycle.

3.5 Validation of the findings

For the purpose of this confirmative study, two targets of validation were considered: (i) source validity, and (ii) investigator validity.

3.5.1 Source validity

In this subsection we will discuss the validity of our sources (i.e., participants in the focus groups and papers collected for the literature study) and their possible influences on the findings. As major issues, we will consider the characteristics and randomness of sampling and, for the focus groups, the cultural background of the participants.

It is well known that social behaviors, cognitive processes, and attitudes are influenced by cultural background and the related values and norms [4]. Similarly, driver behavior is influenced by the local road infrastructure and road situations, the particularities of typical cars and how they have been engineered, as well as factors related to road users and traffic culture [5]. The focus group sessions were conducted in Colombia. Compared to the United States of America (US) and European countries, Colombia has less strict requirements for obtaining a driving license and the infrastructure and road traffic regulations, which affect driver behavior, are different. In Colombia, the road signs tend to resemble the United States signage conventions more than the European and Asian conventions. In addition, Latin-American countries rank among the most collectivistic cultures while European countries such as Great Britain and the Netherlands have very high scores in individualism [6]. According to some researchers, drivers in individualistic cultures show a more conscious involvement in traffic, which leads to a safer driving compared with drivers in collectivistic cultures [7]. In this sense, the driving style in Colombia may have large variation relative to the US and European countries, which may question the relevance of the data to other contexts and make generalization of this study to a larger population problematic.

Focus group participants were gathered through a process of non-probability sampling, which does not provide the proper degree of representativeness of a larger population that may be achieved in, for example, e-mail surveys, web-based surveys, etc. Besides, it has to be noted that focus group data are firmly contextualized within a specific social situation. Therefore they produce 'situated' accounts, tied to a particular context of interaction. Although this empirical generalization may be difficult to achieve, theoretical generalization may be possible [8]. The data gained from this study provided theoretical insights that possess a sufficient degree of generality to allow their projection to other contexts or situations, which are comparable to that of the original study. In addition, it has to be considered that the findings of the focus group sessions were compared with other studies conducted in other countries (literature study). In this literature study, only scholarly journals, traffic reports issued by governmental agencies of different countries and peer-reviewed conference papers were considered. This increases the validity of the findings. However, whether we can extend the study into a more general context is still an issue for further research.

3.5.2 Investigator validity

According to the conventions, as a test, investigator validity evaluates the influence of the researcher on the findings. In this research project, the main researcher has a background in mechanical engineering and not in psychology. For minimizing the effect of the experimenter we used a "blind" data collection procedure. This means that the main researcher did not actually collect data or make observations but instead a "naive" observer was trained to do so. The person collecting the data and making the observations was unaware of the purpose of the study. This person was a design engineer master level student with good communication skills.

As suggested by Rubin & Rubin [9], we also established a detailed procedure for another investigator to know and check what we had done. Toward this goal a data collection protocol was produced such that the conditions under which each of the focus groups was carried out were standardized. This guaranteed that no information was left out and that the procedure was stable over time and across researchers. In the same way, throughout this chapter, the researcher presented a detailed data analysis procedure in order for other researchers to reproduce similar results.

3.6 Discussion and conclusions

The applied general methodological framework allowed us to define a proper approach for reviewing the literature and conducting the focus group study. The applied research methods proved to be appropriate for gathering information about driving in haste. The use of focus groups for this knowledge exploration provided insights into the perceptions and opinions of participants about the studied condition. This approach proved to be well suited for generating preliminary hypotheses in a domain where little research has been carried out. In the same way, the literature study complemented the information found in the sessions and, at the same time, acted as a check or confirmation of the possible observable manifestations mentioned by the non-experts and experts in the sessions. However, the reported study faced some limitations.

The available literature was not centered on the topic of our study and did not reflect our objective. In a sense, it was more a general literature. The majority of the studies only focused on psychological understanding of this state. Only a few of them presented limited information regarding system-oriented solutions. Although we conducted four focus group sessions with regular drivers and one with experts, generalization of the findings to a larger population may be problematic. If this generalization is desired, focus group sessions or surveys in different countries have to be performed. The reasoning model provided sufficient guidance to the exploration of the manifestations related to driving in haste. In the literature and in all the focus group sessions, people mentioned facts in each domain confirming our null hypothesis: when driving in a hurry, people manifest symptoms not only in the body, but also in the relation with the car, the car behavior and in the interaction of the car with the environment.

The wide range of observable manifestations described in the literature study and in the focus group sessions had different descriptive power or, in other words, they were not equally significant. Focus groups sessions conducted with professional drivers contributed more to the knowledge exploration, but were confirmed only by some experts as it was shown in the congruency analysis. The studies described in the literature were few but their content was confirmed by peer reviewers. In this sense, the research question about the observable manifestations of driving in haste was partially answered. We could verify some of the statements mentioned by the groups with the statements found in the literature, but there is still uncertainty about some observable manifestations that were only verified by some experts. For this reason, only manifestations closer to the source (driver) with high correspondence to the state of driving in haste (according to the focus group sessions and the literature study) are taken into account.

These high correspondence manifestations are heart rate, blood pressure (cardiovascular activity), gaze variance (visual behavior), skin temperature/conductivity, respiratory frequency, intensity of body movements, and intensity in the operation of the car controls. However, it is clear that further research is imperative in order to justify whether other characteristics can also be observed and to see if they should be considered from an instrumentation point of view. Indeed, the congruency and correspondence analyses provided considerably high indices for some observable manifestations in the car behavior and car-environment interaction domains and thus, measuring them should not be radically discarded.

3.7 References

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Chapter 4

Research cycle 3: Time pressure as a proxy of being in haste

4.1 Introduction

Studying haste in drivers to find indicators cannot be done in real life, since intentionally inducing haste in drivers on the road can lead to unsafe situations and is therefore unethical. Reproducing haste in a laboratory setting appears to be the most feasible alternative approach. However, since not all the underlying factors exposed in Chapter 1 can be reconstructed in experimental research, some sort of simplification is needed. Due to the fact that time-related factors have been widely reported as the cause of traffic accidents and are the most feasible to implement in laboratory settings, this research will focus only on the phenomenon of being and acting in haste resulting from a tight time constraint imposed on the completion of an important task. Maule & Hockey [1] propose a general theory of behavioral adaptation to stress and workload: the Variable State Activation Theory (VSAT). According to this theory, the sum of the cognitive awareness of not having enough time and the importance of completing a task results in the need to perform actions rapidly with an associated feeling of stress. This form of stress is what is called haste due to a time constraint and what has been often referred to in the literature as time pressure (stress due to time) [2-4]. Moreover, the VSAT states that under time pressure, people try to adapt to the time constraint at the expense of increased effort (also known as the "trying-harder" reaction) and through several coping strategies, including: (i) acceleration in the execution of actions, (ii) filtration of information/actions, and (iii) change in strategy for the execution of the task. Acceleration, as a mode of adapting to time pressure, is very costly and is only likely to be applied if the task is important and if the acceleration is needed only for a short period of time. Benson et al. [5] also suggest that, in order to experience time pressure, a time constraint alone is not sufficient and that the task itself has to be important for the person. In extreme cases, individuals may do nothing because of a lack of commitment to completing the tasks, or because none of the other coping strategies are considered to be effective. The latter situation can lead to more extreme affective states associated with anxiety and panic [6]. Our research focuses on the time pressure that produces the need to accelerate actions and does not cover the study of extreme cases of time pressure that lead to anxiety and panic.

In order for the people to feel hurried in a driving simulator, the operational conditions in this laboratory setting have to be similar to those likely to be encountered in a real driving environment. Simulations of other high-stress environmental conditions have been successful in a variety of military applications including firefighting and water survival [7,8]. However, there is little available information on how to create the conditions to induce haste in a simulated driving environment. State-of-the-art simulations can reproduce a specific operational environment with extraordinary physical fidelity. A driving environment can be developed with exact spatial, aural and visual specifications for a specific task. The realism needed for the subject to identify himself with the task has been obtained. Yet, when we attempt to develop a "stress situation due to time pressure" for such system or try to develop the functional specifications for a stress environment for research purposes, guidance on how to design this is at best ad hoc and intuitive rather than systematic and theory-based. In most cases, the researcher designs a stress environment based on intuitive grounds and then assesses individuals' reactions, or the researcher or designer simply use what they think will cause time pressure in people based upon their own personal judgment. In some cases, they end up with a situation or scenario with physical fidelity and face validity (i.e., it "looks" like a stress environment), but little psychological fidelity (i.e., it does a poor job in inducing stress due to time shortage). Currently, there is no consensus and there are no guidelines suggesting particular factors that are determinant to induce a proper state of time pressure in individuals and that lead to accelerated actions and to the experience of being rushed.

4.1.1 Objectives of the research cycle

The objective of this research cycle is to determine a reliable motivation and level of time manipulation to induce the feeling of being in haste in driving simulator studies in order to provide the guidelines for the development of a posterior study to further explore the identified set of detectable behavioral indicators for the recognition of driving in haste. This is to be done based on a systematic literature review of reports and journals related to the induction of haste via a time constraint (time pressure) and the execution of a preliminary empirical exploration to evaluate the effectiveness of different manipulation strategies.

4.1.2 Methodological approach

The approach undertaken in this project involved two phases: (i) an analysis of the literature on time pressure in order to define the determinant aspects to properly induce this state and to identify how such aspects have been implemented in laboratory settings and (ii) a preliminary empirical exploration to evaluate whether the use of certain manipulations of time pressure in a small sample is sufficient for the recognition of symptoms of driving in haste and to assess if one of these manipulation strategies presented a considerable variation in intensity with respect to the others. The different manipulations were evaluated using the information collected in our forerunning focus groups studies concerning observable manifestations of haste [9]. The goal is to use this information in a posterior larger scale experiment.

4.2 Using time pressure as a proxy of haste in experimental studies

The following sections present a survey of the literature related to the induction of time pressure and an approach to compare options to induce haste based on time constraint and motivations.

4.2.1 Survey of the related literature

It is already known that in order to induce time pressure, the time constraint imposed on the completion of a task has to work as a stressor. VSAT states that, in order to work as a stressor that leads to acceleration of actions, two criteria must be fulfilled [1]: (i) the amount of time available to complete the task is less than the amount of time the subject needs to complete it (i.e., there is a time shortage), and (ii) the person who is to perform the task has to be motivated to complete it in the available time (i.e., the task has to be sufficiently important for the person). If, in a real life situation or in an experimental setup, one of these components is missing, subjects will not experience pressure and, therefore, will not manifest accelerated actions. From this, we have derived our basic assumption that haste is a function of time shortage and motivation for the completion of the task, and that the change in the intensity of the state of haste can be produced either by varying the time shortage, the motivation or both.

In this section we describe, in detail, the different strategies researchers have used to guarantee time shortage and the different motivations that have been used in general laboratory settings to support the formation of the state of haste. This information was collected by using keyword-based search and was further complemented with the information found in the relevant articles included in the reference lists. The terms used in the search were constructed as combinations of the following words: 'induce', or 'time pressure', or 'operationalization', or 'manipulation' (e.g., induce time pressure, time pressure operationalization, time pressure manipulation, etc.). From that search, several ways to manipulate time shortage and the motivations were identified. Figure 4.1 presents the summary of these findings, which are further explained below.

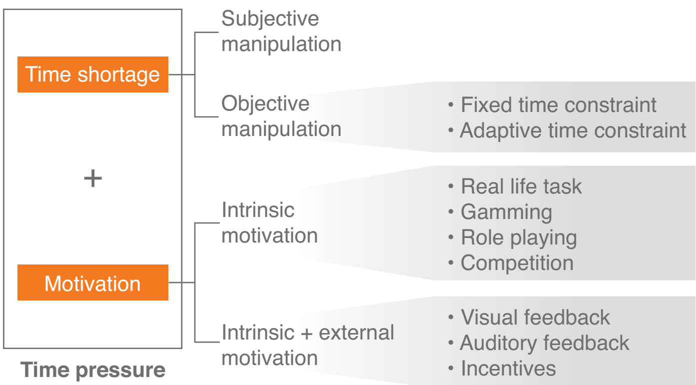

Figure 4.1. Time pressure manipulation

The time shortage for completing a task has been determined by manipulating/controlling the time available to perform the task [10]. Various types of manipulation have been studied. Some researchers simply made statements such as "you must hurry up", in the instructions to subjects. For example, in a study on the effects of time pressure on problem solving, the researchers manipulated the time shortage by instructing the experimental subjects to work as quickly as they could [11]. This type of manipulation, where the experimenter typically suggests the participants that they are late to complete the assigned task without quantifying the remaining time, will be referred to as "subjective manipulation". Normally, in experiments with subjective manipulation, there are only two categories: "with time pressure" and "without time pressure". In driving-related experiments, the urge to speed up is usually emphasized through rational argumentation or other cognitive incentives [12].

Other researchers have manipulated time shortage by imposing a firm time constraint on completing the experimental task. For example, test subjects might be given only 10 minutes to complete a task that would normally require 20 minutes. This manipulation will be referred to as "objective manipulation". Various procedures have been applied to impose the constraint. The main distinction that can be made is the one between using fixed or non-adaptive time constraints [13-17] and constraints that adapt to the subjects' regular performance [18-20].

In the case of fixed time constraints, investigators typically do not justify their rationale behind choosing the time interval [13,17]. They just assume that people will experience pressure due to the restricted available time. It has been argued that this approach cannot guarantee that the limited time is indeed sufficiently shorter than the time needed to complete the task at a regular pace and thus may not impose sufficient time pressure on all participants [5].

To overcome the disadvantage, adaptive time constraints have been introduced. The procedure for applying an adaptive time constraint is to identify the average time a person, or group of people, needs to complete a given task regularly, and then to impose a time constraint that is a specified fraction of the average regular time [19-21]. Usually, a trial and error approach is applied to determine a time constraint that induces enough strain in completing the task at hand [1].This way, an appropriate shortage of time could be guaranteed for the majority of participants in the reviewed studies. With this type of manipulation, different levels of haste can be induced depending on the variation of the time allotted to the specific task.

We already mentioned in the previous section that, in laboratory settings, additionally to experiencing a shortage of time, the subject has to be motivated to finish the task in the time given [22]. Based on the assumption that motivation can be inherent to the task that is being performed, researchers have aimed at designing tasks that psychologically engage participants and stimulate their performance, for instance by making the task interesting or challenging. One way to achieve this is to specify tasks related to the actual job of the participant [23]. Other approaches to motivate participants involve gaming, role-playing and competition. Games are, for instance, used if the task involves decision-making and the decisions that have to be taken can be transferred to a gaming context [20,24]. In the case of role playing, participants have to imagine the task in a given context. The motivation is fostered by encouraging individuals, using mental images for example, to imagine themselves in a real-life situation [25]. A competition setting can be accomplished by letting participants compete for the top score in performing a task in the shortest possible time [26]. Researchers believe that individuals engaged in competitive tasks obtain satisfaction from comparing their performance. They claim that a competitive environment forces individuals to perform as fast as possible [27].

In the time-pressure research described throughout the previous paragraphs, the selected motivation had the purpose of engaging the participant in the task in order for him/her to try to finish it in the given amount of time. There are also researchers who assert that this intrinsic motivation that is induced by the above approaches is insufficient and that, in addition, external motivations have to be offered. External motivations that have been implemented in experiments are (i) visual feedback, (ii) auditory feedback and (iii) incentives. The visual and auditory feedbacks have been used in order to emphasize the temporal constraint towards the participants by communicating the elapsed or available time. Visual means that have been applied are numeric displays [25], progress bars [18] color indicators [28] and accumulated performance score [17]. Examples of auditory feedback are sounds or noise to alert the subject when time is running out [17,26], a voice announcing intermittently how much time is left [25] and an intermittent verbal provocation telling the subject to hurry up[29]. In the case of incentive-based external motivation, the most common approach is to offer positive incentives, e.g., a monetary reward depending on the subject's performance, one single prize to the participant with the best performance [30], or an extra reward in addition to a basic payment if the performance was above a certain level [31]. Negative incentives (penalties) are not commonly used in experimental settings, but in some cases a subtraction from a basic payment was applied if the participant was underperforming [32].

Unfortunately, we could not find any reports on comparative research among the variety of options discussed above to facilitate the identification of the most appropriate way to induce time pressure that would lead to a distinctive driving in haste. From the literature, it is not clear whether, for instance, telling the subjects to work as fast as possible is enough to induce the pressure and produce haste in a driving simulator or if it is better to use an objective way to induce this pressure. It also remains unclear if different motivations (i.e., competition, imaginary situation, etc.) will incite different levels of psychological engagement in the participant and therefore different levels of haste intensity. In conclusion, for a large-scale experiment that studies the phenomenon of haste, if we want to make a justifiable choice from all the available options we first have to compare them for ourselves with a view to our specific goals.

4.2.2 Approach to compare options to induce haste

Unfortunately we did not have the resources (time, staff) to test all of the aforementioned ways to induce time pressure (all combinations of time shortage and motivations) in a laboratory setting. Therefore, we reduced the number of possibilities by focusing on comparing the different motivations to reinforce engagement in the task, which was *driving* in our case. Regarding the other decisions that have to be made, we limited ourselves to objective ways of manipulating time shortage, i.e., our goal was to explicitly impose a time constraint that would ensure that people were unable to complete the given task if they did not hurry. The selection of this alternative was based on studies in which it was demonstrated that the use of objective manipulations produced higher increments in speed performance and significant impairment of performance accuracy suggesting a higher level of stress compared with subjective manipulations [33]. In agreement with Benson et al. [5], who asserted that adaptive time constraints more effectively guarantee that all participants are encountering time shortage than to non-adaptive time constrains, we decided to use adaptive time constraints. The time each subject needed when driving normally was recorded and shortened by applying a high reduction ratio. This ratio was kept constant for all the participants. Since we were not interested in studying how different levels of time limitation affected the amount of pressure experienced, a single reduction ratio was applied.

From the motivations discussed in Section 4.2.1 we selected some combinations for further exploration. The goal was to evaluate whether the use of the time pressure construct, expressed as the combination of time shortage and motivation in a simulated driving task, was indeed enough to induce a certain level of driving in haste. A comparison between motivations was done in order to assess whether there was a motivation that, in a small subject sample, could result in significantly different levels of haste when driving, which could be implemented in a large-scale experiment. From the different motivations identified, we selected: gaming, role-playing or contextualization in an imaginary situation, competition, gaming plus money reward and competition plus money reward. Together with all these motivations visual feedback in the form of a timer was used to reinforce the time pressure. This option was chosen because it is often reported in literature and because a timer clock is typically present in real driving conditions. Auditory feedback in the form of a beeping sound was not considered in the time pressure task because it could become a source of stress in itself.

The comparisons between motivations were expressed as statements that could be further analyzed in a small pilot study:

(i) If the time to complete a driving task is reduced (that is, the available time is shorter than is needed for a normal completion of the task), and there is a motivation to finish the task in the reduced time, then the participants will intend to complete the assigned task in less time and will show symptoms of being in haste.

(ii) If we reduce the time to complete a driving task and we use competition or contextualization according to a fictitious scenario (imaginary situation) as motivations to complete this task, participants will complete the task in less time and manifest symptoms of haste more frequently than participants in a condition in which the only motivation is to complete the driving task in a limited time in a driving simulator (simulator game). This task becomes a game due to the type of subjects and the novelty of the simulator.

(iii) If we compare the case in which competition is applied as motivation together with the reduction of the time available for completing the driving task with the case in which contextualization according to a fictitious scenario is applied together with the time reduction, then the participants will complete the task in less time and manifest symptoms of haste more frequently in the competition-based condition.

(iv) If we reduce the time to complete the driving task and we offer the participants an external motivation in the form of a financial reward, participants will complete the task in less time and manifest symptoms of haste more frequently than participants in situations where no reward is offered.

4.3 Research design of the pilot experiment

The following sections describe the research design of the pilot experiment, including the setup and conduct of the experiment, the implementation of the five experimental conditions, the description of the sample, experimental apparatus and materials used; as well as the description of the data processing.

4.3.1 Setup and conduct of the pilot experiment

As we mentioned earlier, the objective of this pilot experiment was to study how the construct of time pressure could be used to induce the state of haste in laboratory settings. The specific context in which haste had to be induced in this research was driving. The laboratory setting used was a driving simulator. The purpose was to identify the most effective way to induce the state of haste when driving that could be used in the full-scale experiment. By effective we mean that it must be ensured that haste is indeed induced for a small sample and that it is desirable that the way of inducing haste introduces minimal complications in the research if possible (i.e., having to pay subjects, adding additional tasks that distract from driving, having to perform additional computations, etc.).

The independent variable was time pressure expressed as the combination of time shortage and motivation. The experimental group performed the task with the same adaptive time constraint and five different conditions as motivations, whereas the control group performed the task without any time constraint and only the task as a motivation. The independent variable was tested under the experimental condition with time constraint according to the following levels: (i) only the task as a motivation, (ii) the task and a money reward as external motivation, (iii) competition as a motivation, (iv) competition and reward as a motivation, (v) contextualization (i.e., the subject had to imagine a real situation) as a motivation. A fully detailed description of these experimental conditions is presented in Section 4.3.2. The primary dependent variable was the manifestation of haste. The state of haste was operationalized as the percentage of occurrence of the manifestations of haste that were collected in the focus group studies that we conducted earlier [9]. The manifestations selected will be described later and can be found in Table 4.2.

In the experiment, the driving task and the procedure to guarantee time shortage for this task were the same for all the participants. The factor used to guarantee the time shortage was determined in a pre-test with five subjects. In this test, it was determined that none of the five subjects driving as fast as possible (disregarding the traffic signs) could finish the drive in less than 55% of the time they needed when driving normally. Further time reduction appeared to induce excessive strain and promote a driving behavior that would not be realistic. We wished to avoid these effects and, therefore, we decided to apply a reduction rate resulting in 65% of the normal driving time.

The experimental sessions were structured as follows: at the start, participants filled out a questionnaire to establish their driver profiles, which included information such as age and driving experience. Next, participants were briefed on how to operate the simulator. They executed two training tasks (each task took five minutes). The first training task in which they were told to drive freely, was a driving session to familiarize them with the environment. In the second training task, participants were told to drive as fast as possible in order for them to perceive the limitations of the simulated car.

As a reference, after those two training tasks each participant was instructed to perform a given driving task without any time constraint (control condition) to record the driving behavior of each person under normal conditions and to calculate the time constraint to be applied to that person in the time pressure condition. Each participant had to perform under at least one of the experimental conditions. Consequently, in each session we had one control condition (driving without time constraint) and at least one experimental condition for each subject (driving under time pressure). Each participant was randomly assigned to one or two of the experimental conditions in such a way that each experimental condition was carried out by at least five different subjects. After being subject to the control condition and each of the assigned experimental conditions, participants had to fill out a questionnaire in which they were asked to evaluate the feeling of time shortage and time pressure they experienced based on a five-point Likert scale. This was used to check whether the manipulation of time pressure actually produced a sense of urgency in the subjects. At the end of the sessions, participants were asked about their opinion regarding the usefulness of the external incentive: visual feedback and money reward. They were also asked about possible changes they would propose to enhance the experience of haste.

All the sessions were video-recorded with four synchronized cameras (Figure 4.2). The recording angles covered respectively the (i) environment, (ii) feet, (iii) face and (iv) upper body. The video recordings were coded and analyzed later in order to understand how time pressure could be used as a proxy of haste. The comments of the participants were also recorded and transcribed for posterior analysis.

Figure 4.2. Video recording using four synchronized cameras

4.3.2 Implementation of the five experimental conditions

For all the five experimental conditions under time pressure, the same relative time constraint was used. The conditions only differed in terms of motivation as expressed above. The detailed description of each of the experimental conditions of time pressure is as follows:

Experimental condition 1: Time constraint and driving in the simulator as motivation

This condition was based on the assumption that the given task in the driving simulator is motivating enough for a participant to try to complete it in the limited time. To increase the chance that driving in a simulator was perceived as attractive, we selected our participants so that they had experience in playing video games. The participants were told that they had to complete the driving task, a predesigned route, in 65% of the 'normal' time. It was emphasized that it would be hard to meet the time constraint. The subjects were also instructed to obey the traffic rules, as they would do in real life. A timer on the instrument panel continuously displayed the elapsed time.

Experimental condition 2: Time constraint and a money reward as additional motivation

Under this condition, the participants were given the same instruction as above, but we emphasized that if they managed to arrive in 65% of the time they were going to receive a reward of €10. To maintain the external motivation we also told them that if they could not make it, we would subtract €1 from the original reward. They were also instructed to obey the traffic rules, and that this aspect was also considered in determining the final reward. A timer on the instrument panel displayed the elapsed time.

Experimental condition 3: Time constraint and contextualization of a fictitious scenario as motivation

Under this condition, the participants were instructed to imagine that they had overslept and were now in a hurry to arrive at the airport in order to catch their flight. We told them that they had to be at the airport entrance in 65% of the 'normal' time. We also told the participants that they needed to catch this flight because they had an important appointment with a client and that they had to imagine that their job would depend on it. It was emphasized that it would be hard to meet the time constraint. Again, the traffic rules had to be obeyed. In this case, the timer displayed the time remaining till the check-in deadline.

Experimental condition 4: Time constraint and competition as motivation

Participants under this condition were told that they were competing with other participants with the goal to set the overall time record. They were told that the best score so far was 65% of the time they took when they were driving normally. It was also mentioned that there were still other participants to come so they had to perform as well as they could. Again, it was emphasized that the current time limit was tight. Participants were also instructed to obey the traffic rules because this was also considered in the score. We promised to e-mail the list of time scores. As in most other cases, the timer on the instrument panel displayed the elapsed time.

Experimental condition 5: Time constraint and competition and money as motivation

This condition was the same as the previous one, but in addition we told the participants that the top scorer would receive a €50 reward.

Table 4.1. Experimental conditions performed by subjects

Subject	Experimental condition					
	Control condition	Motivation through challenge	Motivation through challenge + money	Motivation through competition	Motivation through competition + money	Motivation through contextualization
1	X	X				
2	X				X	X
3	X			X		X
4	X		X		X	
5	X			X	X	X
6	X	X	X			
7	X		X			
8	X	X				X
9	X			X	X	
10	X	X	X			
11	X			X		X
12	X				X	X
13	X	X	X			
14	X			X		X
Total	**14**	**5**	**5**	**5**	**5**	**7**

4.3.3 Sampling of subjects, experimental apparatus and materials

Sampling of subjects

Using convenience sampling, we recruited eighteen male and female drivers between the age of 25 and 35 years from TU Delft staff and students that voluntarily wanted to perform the experiment. Subjects had to have a driver's license for at least two years and experience in playing video games. Participants who indicated that they were prone to motion sickness were excluded. Four subjects who experienced motion sickness during the execution of the training tasks were also excluded. With the exception of four additional subjects who experienced motion sickness after driving under the normal condition and one of the experimental conditions, participants were asked to drive under a second experimental condition (Table 4.1).

Driving task

The driving environment consisted of a suburban area with sparse traffic flow. For all the experimental conditions the traffic was similar. The complete road network had sixteen straight road segments, eight wide turns and twelve intersections (Figure 4.3) with a total length of approximately 6 km. Participants had to start at point A, follow the green path until they reached point A again and then turn to the right at point B where they had to follow the red path until they reached point B again. For all the participants and conditions, driving along this route took less than 12 minutes.

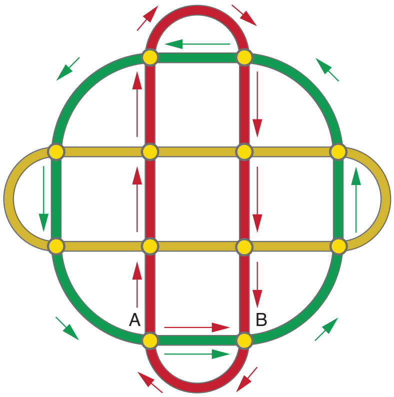

Figure 4.3. Driving Task

Driving simulator hardware and software

The simulator was a fixed-base simulator of the manufacturer Green Dino (GD) Virtual Realities (Figure 4.4). The cabin of the simulator resembles the front portion of a regular passenger car with a manual transmission. The steering wheel, pedals, gear lever and indicators are obtained from a real car and the dashboard, interior, and mirrors are integrated in the projected outside world image (road and other traffic), as shown in Figure 4.4. The simulator provides a horizontal field of view of 180° through three projectors. The front view projector: (NEC VT676) has a resolution of 1,024 x 768 pixels, while the side view projectors (NEC VT470) feature a resolution of 800 x 600 pixels. Four speakers in the simulator cabin provide realistic engine and wind noise. Simulations run at 100 Hz (i.e., re-computation per second) and the refresh rate of the visual

Figure 4.4. Green Dino Driving Simulator

projection is faster than 25 Hz. The simulator software records changes in positions and/or angles in the controls and interactions with other traffic caused by the driver (i.e. distance to other cars). The car model includes simulation algorithms for the engine, the drive train dynamics and also aerodynamics.

4.3.4 General data-processing workflow

The sessions resulted in 41 video recordings. In 14 of them, the subjects were driving under normal circumstances (the control condition) and in the other 27, the subjects were driving under one of the experimental conditions. In each condition, five video recordings were produced, one recording per subject, with the exception of the contextualization-based condition with a fictitious scenario as a motivation, which produced seven videos.

The videos were analyzed to determine if the participants under the different time pressure experimental conditions manifested symptoms of haste and to investigate whether the various forms of motivation influenced the level of haste produced. As reference material, in the analysis, we used the outcomes of our focus group sessions about manifestations of haste when driving [9].

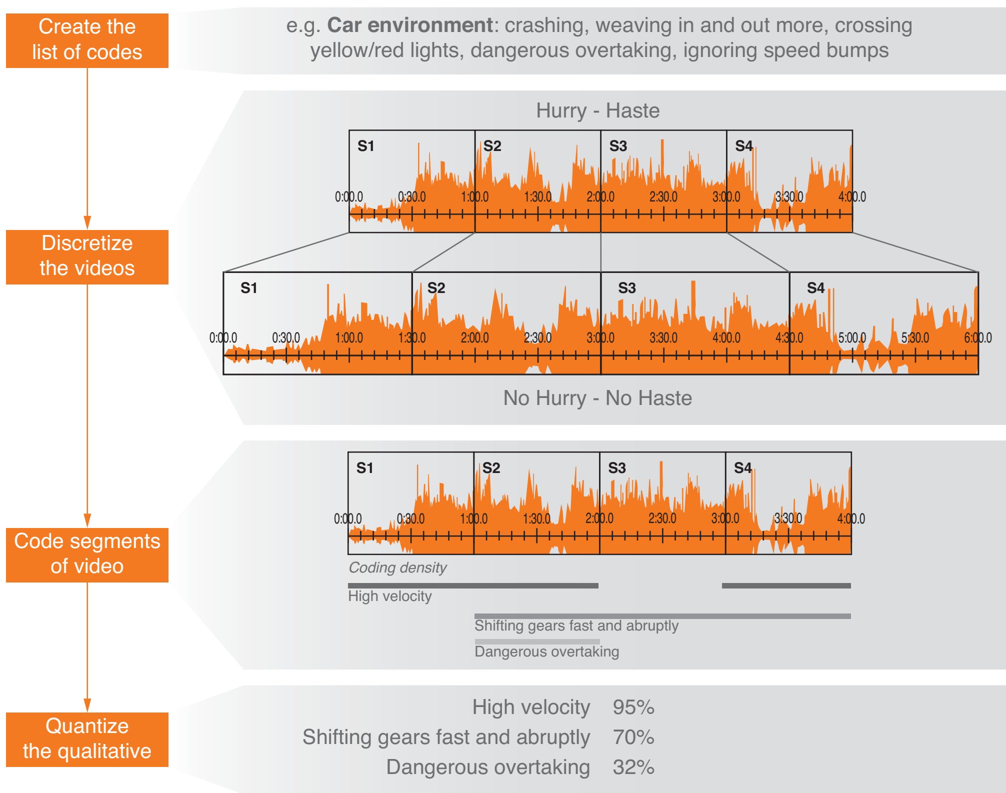

Figure 4.5. General workflow of data processing

In order to facilitate the analysis, all video footage was imported into the qualitative data-analysis software package Nvivo from QSR International.

Occurrences of the manifestations of haste were identified and counted by comparing the video that contained the driving behavior of each person under normal circumstances (control condition) with (one of) the video(s) of his/her driving behavior under time pressure. This analysis involved the following actions (Figure 4.5): (i) creating the codes in order to label segments of video, (ii) discretizing the videos of the two conditions for each subject, (iii) coding each segment of video by comparing the behavior of the subject under normal condition with his/her behavior in the experimental condition and (iv) quantifying the qualitative observations.

Creating the codes in order to label segments of video and discretizing the videos

The codes that we used to label the segments of video were selected from the most-mentioned manifestations of driving in haste put forward by regular drivers and experts in five focus group sessions as well as by a selected set from the literature in this field. In this study [9], the number of mentions of a manifestation was assumed to correspond to its significance.

After importing the video recordings into Nvivo, each of the recordings made in one of the time-pressure inclusive experimental condition was discretized into intervals of one minute. To allow for consistent comparing, the corresponding video under the normal condition was discretized into corresponding segments based on the subject's progress on the predefined route. This means that each segment of video in the experimental condition had its equivalent in the video under normal condition covering the same stretch of the route driven by the same subject.

Coding segments of experimental condition videos

For coding the video segments produced under the experimental conditions, we compared the behavior of the subject under normal condition with his/her video under one of the experimental conditions. We were looking for the manifestations of haste presented in Table 4.2. In analyzing the video footage we obviously had to exclude those manifestations that are not visually observable, such as increase of heart rate. These manifestations were excluded due to lack of time and technical resources available at the moment of this study. The remaining manifestations were divided into groups in order to facilitate their observation in the set of synchronous recordings from the different cameras. Each manifestation of haste was assigned a code. The list of codes and groups are presented in Table 4.2.

Occurrences of manifestations or codes were established based on comparison of the time-pressure condition with the normal driving condition. For example if under the time-pressure condition a subject argues and self-complains more than in the corresponding video segment recorded during normal driving, this was counted as an occurrence of 'arguing and self-complaining more'. To label the segments of video without visible manifestation, one additional code named "normal driving" was introduced.

Table 4.2. List of codes (from[9])

Groups	Manifestations of haste in driver / codes
Face	Arguing and self-complaining more: the number of phrases uttered to complain is higher than in normal condition.
	Facial expression changes: there is more presence of frowning than in normal condition.
	Looking to the mirrors and instruments more often (eyes move fast): frequency of moving the eyes or head to look to the mirror is higher than in normal conditions.
	Moving the head fast and abruptly: the speed of the movement of the head performed to overtake, change lanes or in the intersections is higher than in the normal condition.
	Leaning the body forward: the space between the body trunk and the chair is higher than in the normal condition.
Hands	Horn-honking more frequently: frequency of pressing horn honk higher than in normal condition.
	Unconscious movement of the hands: frequency of hands movements not intended to operate the controls of the car is higher than in the normal condition.
	Shifting gears fast and abruptly: the amount of time the person took shifting up or down the gears is lower than in the normal condition.
	Manipulating gear stick or steering wheel in vain: Presence of intention to move the steering wheel or the gear stick but actually not moving it. Failed movement.
	Suddenly moving the steering wheel: the speed of movement of the steering wheel to change lanes or to overtake is higher than in normal condition (angular velocity of the steering wheel).
	Flashing headlights: presence of moving the lever to flash headlight.
	Mistakes: the number of incorrect movements of the clutch to shift gears is higher than in normal condition.
Legs	Unconscious movement of the legs: frequency of movements of the legs not intended to operate the controls of the car is higher than in the normal condition.
	Shifting or switching pedals fast: amount of time spent when releasing the throttle and pressing the brake is less than in normal condition.
	Pressing pedals hard and fast: pressing the clutch, throttle and brake faster than in normal condition (displacement of each pedal in time).
Car	Higher velocity: velocity of the vehicle is higher than in normal condition.
Car-Environment	Crashing: frequency hitting another vehicle or the infrastructure is higher than in normal condition.
	Weaving in and out more: frequency of changing lanes higher than in normal condition.
	Crossing yellow/red lights: frequency of crossing traffic lights in yellow and red higher than in normal condition.
	Dangerous overtaking: frequency of performing a dangerous overtaking maneuver which is defined as starting to overtake with a headway shorter than 1 second.
	Ignoring speed bumps: frequency of crossing the speed bump without reducing velocity is higher than in normal condition.
N/A	Normal driving: None of the symptoms above.

The detailed procedure was as follows. We selected the discretized videos of one participant under the normal condition and under an experimental condition. We took one group of manifestations of haste (e.g., the manifestations of the group Car) and we watched the first segment of video under the normal condition focusing on these manifestations.

Then we compared it with the equivalent segment under the time-pressure experimental condition searching for at least one occurrence of an increase in these manifestations. To establish the speed of moving controls of the car, such as the pedals and steering wheel, or some of the car dynamic variables, such as the acceleration, we used the information recorded by the driving simulator as a function of time (e.g., displacement of brake pedal in a period of time, angular speed of the steering wheel, etc.).

Then, the means of these variables were calculated for each segment and compared with the equivalent segment in the other condition. The occurrence of a manifestation in a segment was based on these mean values. For example, if the value for the speed of the car in the experimental condition was higher than in the normal condition that segment was labeled with "higher velocity". To estimate how fast the movements of the hands, legs and head were, we used a video editing software for computing the elapsed time in the execution of a movement.

Each segment of video had to be observed at least five times: one time per group in the table. This means, that each segment was coded using the manifestations of haste in the group *car*, then the group *hands* and so on until we had finished all the groups and all the segments in the video of the participant under the time-pressure condition. At the end we had all segments of all the participants' videos under the experimental conditions labeled with the manifestations of haste that showed an increase in that segment in comparison with the normal condition.

Quantification of the data

In order to analyze the data objectively, we subsequently translated the coded qualitative data into a quantitative form. For such purpose, we counted the number of times the code occurred in all video recordings of driving under the time-pressure condition and we converted these into a percentage of occurrence. So if the code occurred 4 out of 8 segments of a video, then we reported a score of 50% occurrence of that code for that particular video.

4.4 Results

Table 4.3 presents the results of the questionnaire with which we evaluated the subjects' subjective experience of time pressure. Under all the experimental conditions, the participants agreed that there was not enough time to complete the ride (M=2.26, SD=0.52) and that they had experienced time pressure during the ride (4.22, SD=0.698). On the basis of these results, we concluded that, in the subjective experience of the participants, all the experimental conditions sufficiently induced time pressure.

Table 4.3. Time pressure manipulation: questionnaire results

	N	Mean	SD	Median	Mode
I think there was enough time to undertake the task	27	2.26	.526	2	4
I felt in a hurry (time pressure) to complete the task	27	4.22	.698	2	4

(1= strongly disagree 5 = strongly agree)

Table 4.4. Average completion times of subjects per condition

Experimental Condition/ Motivation	Average time spent under normal condition	Average time under experimental condition (Te)	Average time constraint per condition (Tc)	Average time shortage Te - Tc
Intrinsic challenge	8:44	6:44	6:07	0:37
Money reward	9:27	7:12	6:37	0:35
Competition	8:34	7:12	6:02	1:10
Competition + money	9:37	6:32	6:36	-0:04
Fictitious scenario	8:37	6:51	6:02	0:48
Average over all conditions	**8:59**	**6:54**	**6:16**	**0:37**

All times in minutes : seconds

Table 4.4-4.5 and Figure 4.6 present the results of the pilot experiment. As an overview, Table 4.4 shows the average driving times per subject and per condition. The underlying individual data showed that, under any of the time-constrained conditions, all the subjects managed to finish the driving task faster than under the normal condition. The averages in the

Table 4.5. Occurrence of manifestations of haste in each experimental condition: average percentages

	Manifestations of haste in all subjects used as codes (average percentage of ocurrence in video)																									Normal driving (%)
	Crashing	Dangerous overtaking*	Driver argues ans self-complaining more	Facial expression changes	Manipulating gear stick or steering wheel in vain	Hesitating movement with the feet	High velocity*	Horn honking	Ignoring speed bumps	Jerky movement of the hand showing impatience	Looking to the mirrors-instruments more than normal	Mistake in handling the gearstick	Moving the head fast	Pressing pedals harder than normal*	Shifting gears fast and abruptly*	Shifting pedals fast*	Unconscious movement of the hand	Unconscious movement of the leg	Suddenly moving the steering wheel	Crossing yellow-red lights	Weaving in and out*	Leaning the body forward	Flashing headlights	Overall average	Average of highlighted manifestations	
Intrinsic challenge	23	44	6	3	10	3	78	5	24	3	10	0	14	23	70	39	0	0	0	16	36	0	0	**18**	**48**	7
Money reward	11	32	2	2	6	6	72	10	11	5	23	8	36	43	57	46	7	10	8	11	23	2	5	**19**	**46**	7
Competition	14	22	12	15	11	20	68	11	24	10	9	2	14	63	54	45	7	8	0	10	27	2	0	**19**	**47**	0
Competition + money	14	21	8	2	2	18	68	0	26	2	8	0	18	45	50	35	3	0	14	25	24	3	0	**17**	**41**	4
Fictitious scenario	19	32	15	12	9	18	67	16	22	6	12	7	11	56	57	49	6	6	0	15	21	0	0	**20**	**47**	3
Average over all conditions	**16**	**30**	**9**	**7**	**8**	**13**	**70**	**9**	**21**	**5**	**12**	**4**	**18**	**47**	**58**	**43**	**5**	**5**	**4**	**15**	**26**	**2**	**1**	**19**	**46**	**4**

The data marked with * represent the manifestations of haste most often coded in the videos.

table show that in most cases, although the subjects managed to reduce their driving times, most of them could not complete the task before the deadline. For most conditions, the resulting time shortage $T_e - T_c$ was in the range between 30 and 70 seconds on average. The best average performance was delivered under the two conditions involving a reward. In the case where the reward was linked to a competition, the subjects on average even managed to finish only within the constrained time.

Table 4.5 shows the analysis of video coding per experimental condition. In all the videos in which the subjects were under time pressure, regardless of the motivation used, participants showed a visible change from their normal behavior for at least 93% of the time. Only 7% of the video segments had to be labeled 'normal driving' because we could not observe any of the manifestations of haste.

For all the experimental conditions, the percentage of occurrence averaged over all of the manifestations was in the range from 17 to 20% (Figure 4.6). None of the conditions stood out in this respect.

There are six manifestations (highlighted in Table 4.5) that could be observed considerably more often than the 17-20% of the times mentioned above. When we compared the conditions based on these highest-scoring manifestations, we again found little difference between the conditions, showing a range between 41 and 48% (Figure 4.6).

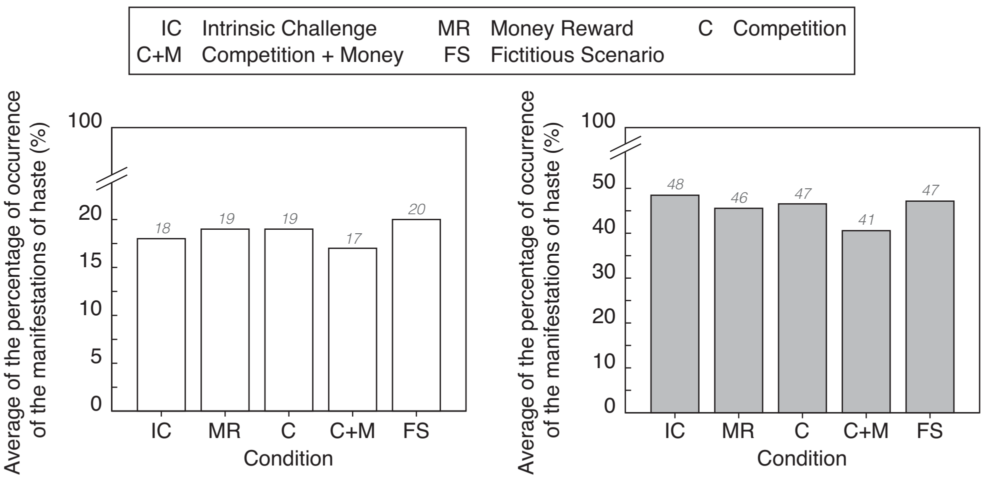

Figure 4.6. Average of all manifestations of haste per condition (left) and average of the manifestations of haste more often observed on subjects per condition (right)

4.5 Discussion of the implications of the findings

The time reductions that the participants had when they completed the task under any condition of time pressure compared with the normal situation indicated that people tried to cope with the limited amount of time. Furthermore, the experience of being under pressure when driving and the lack of time reported by the participants suggest that there was a change in the emotional state of the person. In addition, the low percentage of occurrence of normal driving in all the videos in which the participants were under time pressure indicated that an experience of being rushed manifested itself as a consequence of having to complete the driving task in less time. This is consistent with the outcomes of the focus group studies we reported in a previous study [9]. This suggests that our first statement (see Section 4.2.2) is correct: in a driving simulator, which poses a novel experience to the subject, a considerable reduction imposed on the time to complete a driving task will stimulate a subject to complete the task in less time, manifesting some symptoms of haste. This appears to be true in combination with any of the motivations used.

However, we were expecting large differences *both* in driving times *and* in occurrences of the manifestations of haste when comparing the effects of different motivations. Our pilot study revealed such differences only for the driving time, which was, on average, considerably shorter under the condition in which a reward was linked to a competition.

Nevertheless, the percentages of occurrence of manifestations of haste were about the same for any of the conditions. This suggests that in cases where subjects managed to achieve more time reduction, they may have not been more in haste than in other cases. Possibly, the combination of competition and the reward evoked additional emotions other than haste (e.g., the 'kick' from gaming), which also increased the need to drive fast. Another possible explanation for the observed difference in completion times is that we told the subjects to complete the task even after they had already passed the deadline. If a subject already knew that he had 'failed' he might no longer have been motivated to perform well for the last part of the route. This may very well have caused a biasing effect on the driving-time measurements (which does not compromise our acceptance of the first statement because the bias can only increase driving times). With hindsight, it would have been better to let the drivers stop at the time of the deadline, and use the remaining distance to the endpoint to compare the levels of success in coping with the time constraint.

We included expectations about driving time in our second, third and fourth statement because we wanted to evaluate whether certain motivations were more effective, and this would be confirmed by a more frequent occurrence of manifestations *and* a shorter driving time. If a motivation had led to a more frequent occurrence of manifestations but *not* a shorter driving time, this would falsify the respective statements.

Now that there is no clear distinction between the motivations regarding the occurrence of manifestations, the driving times are no longer relevant in evaluating the second, third and fourth statement (they do however only support the first statement). As far as we can conclude based on this limited experiment – that did not allow establishing a statistical significance – we cannot conclude anything about the second, third and fourth statement proposed for exploration. In other words, in the evaluation done with a small subject sample, any of the motivations used produced more or less the same symptoms of haste. In a large-scale experiment there is apparently no reason to offer money rewards when the result produced by all the motivations is more or less the same. However, in order to allow full statistical underpinning, it is commendable to repeat the study with more subjects and a denser population of subject-condition combinations according to the matrix shown in Table 4.1. Due to resource limitations, such a setup was not possible in this research. Besides, our interest was to use a motivation that would produce a large difference in haste symptoms but keep the investments low. Because the differences between the motivations that we found in our limited experiment were small – i.e., the relatively large sample of all 27 drives with the different motivations together produced results within a small bandwidth – we do not have reasons to expect that testing more subjects would produce results with considerably larger differences in the occurrence of haste manifestations.

A possible reason why there were no striking differences between the motivations regarding driving time and manifestations of haste, is that subjects apparently had an intrinsic drive to deal with the task in this limited time, which was not attached to any of the particular forms of motivation used in the experiment. Not even the monetary incentives drastically affected human behaviors or improved the performance in the task. The subjects, in this experiment, were not forced to participate. They mainly volunteered, so they probably had a high intrinsic motivation in performing the task. This is consistent with the literature review reported by Camerer and Hogarth [34] where they found experimental data supporting the fact that for easy or hard tasks, and intrinsically motivated subjects, marginal changes in incentives did not improve performance much. Besides, driving in a simulator was a novel experience for them and perhaps, driven by the curiosity, the participants tried to perform as well as possible. The use of a more realistic set up such as a 3D stereo driving simulator with 6 degrees of motion freedom, may even further enhance the internal motivation.

In addition, we believe that the instructions given influenced the performance of the participants. In all the time-constrained conditions, we emphasized that the available time was short. As DeDonno and Demaree [24] have found in similar experiments, participants that are explicitly instructed that time is insufficient to complete the task will try to execute actions faster, performing worse than those who are told they have enough time.

Based on our data analysis it was not possible to obtain a reliable assessment of the intensity of haste manifested in the subjects. By relying on observations only, it is difficult to objectively compare the different motivations regarding the intensity of the manifestations. To clarify if the different motivations have different influences on the intensity of the haste produced, we suggest recording the information using sensors. In such a way, motivations can be objectively compared using quantitative data. Recordings from sensors can also provide clues on how to detect haste automatically, which is our ultimate goal.

If a clear difference between experimental results in a hasty and non-hasty condition is necessary, the intensity of haste needs to be strong. We believe that to maximize the intensity of haste we would either have had to experiment with reducing even more the time shortage or with using only one of the motivations studied in this research and try to vary the level of difficulty of the task. However, further reducing the amount of time to complete the task can be dangerous. People can get into other states such as frustration as was suggested by Maule and Hockey [1]. So they can fall back on the strategy of doing nothing because the completion of the task in this time is so difficult that it goes beyond their ability. And raising the level of difficulty of the driving task may involve changes in the road geometry, the road network condition and the level of traffic. All these variables may raise the level of difficulty of the task and therefore raise the feeling of being in haste. However more careful exploration on these issues is needed because too much difficulty in the task may also lead to a state of frustration.

4.6 Conclusions

Based on the conducted study, we conclude that reducing the time available to complete a driving task by applying a high reduction ratio and using various forms of motivation induced a detectable form and level of feeling haste in all the participants. Compared to the situation in which they drove without any time constraints, a change could be observed in the participants' driving behavior. These behavioral changes correspond to the manifestations of haste that we had earlier collected from drivers and experts in focus group studies and from the literature. However, in the experiment that we conducted using a driving simulator, we could not find that any of the different forms of motivation produced significantly stronger manifestations of haste that will justify the selection of any particular choice for a larger experiment. Imagining a fictitious scenario, competing or rewarding were not found to make a considerable difference. If a researcher wants to know which motivation is the most effective in inducing haste, despite the sensitivity, a more robust experimentation is needed.

Nevertheless, for our full scale experiment, we have concluded that using the driving simulator and designing an experiment that engages subjects' attention and curiosity together with an adaptive time constraint for completing a task ought to be enough to ensure that the state of the driver resulting from the experimental condition (i.e., driving in a hurry due to time shortage in the simulator environment) is sufficiently similar to hurriedness under real world situations. This is possibly because a driving-simulator environment, which is new to most participants, presents an effective stimulus to perform well. However, the experimenter should be careful with the instructions given to the participants as these may have an influence on their behavior

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Chapter 5

Research cycle 4: Finding indicators of driving under time pressure

5.1 Introduction

General manifestations of driving in haste were gathered in the literature reviewed in Chapter 2 and the information gathered in the focus group sessions presented in Chapter 3. These general manifestations were not tied to particular triggering factors (i.e. motivational factors, time related factors, etc.). In chapter 4 the phenomenon of haste was simplified to the haste associated to time pressure. This means haste produced by the triggering factor temporal constraint to complete a task. Considering that it is not possible to generalize the effect of different stressors (triggering factors) to human behavior, even within the same situation, if we consider the temporal constraint as a stressor, it could be expected that there are different tendencies for certain manifestations of haste associated to this particular stressor (factor). That is, for example, a change in the cardiovascular activity may be observed both in a person pressed by time or pressed by a social pressure, yet the pattern described by the signal associated to these factors may be different. In the focus group studies, most of the observable manifestations gathered were not specifically tied to a single triggering factor and were mostly defined in global terms, meaning that the behavioral changes in an upper level were known but the specific indicators (lower level manifestations) for these changes were still uncertain.

For example, referring to a change in cardiovascular activity corresponds to an upper level indicator, which can be further operationalized into several lower level indicators such as mean of the heart rate, standard deviation of the inter-beat intervals, etc. Therefore, in order to be able to recognize when a person is driving in haste due to a temporal constraint, it is necessary to reduce the set of observable manifestations identified in previous chapters to a set of specific lower level indicators representative of time pressure and their possible tendencies. Little is known about the individual characteristics that predict hurried driving and how time pressure affects driving behavior. However, time pressure and its effects on the human behavior have been studied in different fields. Consequently, in this Chapter, literature concerning the effects of time pressure in both driving and, mainly, non-driving related contexts was further explored in order to complement the findings of the focus group studies which revealed that manifestations closer to the source, in this case the driver, are better to recognize this state. As a result, particular lower level manifestations of time pressure, that could be used to recognize the state of driving in haste, were identified.

These theoretical findings were used to derive preliminary hypotheses (i.e. set of indicators with respective tendencies). These hypotheses were experimentally tested in the next chapter. Additionally, the last sections of this chapter present a pilot study based on the design of the experiment to be used to test these hypotheses. This study was performed in order to evaluate the feasibility, the time required for the experiment and to recognize possible inconveniences related to the experimental procedure used. This was done in order to improve upon the design of the study prior to the performance of a full scale experiment.

5.1.1 Objective of the research cycle

The objective of this research cycle, which is reported in two chapters, is to determine the discriminative power of a set of detectable behavioral indicators for the recognition of driving in haste resulting from a time constraint imposed on the driving task. The purpose is to identify viable indicators that can eventually be used as the basis of a system to detect driving in haste. A systematic literature review of reports and journals related to the effects of time pressure on human behavior, physiology and body dynamics is used to reduce the set of detectable behavioral indicators only to those that could originate from a time constraint. The discriminative power of this reduced set of indicators is analyzed and evaluated through the execution of an experiment using a driving simulator and a custom sensing system specifically devised for the assessment of the required data.

5.1.2 Methodological approach

In order to fulfill the research objective, the research cycle has been methodologically framed as design inclusive research (DIR). As a framing methodology, DIR offers the possibility to embed design as a research means, and allows combining scientific study and designerly inquiry in a systematic way [1,2]. Design as a research means can be found in the form of artifacts, process and entities. In this research, artifacts manifested as hardware and software are used as means for detecting and testing the indicators, as well as an evolving research tool. Likewise Research in Design Context - RDC, DIR also requires that the research procedures and methods are tailored according to the context, in this case driving in haste. The general process of DIR is shown graphically in Figure 1.3. This process is divided in three phases: (i) phase of explorative research actions, (ii) phase of creative design actions, and (iii) phase of confirmative research actions.

The goals of the explorative research phase are: (i) aggregation of knowledge and construction of new knowledge related to the manifestations of time pressure, (ii) formulation of a critique of the current understanding and existing approaches regarding haste due to a temporal constraint,

(iii) development of hypotheses associated to low level indicators of driving in haste, (iv) definition of the goals for the design of the experimental setup for measuring and evaluating indicators.

The goal of the creative design phase (embedded design process) is set as: (i) to propose the concept of a system for measuring indicators of driving in haste in a simulated environment, (ii) to prove the validity and feasibility of the system by creating a testable setup (pilot study), and (iii) to perform tests towards an enhancement of the proposed system.

The goals of the confirmative research action are aimed at: (i) the verification of the hypotheses about indicators of driving in haste, (ii) the internal validation of the research methods, (iii) the external validation of the findings of the research and (vi) the consolidation of the results by matching them against the existing body of knowledge, and by generalizing them towards other applications.

The results of the explorative research phase along with the creative design phase will be presented in Sections 5.3-5.5. The results of the confirmative phase will be presented in the following chapter.

5.2 Time pressure appraisal and coping response model in driving

Stress is a concept that the scientific community continues to struggle to define and, thus, the research literature in this area is often confusing and contradictory [3]. Despite the number of models proposed, the relationship between stress and performance is still subject to further exploration since there is no sense of cohesion among concepts. These limitations are even more obvious when dealing with specific types of stress, such as haste, or stressors, such as externally imposed time constraints. Given this situation, it would be rather inaccurate and misleading to identify effects of time pressure on humans without first clarifying important concepts and definitions for the current study. Consequently, a framework that describes the processes and mechanisms associated with human performance under stress, and more specifically under haste due to time a constraint, has been constructed based on some previously proposed models. Chapter 1 presented a general approach towards the definition of such framework. This approach was based on a transactional model which views stress as the interaction between the environment (demands of the task) and the individual (resources for coping), emphasizing the role of the individual's appraisal of situations in determining their responses.

The model used to guide the current research elaborates on that first approach. It is based on Lazarus and Folkman's Transactional Model of Stress and Coping, and further modified based on Sweller's Cognitive Load Theory and other stress-related theories [4,5]. The model describes the processes of coping with time constraint-related stressful events (Figure 5.1). To further understand the impact of a time constraint on the driving task, Lazarus and Folkman's original model and its relationship between the individual and the environment (influencing factors) was combined with Sweller's Cognitive Load Theory, more exactly with his categories of cognitive load. Sweller's Cognitive Load Theory distinguished three categories of cognitive load, of which only two are of interest for the current study [5]. Intrinsic cognitive load, on one hand, refers to the load induced by the intrinsic nature of the items being processed, such as task difficulty, and is thus fixed and inherent to the task. On the other hand, extraneous cognitive load is induced by

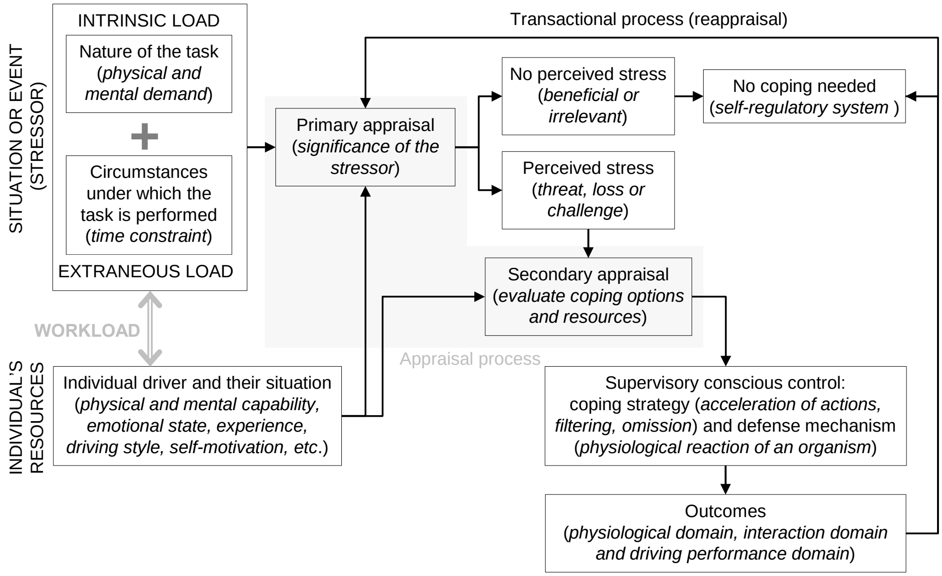

Figure 5.1. Coping model of haste due to a time constraint based on the Transaction Model [4]

external factors (i.e. time constraints) and can vary according to the demands of the instructional procedures [6]. Furthermore, intrinsic and extraneous cognitive loads are additive in the sense that task difficulty directly affects cognitive load, whereas a time constraint activates an emotional component that indirectly affects cognitive load [7].

Since cognitive load represents the load that performing a particular task imposes on the cognitive system of a particular person, cognitive load is, hence, the result of an interaction between task demands and individual characteristics. Because the demands required by vehicle driving tasks are not only cognitive/mental but also physical, the cognitive load needs to be considered together with the physical load. Workload is defined as the construct that reflects the degree to which the demands of the task fall within the mental and physical capabilities of the individual (the driver). It represents the cost incurred by the driver to achieve a particular level of performance [3,8]. Workload is, therefore, a relatively subjective measure, experienced differently by different people, and is affected by (i) the nature of the task (i.e. physical and mental demands) or intrinsic load, (ii) the circumstances under which the task is performed (i.e. time available to perform the task) or extraneous load, and (iii) the individual and their situation (i.e. skills both physical and mental, their health, their experience, their emotional state, their self-motivation) or individual's resources.

The combination of intrinsic and extraneous loads defines the situation or stressor. The assessment of time pressure is a two-level process, relating the stressor to the individual's resources, and involving a primary appraisal and a secondary appraisal. During these appraisal processes, the current state of cognitive/physical activity is continuously compared to a target state [9]. Primary appraisal involves the determination of how stressful the event is: irrelevant, beneficial, or stressful. If either of the first two is the case, small discrepancies between the current and target state are regulated by (sub-conscious) automated and routine control actions, and form a self-regulatory, stable system [10]. If the latter is the case, the event is then classified as harmful (injury that has already taken place), a threat (something that could produce harm), or a challenge (potential for growth or gain). These categories are based mainly on the individual's prior experiences and, thus, generate different emotional responses. Secondary appraisal occurs after this assessment of the event and consists on the individual's evaluation of his or her coping options and resources. On this level, the discrepancy between the current cognitive/physical state and the target state is too large and routine control strategies are inadequate. Hence, control can temporarily be shifted to a higher level of supervisory (conscious) control [9,11].

Research suggests that large discrepancies between the current cognitive/physical state and the target state result in strong effects on human behavior and decision-making. Particularly, degradation of performance, as a result of time pressure, has been reported in the following cognitive domains: vigilance and attentional processes (related to visual behavior), decision-making processes and motor processes. The degradation in these domains is mainly due to an increase in the level of arousal, an increase in the cognitive demands or an information overload, primarily caused by the requirement to perform a task in a limited amount of time [3]. Coping strategies, selected as a result of the appraisal process, are used to manage the demands of the stressor. Four regulatory modes are available to cope with the increased cognitive/physical activity: (i) increase the control effort by accelerating control actions, (ii) modifying the target state, by filtering the input, (iii) changing or eliminating demands (omission or change in strategy), and (iv) take no action (associated with anxiety and panic)

The two-level process of behavioral adaptation can be classified in the three-level behavioral taxonomy formulated by Michon [12]. At the operational level, drivers under time pressure can increase their control effort to maintain acceptable task performance. At the tactical level, filtering input and neglecting sub-tasks can reduce the intensity of cognitive/physical activity, and at the strategic level, the cognitive/physical activity resulting from time pressure can be reduced by altering the driving task. The implementation of such coping strategies leads to outcomes reflected as physiological, interaction and performance responses. These responses can be measure with specific lower level indicators accordingly. Finally, this process continues until the condition is considered not stressful or until it reaches an acceptable level. In summary, this model includes influencing factors (in the form of individual's resources, intrinsic and extraneous load), appraisals, coping strategies and outcomes, to define the process that occurs during driving under a time pressure condition.

In conclusion, in order for an event to be considered as a stressor, it must be personally relevant and there must be a perceived discrepancy between the situation's demands and the individual's resources to cope with it. Additionally, this approach assumes that subjects adapt to time constraints by comparing the demands of the situation to the current cognitive/physical state and evaluating the costs and benefits of control activity to reduce any discrepancies identified by this comparison. Control activity involves expending effort, which is assumed to be limited in supply. If no appropriate control activity is available in a situation of some importance, then all the symptoms associated with panic and pressure would be expected [13].

Following the described model, for instance in a context of driving (intrinsic load) under time pressure (extrinsic load), the driver's primary appraisal compares the estimated time needed to arrive at a given destination (constantly considering road events, as well as personal resources, etc.)

with respect to the externally imposed time constraint and the consequences of not arriving on time. In a secondary appraisal, the driver assesses his coping resources to manage the demands of the situation (e.g., acceleration of driving control actions, choice of alternative route, modification of time constraint, etc.). The implementation of coping strategies leads to outcomes reflected as physiological, interaction and performance responses. If coping strategies cannot be implemented or if estimations are unfavorable, then negative emotions may appear. Contrarily, if the task is perceived as a challenge for which resources to cope are available and guarantee success or optimal performance, positive emotions may arise.

5.3 Interpreting the effects of time pressure on humans

According to the model defined in the previous section, time pressure causes discrepancies between the current cognitive/physical state and the target state, resulting in strong effects on attentional processes, decision making and motor processes. Regarding attentional processes and vigilance, time pressure has been related to a degraded vigilance and attention that can be explained with the tunnel hypothesis [3]. The stress due to time limitation tends to tunnel the attention by reducing focus on peripheral information and tasks, and by centralizing focus on the main task. Under conditions of time stress, researchers found that the perceptual field is constricted or narrowed and the scope of behavior tends to be restricted to those elements that appear to be the most threatening [14,15]. This tunneling of attention, according to some researchers, can result in either enhanced performance or reduced performance, depending on the nature of the situation and the nature of the task [16]. For example, when the peripheral information is not relevant for completing the task the ability to filter it is likely to improve performance. Yet when it is important for completing the task, the performance suffers.

In the decision making process, when time pressure increases (when it is almost severe), the information overload threatens the cognitive capacity and quickly degrades the performance [13]. When a time constraint is imposed, subjects simply cannot process information fast enough and are forced to simplify their decision, for instance, by reducing their visual scans and by considering fewer decision-related alternatives [17]. In most of the experiments that investigated time pressure, the decline in performance is gradual. This has led researchers to support the conclusion that high levels of time pressure increase errors, and affects the variability and dynamics of human preferences and choice process mechanisms in some tasks [18].

There is also evidence that time pressure affects users' motor behaviors (e.g., tapping or dragging on a touchscreen with a stylus). Van Galen and Van Huygevoort [19] found that high levels of time pressure generally resulted in more errors, greater movement variability and greater cursor control pressure on a graphical aiming task in which the subject had to make pen movements as quickly, as accurately and as smoothly (i.e. in one single move towards the target) as possible. These findings suggest that time pressure tends to increase the stiffness of a person's limbs, which in turn tends to cause actions like tapping on the screen to be performed with relatively higher force. Accordingly, when a given user employs more than the usual amount of force, this fact has been interpreted as suggestive evidence of time pressure [20].

All these higher levels effects of time pressure can be translated into lower level effects that can be measured in particular behaviors of the human body. The following sections refer to these specific measures that have been derived by researchers under general conditions of time pressure. Particularly, specific effects on physiology and human body dynamics will be explored. Note that these effects are not necessarily driving-related.

5.3.1 The effects of time pressure on human physiology

The concept of time pressure has been connected to concepts such as anxiety, frustration, burnout, stress, mental load, exhaustion, strain, tension, and arousal. Researchers have found that separating time pressure from these concepts is still an open scientific issue. Since trying to convincingly separate the concepts appears to be outside the scope of this PhD research, it will not be addressed here. Although, there is no unambiguous definition of time pressure that is used throughout the scientific community, it has been commonly seen as a state of activation of the human body with its associated physiological reactivity that is preceded by arousal due to an external stimulus, i.e., temporal demand [3]. Given the apparently inseparable relation between arousal and time-related stress, researchers have commonly linked physiologic reactivity to the human time stress response. Physiological signals are inherently controlled by the Autonomic Nervous System (ANS), which has two branches: the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS). Under normal conditions, there is a balance between these systems, placing the body in a state of homeostasis, i.e., internal stability or physiological equilibrium. However, when a person is put into a pervasive or intense psychological state (e.g. anxiety, stress, etc.), the balance between these systems is altered, which manifests in the physiological activities of the body [21]. From the physiological signals that have been explored by researchers, breathing (or respiration), cardiovascular activity and visual behavior are considered to be the most noticeably influenced by the imbalance between these two systems when a person is subject to time pressure.

Some recent investigations have focused on the variations of cardiovascular activities (heart's electrical activity and blood pressure) associated with sympathetic activation. Specifically, researchers found that, in comparison to a normal state, the heart rate variability (regularity of the interval between successive heartbeats) and the mean heart rate (the number of heartbeats per unit of time) change under time pressure [22,23]. An increase in the mean heart rate, when a person is under time pressure, has been observed both in physically demanding tasks in which the person is walking or running [24], as well as in less demanding tasks in which the person is in an office environment using mouse devices or keyboards [22,25]. Studies on the influence of time pressure on heart rate variability (HRV) show contradictory results. Although some studies suggest that heart rate variability decreases in the higher frequency (HF) ranges (>0.1 Hz) [26] and increases in the lower frequency (LF) ranges (≤0.1 Hz) as well as in the ratio LF/HF [27], other studies report that, in comparison to normal conditions, time pressure does not change the HRV [28,29]. A possible explanation for this effect is that changes in heart rate variability may only be perceptible under high levels of time pressure (acute time pressure) [28].

The impact of time pressure on visual behavior has scarcely been investigated. Few researchers have studied the effect of a temporal constraint to perform a task in visual attention. Results of these studies indicate that subjects under time pressure have more gaze concentration due to "perceptual tunneling". In general, it was concluded that there is an increase in the time spent looking straight ahead and a concomitant reduction in detection of peripheral stimuli (higher information filtration). In addition, some studies have linked the concept of cognitive and visual demand to the concept of time pressure [30]. Therefore, some indicators of these demands may apply to time pressure. Researchers have studied the effect of cognitive demands on visual behaviors when driving and have concluded that higher cognitive load produces longer fixations, spatial gaze concentration (lower variability in spatial gaze direction), and less frequent glances to the mirrors and speedometer [31]. The marked reduction in the speedometer and inspections of the rearview mirrors (located in the peripheral areas of the visual field) were interpreted as reduced situation awareness, as a need to optimize visual resources and as a simple mechanism to reduce the probability of missing relevant information.

In general, drivers spent more time looking centrally and less time looking at the periphery. Harbluk et al. [32] also reported that drivers under this state made fewer saccades per unit time, consistent with a reduction in glance frequency and a lower exploration of the driving environment. Similarly, in a posterior study, Liao et al. [33] confirmed that, in addition to blink rate reduction and increased gaze concentration, drivers also close the eyes faster and their pupils are more dilated when the mental load is high. However, the results about the effects of cognitive demands on blink rate are contradictory. Recartes and Nunes [34] found a blink-rate increase attributed to the cognitive task during drive. With this evidence, they suggested that the visual nature of the tasks in the previous experiments introduced some biases. In a later study [35], they proved that visual and mental workload result both in pupil dilation but with regard to the blink rate, a higher visual demand of the task led to a higher blink-rate inhibition effect. Therefore, their interpretation is that cognitive tasks interfere with the blink inhibition process due to visual search.

To the author's knowledge, the relation between time pressure and respiration has not been directly established. However, assuming a tight relation between mental/visual demand and time pressure, respiratory changes produced by these demands could also be expected when time pressure occurs. According to earlier studies, an increase in mental load leads to a decrease in respiratory depth and to a marginal increase in the respiratory frequency (also known as respiratory rate or breathing frequency). Later studies revealed that an increase in the difficulty of the task is associated with a significant increase in respiratory frequency, and either a decrease in tidal volume Vt (volume inspired/expired with each breath) [36,37] or no change in tidal volume [38,39]. In Wientjes et al. [40], additional respiratory parameters during stressful mental tasks were measured and it was concluded that, compared to the resting condition, the duration of the time components of the breathing cycle (inspiration time - Ti, expiration time - Te, pauses after inspiration and expiration - Pi, Pe, and duration of each respiratory cycle - Ttot) decreased (and hence respiratory frequency increased). This study also demonstrated that a decrease in the magnitude of tidal volume is systematically linked to mental effort investment. These findings seem to indicate that respiratory measures can be significantly related to pervasive psychological states (e.g., stress).

5.3.2 The effects of time pressure on human body dynamics

Time pressure does not only influence the physiological responses in the human body but also human body dynamics, which consist on: (i) kinematics (i.e., the motion of the body in the metric space) and (ii) kinetics (i.e., the forces and moments that the human body exerts through muscle activation). Specifically, researchers have shown that the kinematics (position, velocity and acceleration) of the body parts and the kinetics, forces and moments exerted by a person, change when a person is under time pressure. Early in the 90s Bonger [41] hypothesized that psychosocial factors (i.e., fatigue, time stress) directly influenced the body through changes in postures, movement and exerted forces. This was empirically tested, years later, in studies that investigated the effects of time pressure during visuomotor tasks such as manual assembly and computer interactions using mouse and keyboard. Birch et al. [42] proved that even if other demands were not so strong, high time pressure causes an increase in (i) the number of mouse clicks and (ii) the activity in all the investigated muscles in the shoulder and the forearm.

In a subsequent study, in which, the influence of time pressure and verbal provocation was investigated, Wahlström et al. [22] concluded that time pressure did not only influence the kinematics of the hand/wrist motion and the activity of the muscles but also the peak forces on the button of the computer mouse. In this study, the forces on the mouse button and the mean velocity of the wrist movements tended to be higher under the time pressure condition, and the number of repetitive wrist movements increased. In visuomotor computer task studies, in which the keyboard was used instead of the mouse, time pressure resulted in similar effects. The results indicate that increased time pressure also results in increased muscle activity, increased mean, median and maximum key strike forces, increased typing speed and an increase in the total number of key strokes [43]. In line with these results, Gerard et al. [44] found that a higher speed of typing induced by imposing a higher work pace, leads to higher forces and also higher electromyographic activity in the upper extremity.

These findings were also confirmed by Mazloum et al. [45] in an investigation on time pressure as a factor contributing to quantitative overload in data-entry tasks. They found that increased time pressure increases the perceived workload and the typing speed, and decreases the response time and typing duration. They also found that time pressure results in more forceful and jerkier movements. However, in this experiment, the typing speed under time pressure did not lead to a significant increase in error rate as it was reported in previous studies performed by Birch et al. [42] and Hughes et al. [25]. The differences in the findings may be explained with the inverted U hypothesis of the relationship between arousal and performance (for review, see Landers [46]). Increased arousal is followed by increased performance, but only up to a point. If arousal continues to increase beyond this point, performance begins to decrease. Hence, the differences in the feelings of arousal generated in the different studies may explain the difference in the amount of reported errors.

Variations in the kinematic parameters of the upper extremities were also found in other, non-computer-related tasks. Glasscock [47] showed that time pressure caused significant increases in wrist motion kinematics during assembly, disassembly and pipetting tasks. However, some of the outcomes were gender-dependent, i.e., they could only be observed in females.

5.3.3 Possible indicators of driving under time pressure and expected tendencies

As mentioned in Section 5.2, subjects driving under time pressure adapt to time constraints by comparing the demands of the situation to the individuals' resources. Coping strategies are implemented to manage the demands of the imposed temporal constraint. This leads to outcomes reflected as physiological, interaction and performance responses. Considering that driving a car is also in essence a visuomotor task, similarly to the abovementioned office-related tasks, it can be expected that some of the reported effects of time pressure in physiological activity and the body dynamics during these tasks can also be observed in the context of driving. Specifically, and considering the results from Chapter 3, it is expected that, from the physiological activity, the cardiovascular activity, respiration and visual behavior will be affected during the time pressure condition in comparison to the normal conditions of driving.

Similarly, from the human body dynamics, the kinematics of the body and forces exerted on the controls of the car will also change. According to the studies reported previously, we specifically expect the indicators and respective tendencies presented in Table 5.1. Note that these expectations are tied to the design of the experimental setting presented in Section 5.5.1 (e.g.

Table 5.1. Outcomes, indicators and expected tendencies when driving under time pressure

OUTCOMES	LOWER LEVEL INDICATORS OF THE OUTCOME	EXPECTED TENDENCY RELATIVE TO NORMAL CONDITION
Driver physiology		
Cardiovascular activity	Heart rate (mean)	Increase
	Heart rate variability (SD RR, LF,HF, LF/HF)	Decrease
Respiratory activity	Respiratory frequency (mean)	Increase
	Respiratory amplitude (mean)	Decrease
	Mean inhalation time (mean)	Decrease
	Duration of each respiratory cycle (mean)	Decrease
	Mean duty cycle (mean)	Increase
Eye activity	Blink frequency (mean)	Decrease
	Pupil diameter (mean)	Increase
Driver-vehicle interaction		
Kinematic activity	Number of operations of vehicle controls - Pedals and	Increase
	RMS acceleration and jerk of the upper and lower extremities - arms, legs	Increase
	Pedal displacements - Throttle, Brake (Max,variance)	Increase
	Speed pressing pedals - Throttle, brake, clutch (mean)	Increase
	Steering speed (mean)	Increase
Kinetic activity	Force exerted on the steering wheel (mean)	Increase
Driving performance		
Visual behavior	Percentage of time looking at road Centre	Increase
	Horizontal Gaze Variance	Decrease
	Percentage Dials (%)	Decrease
	Percentage Clock (%)	Increase
Lateral control	Lateral position (mean,standard deviation)	Increase
Longitudinal vehicle	Engine speed (mean)	Increase
	Vehicle speed (mean)	Increase
	Vehicle acceleration (mean)	Increase
	Car following time (min)	Decrease

longitudinal behavior, moderate traffic conditions, etc.). The table includes the indicators related to physiological activity and human body dynamics derived from the literature review presented in this chapter. This list is complemented with indicators associated to the car-environment interaction derived from the focus group studies and the previous literature review on haste presented in Chapter 3 and Chapter 2, respectively. The latter were included due to the fact that existing solutions for driver state recognition give priority to these indicators.

Additionally, from the above list of indicators, we believe that indicators closer to the source are the best for identifying driving in haste and that at least one of these indicators is completely independent from the driving context and completely insensitive to differences between drivers.

5.4 Measuring indicators of driving under time pressure

The following sections include a review of the different technologies used to measure the indicators mentioned in Table 5.1. The technologies are classified into 5 groups: cardiovascular activity, respiratory activity, eye activity, kinematics of the body movement and forces exerted by the human. Finally, the last section presents the selection of technologies for the current study.

5.4.1 Measuring cardiovascular activity

There are two type of physiological sensors that can be used to record the activity of the heart [48]: (i) Photoplethysmographs (also called Blood Volume Pulse sensors or BVPs) and (ii) Electrocardiographs (EKG/ECG). Both sensors are noninvasive and detect a specific physiological change associated with the heart's activity, but they are based on very different working principles. In either case, the sensor's output shows a recognizable beat pattern that is used to calculate the time between consecutive beats, or interbeat interval (IBI), and the corresponding heart rate (HR). A photoplethysmograph (PPG) measures the relative blood flow using a photoplethysmographic (PPG) sensor attached by a Velcro band to the fingers tips, earlobe or to the temple to monitor the temporal artery. An infrared light source is transmitted through or reflected off the tissue, detected by a phototransistor, and quantified in arbitrary units [29,49]. Less light is absorbed when blood flow is greater, increasing the intensity of light reaching the sensor[49]. For the heart activity, this amount of reflected light varies during each heartbeat as more or less blood rushes through the capillaries and it is converted into an electrical signal. From this signal, two variables are commonly derived: the heart rate and the heart rate variability (HRV). Although these devices have proved to be accurate for measuring the heart rate, the HRV reading has not been found to be very reliable [50].

The electrocardiograph is the most common device used to record the heart activity. It detects the electrical signal that propagates from the heart muscle throughout the body with each contraction. It is captured by electrodes placed on the torso, wrists, or legs [51]. They are available in a variety of different types that offer different features, from the most basic hand-held devices to fully featured machines to be used in cardiac centers. The main differences between types lie in the amount of information they gather, the information they display and record, their portability, and their usability features. Typically, hard-wired ECG monitors and mobile ECG monitors are distinguished [52]. Hard-wired monitors are mounted permanently on a shelf or wall, typically in care centers. This type of monitor provides a continuous cardiac rhythm display. It is typically also used to track other parameters such as blood pressure and hemodynamic measurements. Although it is attractive for its high accuracy, it is not suitable for use in field settings due to cost, size and complexity of operation [53]. On the other hand, mobile monitors allow the person to whom the electrodes are attached to move freely.

There are two types of mobile monitors, namely, ambulatory monitors and telemetric monitors. Ambulatory monitors (sometimes referred to as Holters) are portable devices that continuously monitor and record the electrical activity of the heart for at least 24 hours [51]. Telemetric devices do not record the information in situ, but they send the course of the electrical signal to another location [52]. These are the most used for monitoring sport-related activities. In experimental research, for detecting human emotional states, researchers have primarily used ambulatory devices that have high accuracy but are more expensive when compared to lightweight telemetric devices. The latter have proved to be reliable devices for measuring heart rate during exercise but not for measuring HRV during longer periods of time. Nunan et al. [54] found a strong correlation when comparing the recording of inter-beat intervals between the conventional ECG (hardwire) and the Polar S810 heart rate monitor at rest. However, they questioned the reliability of HRV from longer (e.g., 10 min) and/or consecutive 5-min inter-beat intervals.

5.4.2 Measuring respiratory activity

There are many different devices to measure respiratory activity [55]. The most commonly used in research are: (i) airflow based methods and (ii) chest and abdominal movement detection. The following text about measuring respiratory activity is based on descriptions found in [55-59].

In the airflow-based methods, the devices detect the fluctuation caused by the air inhaled and exhaled and then generate the respiratory waveform signal. The measurement of the airflow can be achieved by using (i) a nasal or oronasal thermistor that detects changes in temperature between the inhaled and exhaled air [56], or (ii) a nasal pressure transducer that measures the pressure of breathing [57]. From these, the nasal pressure systems have been shown to be more sensitive and accurate than the inspiratory and expiratory fluctuations recorded via a thermistor. However, a general problem with the airflow measurements is that subjects may not feel comfortable wearing a sensor attached to the airways. The devices based on chest and abdominal movement detection measure the thoracic chest and abdominal wall movement contraction and expansion during the respiratory cycle [58,59]. The chest wall movement is commonly measured by means of piezo-resistive belts or inductance belts fastened around the chest or abdomen.

The piezo-resistive belt uses a piezo resistive sensor, which is usually a conductive elastic coating or knitted conductive yarn that changes its resistance when stretched. The inductance belt uses an inductive sensor based on a wire configured in a sinusoidal arrangement that measures changes of inductance in the wire associated to the change in tension as the chest or abdomen expand and contract. The resistive belts are cheaper and easier to use. However, their sensitivity to movement artifacts is higher than that of the inductive belts. The resistive belt has the disadvantage that all types of movements will cause in a piezo spike wave distortion. Additionally, inductive bands produce an output that is proportional to changes in the area enclosed by the wire loop. Piezo sensors, on the other hand, produce an output proportional to the tension in the elastic band strapped around the body. This tension depends on many factors, such as the placement of the band, slipping of the band, initial tension and many others - all of which produce the errors and artifacts mentioned above. To ensure quality in the signal produced by inductive belts, they should be placed at the standard locations: near the nipple line (or mid-chest) and just above the belly button. Besides, the belts should not be placed too tight as to cause the subject breathing problems, or too loosely as to allow for the displacement of the belt.

5.4.3 Measuring eye activity

There are many approaches for eye/gaze detection. The most common ones according to the reviewed articles [60-63] are: (i) scleral search coils, (ii) slectro-oculography (EOG), and (iii) image based methods.

Scleral search coils use a small coil embedded into a contact lens that is tightly fit over the sclera. The user's gaze is estimated from measuring the voltage induced in the search coil by an external electro-magnetic field. The scleral search coil has a high temporal and spatial resolution (approximately 0.08 degrees) allowing even for the smaller types of eye movements (e.g. micro saccades) to be studied. However, it is very intrusive since it requires a lens to be placed in the eye. The insertion of the lens requires care and practice, and wearing it may cause discomfort. A less expensive technique is electro-oculography. Electro-oculography relies on the recordings of the electric potential differences of the skin surrounding the ocular cavity (electrodes are placed around the eye). EOG is not a reliable method for quantitative measurement, particularly of medium and large saccades. This method is prone to drift and the state of the contact between the skin and the electrodes represents a source of variability in the recordings. However, it is a cheap and easy to use method frequently employed by clinicians.

The abovementioned techniques are, in general, suitable for eye movement measurement but they do not often provide information about the orientation of the eye in space or the Point Of Regard (POR). Image-based tracking techniques use cameras, or any other optical or photosensitive device and image processing hardware to compute the point of regard in real-time. The tracking system may be table-mounted or head-mounted. These devices typically measure the corneal reflection of the light source (usually infrared) relative to the location of the pupil center. This is commonly known as Purkinje reflection or Purkinje image. Based on this information, and with an appropriate calibration procedure, these systems are capable of measuring a viewer's Point Of Regard on a suitably positioned (perpendicularly planar) surface on which calibration points are displayed. Table-mounted systems normally use a number of cameras of various types, such as narrow-view and wide-view cameras, or stereo cameras with multiple illuminators. The necessity of using multiple cameras makes these systems complex and expensive. Complicated calibration procedures are also required. However, they are widely used for gaze tracking and are favored for being non-invasive and accurate. The head-mounted systems may be even more accurate since they are less affected by external changes (head pose, lights, etc.). Participants can move their head freely to explore their surroundings while their eye movements are tracked at the same time. However, wearing this type of devices may be uncomfortable.

5.4.4 Measuring kinematics of the body movement

In order to assess human body kinematics, i.e., the movements without the forces that cause them, several tracking solutions, based on different sensing technologies exist [64,65]. Specifically, motion tracking systems most often employ measurements of optical, mechanical, magnetic, acoustic and inertial sensors.

Optical sensing uses data capture from image sensors to triangulate 3D position of a subject between one or more cameras calibrated to provide overlapping projections. Basically, the data acquisition relies on measurement of emitted (active) or reflected (passive) light obtained from markers placed on the human body. Passive marker systems use the reflected infrared light that is sent by Light Emitting Diodes (LEDs) mounted around the camera lens to determine marker position. Active marker systems triangulate positions by illuminating one LED at a time very quickly, or multiple LEDs, with software to identify them based on their relative position. The primary disadvantage of all optical systems is that there must be a clear line of sight between camera and the markers (occlusion problem). Additionally, interference from other light sources or reflections may result in so-called ghost markers.

Mechanical sensing systems, often referred to as exoskeleton motion-capture systems, typically track body joint angles. Usually, these systems consist of two or more mechanical pieces interconnected with electromechanical transducers, such as potentiometers or shaft encoders. When the user moves, the transducers move accordingly and the angle can be extracted. These systems offer high precision and have the advantage of not being influenced by external factors (such as the quality or the number of cameras for optical motion capture). Additionally, these systems measure directly at the anatomical joint so they are free of occlusions. However, they have some disadvantages: (i) aligning the mechanical device is difficult, and (ii) the linkages that subjects have to wear are uncomfortable and impede movement.

Magnetic sensing operates by measuring the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows for these systems to calculate both range and orientation by mapping the tracking volume. The major advantage is that the human body is transparent for the used magnetic field, eliminating the line-of-sight problems. However, the shortcomings of this type of systems are directly related to the physical characteristics of magnetic fields. Magnetic fields decrease in power rapidly as the distance from the generating source increases and, thus, they can be easily disturbed by (ferro) magnetic materials.

Acoustic sensing uses ultrasonic pulses and can determine position through either time-of-flight of the pulses and triangulation, or by measuring the phase shift between the transmitted signal and the signal detected at a microphone (phase coherence). The major drawback is that the physics of sound limit the accuracy, update rate and range of these systems. The tracking can be disturbed by the reflection of the sound, and, in addition, a clear line of sight must be maintained between the emitter and the receiver.

Inertial sensing systems are based on inertial sensors and biomechanical models. Generally, they use accelerometers and gyroscopes to estimate changes in position and orientation. The gyroscope measures angular velocity, which integrated over time provides the change in angle with respect to an initially known angle. An accelerometer measures accelerations, including gravitational acceleration g. When the angle of the sensor with respect to the vertical is known, the gravity component can be removed and by numerical integration, velocity and position can be determined. The main advantage of inertial sensors is that they are completely self-contained, which means no line of sight problems, no multipath problems and no sensitivity to interfering electromagnetic fields. The weakness of inertial sensors is their vulnerability to integration drift caused by noise and a fluctuating offset. However, drift and other errors can be minimized by combining the signals from the inertial sensors with aiding/complementary sensors, and by using knowledge about their signal characteristics,

5.4.5 Measuring forces exerted by the human (kinetics)

In order to assess the force the human exerts on products, force sensors may be placed on the object of interaction or on the subject's body parts. Most attempts to measure forces have been implemented by placing force sensors on the object of interaction. For this research, the interest is on sensors for measuring hand gripping forces and forces exerted by the feet.

The most well-known sensors for measuring these are load cells and tactile sensors (or Force Sensing Resistor -FSR) [66-68]. The load cell is a transducer that is used to convert force into an electrical signal. It can be based on a variety of technologies. Strain gauges, piezo-electric elements, and variable capacitances are among the technologies most used. Strain gauge load cells are most often constructed of a metal and have a shape such that the range of forces to be measured results in a measurable output voltage over the desired operating range. Piezoelectric load cells utilize a piezo-electric material as part of the load cell. When force is applied, a charge proportional to the force is produced. Capacitive load cells use a capacitance sensor to sense the displacement of an elastic element. In most cases, the sensor consists of two parallel plates standing opposite to each other. The changing length of a spring member produces a change in the gap between two plates and, hence, a change in electrical capacitance. Tactile force sensors (or FSR) are sensors that use electrical resistance to measure the force applied to the sensor. A force-sensing resistor is a piezo-resistive conductive polymer, which changes resistance in a predictable manner following application of force to its surface. It is normally supplied as a polymer sheet, which has a sensing film applied by screen-printing. When no pressure is applied to it, the sensor has infinite resistance. The resistance of the sensor decreases when pressure is applied on it.

In general, load cells are well known for high precision. However, load cells have some drawbacks, particularly in applications where size, weight, and/or power are fundamental. Load cells can be bulky. In some situations, the load cell can weigh more than the component being tested. Besides, they can be expensive in terms of price per piece, as well as integration. Additionally, some types of load cells can also be subject to ringing in certain applications because their internal elements have spring-like qualities. An advantage of tactile sensors is their low cost and simplicity. A disadvantage is their low accuracy, low repeatability and drift. The inner material is very sensitive to how the sensor is pressed. These sensors have a non-linear pressure response, which varies with time, temperature, humidity, and even between parts of the same production batch. Additionally, these sensors are very fragile and can be easily damaged if the force is applied for a long period of time.

5.4.6 Concluding remarks

In terms of cardiovascular activity, since both heart rate and heart rate variability need to be measured, the only suitable equipment from the ones reviewed in the previous sections is the electrocardiograph. Specifically, an ambulatory monitor was chosen because it was less expensive, non-invasive, portable and more reliable than a telemetric device. Photoplethysmographs were discarded due to their sensitivity to artifacts and their low reliability for the derivation of HRV measurements. An inductance belt was selected to measure respiratory activity due to its lower sensitivity to movement artifacts and band tension-related errors relative to resistive belts. Airflow-based methods, despite being more accurate, were discarded because they could be uncomfortable for the driver. For the measurement of eye behavior, a table-mounted image-based method (eye tracking system) was chosen because it is accurate and does not cause any discomfort to the driver as does happen with scleral search coils and electro-oculography.

Additionally, most of the eye tracking systems provide measurements of pupil diameter and blink rate. In order to measure human body kinematics, an inertial sensing system based on the use of accelerometers and gyroscopes to estimate changes of position and orientation was selected. This system was selected because it is completely self-contained, it does not need to be aligned with the drivers' physiological joints as is the case for mechanical sensing systems, and it is not sensitive to interfering electromagnetic fields. Also, it is not sensitive to light/sound reflections, as is the case for optical/acoustic sensors. Finally, to measure forces exerted by the driver, both force sensing resistors and strain gage load cells were selected. The latter was selected due to its high precision, while the former were chosen due to their flat profile, low cost and ease for implementation.

5.5 Forerunning pilot laboratory study

Based on the hypothesized indicators to be tested, an experimental setup was designed and a pilot study was carried out to test the feasibility, reliability and validity of the proposed study design for a large-scale study. The specific objectives of this pilot study were: (i) to assess the feasibility of the processes/procedures that are key to the success of the main study, (ii) to assess apparatus, software and materials used for gathering the data and (iii) to assess the quality of the data recorded. The results of the pilot have been used to refine and modify the experimental setup before it was used on a broader scale. Sections from 5.5.1 until 5.5.4 present the first research design planned for the main study which includes the description of the equipment, software and materials used and the conduct of the experiment. Sections from 5.5.5 until 5.5.9 present the procedure used for conducting the pilot study and its results.

5.5.1 Preliminary research design of the main study

This driving simulator study has a within-subject design. As described in Chapter 4, the independent variable time pressure is manipulated by imposing a temporal constraint on the task completion and by using contextualization of two fictitious scenarios as motivations. In both scenarios, the driver has to pick up a friend and bring him to the airport to catch a flight. The first fictitious scenario consists on imagining that the participant has arrived early at his/her friend's place and that he/she has plenty of time to get to the airport. This scenario implies that the driver can drive in a relaxed way (No Time Pressure - NTP). The second fictitious scenario consists on imagining that the participant has arrived late at his/her friend's place and that he/she is running short on time to get to the airport. This scenario implies that the driver has to hurry up (High Time Pressure - HTP). In terms of temporal constraint, in the first scenario no restriction in time is imposed. In the second scenario, the time constraint imposed is individually adapted based on the subject's NTP driving time.

Following the procedure described in Chapter 4, a reduction time factor of 80% over the normal driving time was established for the current driving scenario. This reduction factor is applied as long as this time is not less than 7 minutes 20 seconds, in which case the latter is taken as the time constraint. Additionally, to emphasize the temporal constraint, visual and auditory feedback is used for both scenarios. The visual mean applied is a numeric display that communicates the elapsed time. The auditory feedback is the pre-recorded voice of a fictitious passenger. During the NTP session, the passenger is talking about casual things, whereas during the HTP session, the passenger is complaining about being late to arrive at the airport and is encouraging the participant to hurry up. In both sessions, the passenger sentences are uttered every 15 seconds. The order of the conditions is not counterbalanced due to the use of individually adapted time constraints. The dependent variables investigated for our main study are the physiological changes due to stress during both conditions (that is respiration, heart activity and visual behavior) and the drivers' body dynamics (that is interaction with the controls of the vehicle).

5.5.2 Sampling of subjects

The participants are recruited using purposive sampling. The eligibility criteria applied is: (i) male or female between the ages of 20 and 40, (ii) having a valid driving license (iii) having minimum of 2 years of driving experience. All participants must have normal or corrected-to-normal vision. None of the participants can be under medication for hypertension or any other cardiovascular disease. Prior to the experiment participants have to fill out a questionnaire consisting of 6 general items (age, gender, use of glasses or contacts, use of medication, educational qualification, occupation), three simulation related items (playing computer games, prior experience in driving simulator, number of undergone simulator experiments), and eight driving experience items (driver's license, years of licensure, driving frequency, driving mileage, type of road, estimated driving speed compared to other road users, involvement in accidents, frequency of traffic violations). These items are based on the Driving Habits Questionnaire [69]. Additionally, participants are also requested to fill out the Mini Driver Behavior Questionnaire (Mini-DBQ) to measure aberrant driver behavior, as well the Multidimensional Driving Style Inventory (MDSI) for the assessment of their driving style [70,71]. Subjects are shown a video explaining the examination protocol, and the tests are performed after each subject signs an informed consent form. Prior to its execution, the study must be first approved by the human research ethics committee of the Delft University of Technology (The Netherlands).

5.5.3 Experimental apparatus and materials used

The following sections present a description of the equipment used for the conduct of the experiment.

Driving environment

In both the NTP and HTP sessions, the driving environment consists of the same suburban area with regular traffic conditions. The two-way road network has a total length of approximately 6970m with a four-meter lane width, and consists of 17 two-lane straight road segments and 16 intersections with stop signs. Along the way there are several traffic situations representing real life driving events including: (i) free driving - no traffic on the lane (ii) car-following with and without traffic travelling in the opposing lane, (iii) overtaking obstacles - overtaking in short and long segment, (iv) intersection with and without traffic. Table 5.2 provides an overview of the layout of the driving situations for the complete driving scenario in terms of their longitudinal location and traffic conditions. Figure 5.2 shows screenshots of the four driving situations in the driving simulator.

Table 5.2. Overview of driving situations and traffic conditions

Initial position (m)	Final position (m)	Driving situations	Traffic*	Initial position (m)	Final position (m)	Driving situations	Traffic*
0	180	Cruising	No	3775	3805	Intersection	No
180	210	Intersection	Yes	3805	4100	Car following	Yes
210	810	Car following	Yes	4100	4130	Intersection	No
810	840	Intersection	No	4130	4305	Overtaking	Yes
840	1135	Overtaking	Yes	4305	4335	Intersection	Yes
1135	1165	Intersection	Yes	4335	4935	Overtaking	No
1165	1680	Overtaking	No	4935	4965	Intersection	No
1680	1710	Intersection	Yes	4965	5260	Car following	Yes
1710	2005	Cruising	Yes	5260	5290	Intersection	No
2005	2035	Intersection	Yes	5290	5470	Overtaking	Yes
2035	2635	Car following	Yes	5470	5500	Intersection	Yes
2635	2665	Intersection	No	5500	6100	Car following	Yes
2665	2845	Overtaking	Yes	6100	6130	Intersection	No
2845	2875	Intersection	Yes	6130	6425	Overtaking	Yes
2875	3150	Cruising	Yes	6425	6455	Intersection	Yes
3150	3180	Intersection	Yes	6455	6970	Overtaking	No
3180	3775	Overtaking	Yes				

*Traffic crossing ahead for intersections and traffic on the opposing lane for all other situations

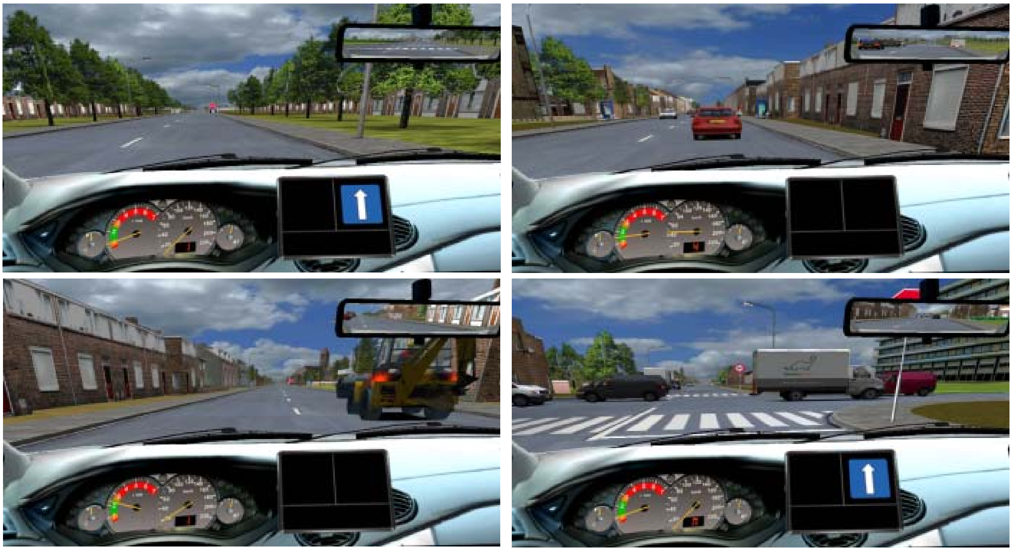

Figure 5.2. Screenshots of the four driving scenarios; free driving (top left), car following (top right), obstacle overtaking (bottom left), and, intersection crossing (bottom right). Note that the intersection depicted (bottom right) is shown with traffic in the intersection lane.

Driving simulator hardware and software

A fixed-base medium-fidelity interactive driving simulator (Green Dino, Wageningen, The Netherlands) is used in this experiment. The simulator cabin is equipped with the following components: steering wheel, ignition key, gear lever, single seat, and pedals. The steering wheel, pedals, gear lever and indicators were obtained from a regular passenger car and the dashboard, interior, and mirrors were integrated in the projected outside-world image (road and other traffic), as shown in Figure 5.3. Steering wheel force feedback is provided by a passive spring system. Surround sound is used to simulate wind, tires and engine noise. The simulator provides a horizontal field of view of 180° through three projectors. The front view projection (front projector: NEC VT676) has a resolution of 1,024 x 768 pixels, while the side views (side projectors: NEC VT470) feature a resolution of 800 x 600 pixels.

The simulation run at a frequency of 100 Hz and the refresh rate of the visual projection is higher than 25 Hz, large enough to guarantee a smooth visual projection throughout the experiment. The simulator software records the driver actions to control the vehicle (i.e. steering wheel angle, displacement of the pedals) and the interaction with the environment and other traffic (i.e. lane position, distance to other cars). The car model includes characteristics of the vehicle such as the engine, drive train dynamics and aerodynamics. The driving simulator is equipped with four synchronized cameras (Elro CCD Quad set), mounted outside the projected visuals, to record the participant inside the simulator cabin. The recorded videos cover the driving environment, the feet, the face and the upper body.

Figure 5.3. Photograph of experimenter in the driving simulator with physiological sensors and eye-tracker

Self-reported workload

The NASA-Task Load Index (NASA-TLX), a common questionnaire in driving simulator research [8], is used to assess the workload experienced by the drivers in the different experimental conditions. The NASA-TLX includes the following six items: mental demand, physical demand, temporal demand, performance, effort, and frustration. Scores are marked on a 21-tick horizontal bar with anchors on the left side (very low) and the right side (very high). For the performance item, the anchors (Good) and (Poor) on the left and right sides, respectively, are used. A total score is calculated for each participant. This score is obtained by averaging the results of the six items. The results are expressed on a scale from 0% (lowest rating) to 100% (highest rating).

Eye Tracking System - Eye behavior measures

A remote eye tracker (Smart Eye 5.9, Sweden) is used to measure eye gaze, head movement, and blink and pupil dilation during driving (Figure 5.4). The eye tracker consists of three Sony XC HR50 monochrome cameras, equipped with two infrared (IR) illuminators mounted below the virtual scenery of the driving simulator. The Smart Eye system estimates gaze position by tracking facial features and matching them to a driver profile established during a calibration procedure that has to be performed previous to the driving sessions. The driving simulator and eye tracker data are synchronized and recorded in separate files using the DriveSimClient software developed by Harm Boschloo©. Eye movement and head movement data are recorded with a sampling frequency of 60 Hz, and are low-pass filtered (Butterworth, 2nd order) with 10 Hz and 5 Hz cut-off frequencies, respectively. The following variables are derived from the above mentioned eye measures: percentage of time that gaze is directed at the center of the road, percentage of time looking at the dials, pupil diameter and blink rate.

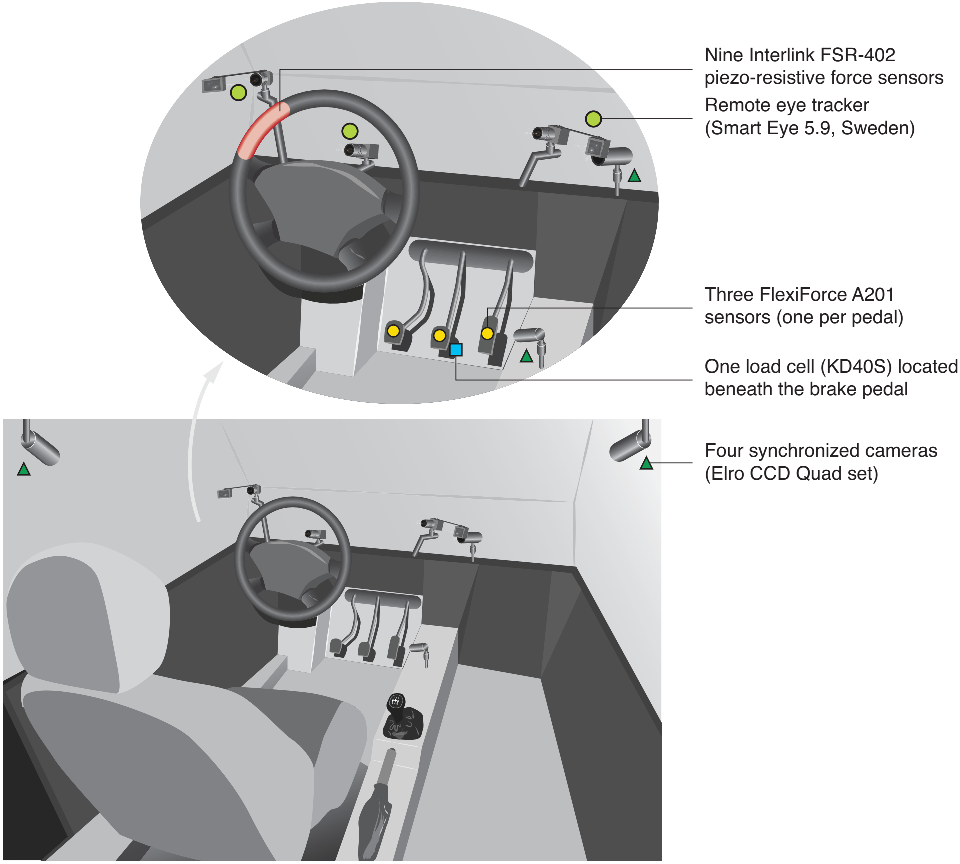

Figure 5.4. Location of the eye tracking system, force sensors and the four synchronized cameras

Biofeedback device - Physiological measures

During all the sessions, the heart rate and heart rate variability are obtained from an electrocardiogram recording which reflects the electrical activity of the heart. The breathing frequency and amplitude are extracted from the recording of the movement of the chest (Figure 5.5). The biofeedback device used to record the electrocardiogram and the movement of the chest is a Portable Mobi8 device from Twente Medical Systems International (TMSI). The mobi8 is a multi-channel ambulatory system that measures a variety of electro-physiological signals, such as EMG, ECG, EEG, respiration, etc., and sends the data directly to a computer using Bluetooth wireless transmission. This system measures the signals with a sampling frequency of 256 Hz by using the Portilab 2 software.

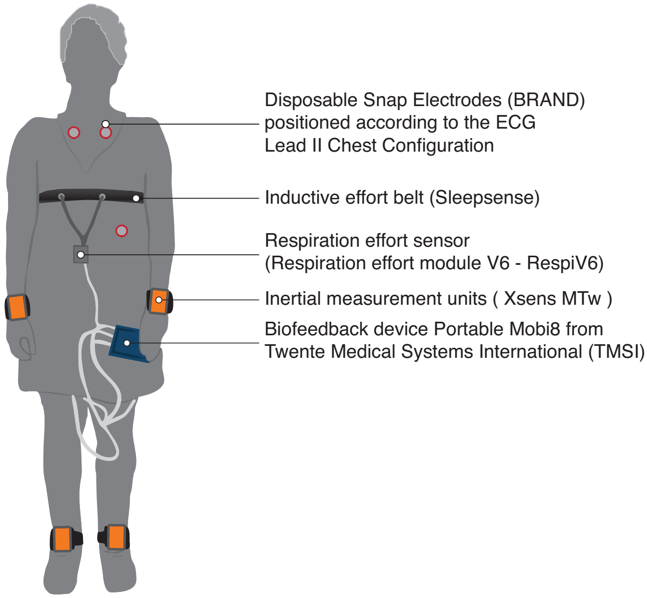

Figure 5.5. Location of the wearable sensors

The electrocardiogram (ECG) signal is obtained from three Disposable Snap Electrodes (Kendall Medi-Trace™) positioned according to the ECG Lead II Chest Configuration (Figure X). A filter is applied in order to eliminate, from the ECG signal, the noise caused by variations in electrode contact, as well as the motion artifacts due to physical movement of the driver. Specifically, a high-pass filter (2nd degree IIR Butterworth) with a 10 Hz cut-off frequency is applied to eliminate the baseline drift (an extraneous, low-frequency activity in the ECG signal which may interfere with the analysis). Other noises present in the signal that can also affect the feature extraction from the ECG signal are removed using Discrete Wavelet transform as suggested by [72].

The HRV and HR are derived from the beat-to-beat RR-intervals (RR tachogram or interbeat intervals) where R is a point that corresponds to the peak of the R wave in the QRS complex of the ECG signal, and RR is the time interval between successive Rs. All peaks in the ECG signal are detected using a peak-capture algorithm implemented in Matlab. Occasional abnormal (ectopic or artifact) beats are identified using a percentage-based filter to detect every RR interval that differs more than 20% from the previous normal to normal (NN) beat [73,74]. For the calculation of the heart rate and the analysis of the heart rate variability under the time-domain, these abnormal beats are replaced with RR interval values interpolated from adjacent data using the cubic spline interpolation method. For the analysis of the heart rate variability under the frequency-domain, these abnormal beats are removed from the signal. The heart rate is calculated as $HR=60/NN$ interval. In the time-domain, statistical variables such as the SDNN, etc. are derived directly from the normal-to-normal (NN) intervals. In the frequency-domain, the HRV is quantified by estimating the power spectral density (PSD) of NN intervals by means of the Fast Fourier Transform (FFT) algorithm using the Lomb-Scargle (LS) periodogram method.

This method weighs the data on a point-by-point basis rather than on a per time interval basis as in the conventional FFT. Consequently, the PSD is calculated from only the known NN interval values and no abnormal data replacement is required. This has been proven to be a more appropriate method for unevenly sampled signals such as NN-interval data, which naturally consists of randomly occurring events [75]. Other Fourier-based power spectrum or autoregressive spectral estimates inherently assume that the signal is stationary and need time series that are regularly sampled in time, thus requiring the NN tachogram time series to be re-sampled at a fixed frequency of 2Hz – 4Hz prior to this analysis [75]. This resampling, however, can introduce significant systematic errors. The obtained PSD is then integrated between band frequency limits to determine the amount of power, in normalized units, of the low-frequency (LF) band (i.e., 0.04 to 0.15 Hz), the high-frequency (HF) band (i.e., > 0.15 to 0.4 Hz) and the LF/HF ratio as recommended in the standard by The Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology [76]. The Very Low Frequency (VLF) (i.e., 0.00–0.04 Hz) band is not analyzed in this study because VLF assessed from short-term recordings (≤5 min) has been shown to be an unreliable measure [76]. All algorithms used during this process are implemented in Matlab. Specifically, the algorithms for the estimation of the PSD and the calculation of the power in the different frequency bands are based on the algorithms developed by Ramshur [77].

The respiration signal is obtained using an inductive effort belt (Sleepsense) worn around the chest (Figure 5.5). This belt is connected to a respiration effort sensor (Respiration effort module V6 - RespiV6) which in turn is connected to the Mobi8 biofeedback device. This sensor measures the expansion of the abdomen or thorax during inhalation and exhalation (respiration wave). The belt is placed at the level of the xiphisternum, tight but without causing discomfort to the subject. Since respiratory frequencies are known to be within a limited bandwidth, a selective pass-band filter is applied to the respiratory signals in order to extract those frequencies and remove noise caused by the driver's movement. That is to remove the low frequency drift and high frequency noise from the signal. The filter is digitally implemented through a pass-band IIR Butterworth of 2nd degree. Cut-off frequencies comprise between 0.05 and 1 Hz.

The resulting signal is used to obtain the respiratory frequency, also known as respiration interbreath frequency (rIBF) and the respiratory depth, also known as amplitude of each breathing cycle or respiratory amplitude (rAMP). A peak-valley capture algorithm is used for identifying the points of maximum and minimum voltage on the respiration waveform, corresponding to inhalation and exhalation respectively. The time interval between two consecutive maximum points corresponds to the respiration interbreath interval (rIBI). This rIBI is used to calculate the rIBF, where $rIBF=60/rIBI$. The elevation difference or vertical distance between two adjacent maximum and minimum points corresponds to the rAMP.

Inertial measurement system - human body dynamics (kinematics)

Four inertial measurement units (Xsens MTw) are used to record drift-free 3D acceleration of the arms and legs (Figure 5.5). The MTw is a small wireless inertial 3D motion tracker that communicates with the PC using the Awinda radio protocol developed by Xsens®. The Awinda protocol guarantees accurate (≤ 10 μs difference) time synchronization between multiple MTw's. These inertial measurement units were attached to the ankles and wrists of the participants using elastic body straps. The synchronized data is recorded using MT Manager Windows's software package at a sampling frequency of 75 Hz and then exported as ASCII text for further processing. For each limb, the magnitude of the total acceleration was calculated.

Force sensors - human body dynamics (kinetics)

Due to calibration difficulties in the setup, steering wheel grip forces and pedal forces are not actually measured in terms of forces but as an equivalent measure of voltage. This means that a set of sensors is used to obtain a voltage signal that is proportional to the applied force. Steering wheel grip forces are measured with an array of force sensitive resistors mounted on the steering wheel at the eleven o'clock position. Nine Interlink FSR-402 piezo-resistive force sensors are placed on this portion of the steering wheel as shown in Figure 5.4. The sensors are covered with a rubber layer in order to ensure that that the gripping load is distributed over the whole array. Each of the sensors can sense applied forces anywhere within the range from 100g to 10kg. To measure the force on the pedals, three FlexiForce A201 sensors are placed on top of each pedal (Figure 5.4). They are covered with a rubber layer to protect the sensor and to distribute the load. Each of these sensors can measure forces between 0 and 44.8 Kg (100lbs). Additionally, one load cell (KD40S) is located beneath the brake pedal to measure the force exerted on the pedal when it reaches its maximum stroke (Figure 5.4). All the force sensors on the steering wheel and pedals are connected to a simple amplifier circuit, consisting of a voltage divider, an operational amplifier and some additional power stabilizing elements. All analogue signals are acquired with a sampling frequency of 512 Hz using a data acquisition system from National Instruments (NI USB 6211) that is connected to a laptop computer.

Synchronization of data

All the equipment described above (i.e. driving simulator, eye tracker, biofeedback device, inertial measurement unit and force sensors) have their own software and use their own format for recording data. Consequently, in order to synchronize the data recorded from the different sensors, a triggering signal is used. The signal is generated from a micro-switch located beneath the clutch pedal. Whenever the driver fully presses the clutch pedal, a logical "1" is sent to the National Instruments data acquisition system. A customary Labview-based software starts recording the data from the force sensors and sends a TTL pulse (trigger pulse) to the XSens unit and the mobi8 biofeedback device for synchronization purposes. To correlate in time the data acquired from multiple devices, this signal, which is recorded into all sensor data files, is used to synchronize the data offline.

5.5.4 Conduct of the experiment

Prior to the simulator test, participants receive a paper handout explaining the experiment and procedures, and fill out a multiple-choice intake questionnaire. Additionally, participants fill out the Mini Driver Behavior Questionnaire (Mini-DBQ) and the Multidimensional Driving Style Inventory (MDSI) [70,71].

Table 5.3. Initial procedure for conducting the experiment

Step number	Procedure
1	Fill out the questionnaires
2	Watch video: General instructions,Training session and Session 1
3	Attach sensors to participants
4	Seat inside the driving simulator and w ear the seat belt
5	Check the proper functioning of all sensors
6	Calibration of the eye tracker
7	Baseline recording of the heart and respiration activity
8	Run training session
9	Step out of the driving simulator and fill out the NASA-TLX questionnaire
10	Seat inside the driving simulator and w ear the seat belt
11	Run session 1
12	Step out of the driving simulator and fill out the NASA-TLX questionnaire
13	Seat inside the driving simulator and w ear the seat belt
14	Watch video: instructions for Session 2
15	Run session 2
16	Step out of the driving simulator and fill out the NASA-TLX questionnaire

Next, participants watch a 5 minutes instruction video. The video is split into two parts to ensure that during the training and NTP session participants are ignorant of the instructions for the HTP session. The first part of the video, presented to the participant at the beginning of the experiment, gives general directions for controlling the car, an explanation of the instrumentation used and instructions for the training and the first session (NTP). The second part of the video is presented to the participant immediately before the second session and provides instructions for the second session (HTP). Subsequently, inertial motion trackers are attached to the ankles and wrists of the participants. The three electrodes for recording the heart activity are placed below the left and right clavicle and below the left pectoral muscle in a Lead II Configuration [78]. The respiration belt is also positioned.

Participants then seat inside the driving cabin of the simulator, and put on the seat belt in order to maintain the body in a relatively constant position with respect to the screen. The proper functioning of the sensors is evaluated by recording all the signals for a few seconds. Next, participants carry out a series of head movements and eye movements to calibrate the eye-tracker. Participants are told to relax in order to have a baseline measurement of the physiological signals (respiration and ECG). Participants then drive a training session, followed by a five-minute break and, then, by the driving test consisting of two sessions with a five-minute break in between. After each session, participants step out of the simulator and fill out the NASA-TLX questionnaire [8] to obtain a subjective assessment of the perceived workload. In addition, participants are asked to fill out a questionnaire evaluating the amount of perceived time pressure, as well as a confidence questionnaire measuring their confidence in the driving task.

In the training session, the participant is instructed to drive straight ahead until the end of the road. Obstacles in the form of construction vehicles are present along the road and have to be overtaken by the driver. The goal of the training session is to familiarize participants with the simulator and the projected environment.

In session 1 (NTP) the participant is instructed to drive straight ahead according to the first scenario presented in Section 5.5.1, in which no temporal constraint is imposed and fictitious scenario is imagined. In session 2 (HTP) the participant is instructed to drive straight ahead according to the second scenario presented in Section 5.5.1, in which a temporal constraint is imposed and the fictitious scenario (i.e., the airport drop-off scenario) is imagined. In each of the three sessions, the ECG signal, respiration signal, eye behavior and forces on the steering wheel and pedals, and all the information regarding the driving behavior (i.e., steering activity, pedals displacement, gear shifting, etc.), are recorded by the specified equipment.

5.5.5 Conduct of the pilot study

The pilot experiment was executed using the research design defined from Section 5.5.1 till Section 5.5.4. A group of participants fulfilling the eligibility criteria described in section 5.5.2 were selected and their information was stored in a database to be used during the execution of the experiment. The experiment was executed iteratively, using small groups of participants (3 to 4 people), in order to enhance the research design up to the point in which no enhancements had to be made. The performance of each participant and group of participants was evaluated according to the techniques and procedure described in Sections 5.5.6 and 5.5.7, respectively. The results and impact of each iteration on the research design are described in Section 5.5.8. The updated research design to be used in the large-scale study is presented in Section 5.5.9.

5.5.6 Techniques for the evaluation of the research design

For testing the research design we developed a list of items to be analyzed during the experimentation. The items were evaluated by using three different techniques: (i) observation, (ii) interview, and (iii) visual verification of data.

Overt observation was used to gather the data by directly watching the behavior of the participants in each of the activities performed during the experiment. The four synchronized cameras located inside the simulator cabin were used to assist the observation process. An observation guide listed the aspects to be observed, based on the questions from Table 5.4, and provided space to record open-ended narrative data for each participant. Field written notes were used to collect observation data that was not expected and not covered by the observation guide. The experimenter kept track of the elapsed time during every activity (i.e. time driving the training session, time filling out questionnaires).

Personal informal interviews were used to supplement and extend the knowledge about the fidelity of the driving simulator, the performance of the measuring devices used (eye tracker, biofeedback device, inertial measurement system, driving simulator recording module), the quality and clearness of the instructions and questionnaires, and the perception of the participants towards the logistics and general conduct of the experiments. Open-ended questions were formulated based on the questions in Table 5.4.

Table 5.4. List of items/aspects to be assessed for evaluating the research design of the experiment

Aspect to be assessed	Research technique used	Aspect number
Does the driving simulator provide enough realism for the participant?	Personal informal interview	1
Are the subject performing all the driving situations defined? (i.e following a car when they are supposed to follow)	Overt observation	2a
	Non-realtime visual inspection	2b
Is the driving simulator recording the information needed?	Realtime visual inspection	3
Is the eye tracker recording information about the eye behaviour (gaze, pupil diameter, blink frequency)?	Realtime visual inspection	4
Does the gaze, pupil diameter and blink signals have good quality?	Non-realtime visual inspection	5
Is the respiration sensor recording information during the session?	Realtime visual inspection	6
Does the respiration signal have a good quality?	Non-realtime visual inspection	7
Is the respiration band comfortable when driving?	Personal informal interview	8a
	Overt observation	8b
Are the electrodes used for recording the heart activity properly attached and measuring the electrocardiogram signal?	Realtime visual inspection	9
Does the electrocardiogram signal have a good quality?	Non-realtime visual inspection	11
Is the biofeedback device comfortable when driving?	Personal informal interview	12a
	Overt observation	12b
Are the inertial measurement units recording synchronized information?	Realtime visual inspection	13
Does the signal recorded by the inertial measurement unit have a good quality?	Non-realtime visual inspection	14
Are the inertial measurement units comfortable when driving?	Personal informal interview	15a
	Overt observation	15b
Are the 9 sensors located on the steering wheel recording information about the gripping force?	Realtime visual inspection	16
Does the signal recorded by the force sensors have a good quality?	Non-realtime visual inspection	17
Does the people locate the left hand on the portion of the steering wheel that has the sensors?	Overt observation	18
Are the sensors on top of each pedal and beneath the brake recoding information about the exerted pressure?	Realtime visual inspection	19
Does the signal recorded by the pedals force sensors have a good quality?	Non-realtime visual inspection	20
Does wearing the complete set of sensors allow for the proper execution of the experiment?	Personal informal interview	21a
	Overt observation	21b
Does the subject comprehend what is asked in the questionnaires?	Personal informal interview	22a
	Overt observation	22b
Does the participant understand the given instructions?	Personal informal interview	23a
	Overt observation	23b
Does the participant experience time pressure?	Personal informal interview	24a
	Overt observation	24b
Is the time available to fill out all the questionnaires adequate?	Personal informal interview	25a
	Overt observation	25b
Is the time available for the driving sessions adequate?	Overt observation	26
Is the training period proper for getting used to the simulator?	Personal informal interview	27a
	Overt observation	27b
Are the eligibility criteria for recruitment of people sufficient or too restrictive?	Observation of the experimenter	28
Is the available staff member enough in number for the conduct of the experiment?	Observation of the experimented	29
Can the data be synchronized, are there any problem with the data synchronization?	Non-realtime visual inspection	30

Visual verification of data was used to check both whether the data was being recorded by the different sensors and to assess the quality of the recorded signals. Two types of visual assessment were employed: (i) real time visual inspection and (ii) non-real time visual inspection. In the first case, six different screens that independently displayed the recorded signals in real time (one screen per device: driving simulator, eye tracker, inertial measurement system, biofeedback device, video cameras, and force sensors) were used by the experimenter to verify that the signals were continuous (no missing data) and were being properly recorded. Field written notes were used to collect the data. In the second case, the recorded signals were post-processed to verify that each complete data set was noise free and to confirm that the implemented triggering signal was appropriate for synchronizing the signals recorded by the different sensors. To assess the level of noise, each signal was graphed and visually inspected for both sessions (NTP, HTP). To check the synchronization, the data was processed as follows. A resampling method was used to uniform sampling frequency of all signals at 100 Hz. For signals sampled at frequencies lower than 100 Hz, the resampling method provides estimations of the missing samples based on linear interpolation. This strategy allows comparing signals with the same sample number over the same time interval (same temporal discretization). After resampling, the triggering signal that is present in all the signals was used to align the data. All aligned signals were merged into a single file in order to visually inspect the correspondence of the information. Field written notes were used to collect the data.

5.5.7 Procedure for evaluating the research design

The evaluation of the research design of the main experiment was done with 10 healthy subjects, 6 males and 4 females, who were recruited mostly from the TU Delft population using the procedure explained in Section 5.5.2. As each participant went through the several steps of the experiment, the experimenter evaluated the complete list of aspects presented in Table 5.4. Table 5.5 presents the steps for the conduct of the experiment and the corresponding features to evaluate. In order to identify aspects to be improved, the experimenter studied the results of this evaluation for the first group of four participants. This procedure corresponds to the first iteration of the experiment, after which several changes were introduced in order to optimize the experimental setup. In the second iteration, three participants were used to evaluate this new setup. The experimenter evaluated again the performance of the participants and identified the small adjustments needed for the main experiment. The necessary modifications were implemented. The third iteration used three participants to confirm that the changes introduced were appropriate. The experimenter evaluated again the performance of the participants and found that no major modifications were required to guarantee the successful completion of the experiment.

Table 5.5. Procedure for evaluating the research design of the experiment

Step number	Procedure	Aspect to be assessed
1	Fill out the questionnaires	22b, 25b
2	Watch video: General instructions,Training session and Session 1	23b
3	Attach sensors to participants	29
4	Seat inside the driving simulator and w ear the seat belt	21b
5	Check the proper functioning of all sensors	4, 6, 9, 13, 16, 19
6	Calibration of the eye tracker	
7	Baseline recording of the heart and respiration activity	6, 9
8	Run training session	2a, 3, 4, 6, 8b, 9, 12b, 13, 15b, 16, 18, 19, 21b, 23b, 26, 27b
9	Step out of the driving simulator and fill out the NASA-TLX questionnaire	21b, 22b, 25b
10	Seat inside the driving simulator and w ear the seat belt	21b
11	Run session 1	2a, 3, 4, 6, 8b, 9, 12b, 13, 15b, 16, 18, 19, 21b, 23b, 26, 27b
12	Step out of the driving simulator and fill out the NASA-TLX questionnaire	21b, 22b, 25b
13	Seat inside the driving simulator and w ear the seat belt	21b
14	Watch video: instructions for Session 2	23b
15	Run session 2	2a, 3, 4, 6, 8b, 9, 12b, 13, 15b, 16, 18, 19, 21b, 23b, 24b, 26, 27b
16	Step out of the driving simulator and fill out the NASA-TLX questionnaire	21b, 22b, 25b
17	Provide feedback to the experimenter	1, 8a, 12a, 15a, 21a, 22a, 23a, 24a, 25a, 27a, 28, 29
18	Non-realtime analysis of the recorded signals	2b, 5, 7, 11, 14, 17, 20, 30

5.5.8 Findings and implications of the pilot study on the setup of the full scale laboratory study

In the first iteration, in terms of instructions, the experimenter noticed that the video instructions were too long. The three participants in the first iteration asked before each driving session what they had to do. They stated that they did not remember the instructions from the video. Regarding the questionnaires, in the Mini Driving Behavior Questionnaire, the experimenter identified that two of the participants had some difficulties with some of the questions because they stayed too long in the questions, they asked for the meaning of a word and stated that some questions were difficult to comprehend. Moreover, filling out the questionnaires at the beginning of the experiment seemed to take too long. With one of the participants the inertial measurement unit was not functioning properly. Since the participant was already inside the simulator cabin, by the time the experimenter evaluated the proper functioning of the sensors, the task of solving this problem became too difficult. The limited space inside the cabin and the complexity of the equipment attached to the participant prevented the experimenter from reaching the different sensors and complicated the mobility of the participant outside cabin. The biofeedback device failed to record the complete data set for two of the participants. In one participant, the electrocardiogram signal was not continuous. The computer used for recording the signal was not fast enough to process the signal coming from the biofeedback device and the inertial measurement system simultaneously. In the other participant, the respiration band was not tight enough to record the expansion and contraction of the chest. Additionally, wearing the seat belt during the experiment resulted in undesired motion artifacts in the signal. During the sessions, the experimenter observed that the three participants often placed their left hand outside the sensor region of the steering wheel. The experimenter also observed that the following behavior and the stop and go behavior at the intersections were not properly executed by one of the participants.

The participant did not follow the vehicle in front close enough and did not stop at the intersections with stop signs and traffic. The eye-tracker signal was not correctly recorded for one of the participants. The system failed to recognize properly the facial features. Two of the participants stated that the feeling of realism in the driving simulator was augmented as they spent more time driving. The length of the training session did not seem to provide enough time for such purpose. Furthermore, the shortness of the training session did not allow for the participants to get used to the response of the driving simulator. The two participants suggested lowering the volume of the surrounding vehicles because this prevented them from hearing their own vehicle engine noise, sound they manifested to be necessary for shifting gears. In terms of the procedure used for conducting the experiment, the experimenter noticed that turning off the lights favored the feeling of realism inside the driving simulator and allowed for a better eye-tracker calibration. Additionally, while observing the participants, the experimenter realized that the results of the physiological signals of the second session could be biased by the physical activity and cognitive load of the previous session.

As a result of the previous findings, several modifications were implemented for the second set of participants (second iteration). The video instruction was split into three segments. The first one, presented at the beginning of the sessions, introduced the participant to the objective and procedure of the experiment. The second and third segments, presented at the beginning of the training session and session 1 respectively, described the task to be performed in those sessions. The ambiguities and difficult words of the initial questionnaires were corrected and some unnecessary questions were removed to shorten the time required for answering. The experimenter decided to verify the appropriate functioning of the equipment while the participant was still outside the simulator cabin. Furthermore, the experimenter decided to keep the participants inside the cabin during the breaks to prevent possible damage to the equipment. The biofeedback device and the inertial measurement system were connected to two different computers in order to guarantee the proper recording of the signals.

Special care was also taken when attaching the respiration band to ensure an adequate tightening. To prevent motion artifacts in the physiological signals, the participants were indicated not to wear the seat belt during the experiment. Two red marks were placed on the steering wheel to delimit the area where the sensors were located in order to provide a visual reminder to the participant. No action was taken with respect to the driving situations (following and stop and go behavior) because the experimenter decided to observe if other participants behaved similarly. The failure to record proper eye tracking data of one of the participants was attributed to the fact that the participant had black-colored eyes and beard. This was still to be confirmed with other participants. The experimenter decided to provide more time for the execution of the training session by lengthening the driving segment. Additionally, the participants were encouraged to explore the speed, steering, shifting and braking limits of the driving simulator. The volume of the surrounding vehicles was lowered and the room lights were kept off throughout the experiment. Finally, to prevent bias in the physiological signals, the experimenter decided to introduce a five-minute relaxing period between all the driving sessions. The last minute of this period was recorded in order to verify that the signal went approximately back to the initial conditions. All aspects that have not been mentioned throughout this paragraph are kept unchanged for the subsequent iterations.

In the second iteration, most of the modifications implemented with respect to iteration 1 provided the expected results. However, the experimenter noticed that the initial questionnaires, despite the modifications made, still demanded too much time to complete due to the number of questions and not to the legibility of the same. The five-minute relaxing period between driving sessions and the recording of the baseline physiological signals guaranteed the recovery of the initial conditions for the three participants in this iteration. The experimenter observed, similarly to the first iteration, that two of the participants in the second iteration did not follow the vehicle in front close enough and did not stop at the intersections with stop signs and traffic. In the in-between session's questionnaire, two of the participants misunderstood one of the questions and responded in an incorrect way. Once again, the eye-tracker failed to record proper eye behavior data for one of the participants due to inadequate recognition of facial markers.

This participant shared similar physical characteristics with the participant of the first iteration and was wearing glasses. Literature further confirmed that data loss can occur for remote mounted eye-trackers when the system is unable to track a participant's facial features, pupil, or corneal reflections due to obstruction of the eye-tracker cameras or large head movements [79,80]. The raw signals recorded by the different equipment during the previous iterations for each participant were processed according to the procedures described in their respective sections. The quality of each post-processed signal was subsequently assessed by the experimenter. The signals corresponding to the force-sensitive resistors mounted on the pedals and the load cell located beneath the brake pedal provided unreliable data. These sensors required that the pressure on the pedal be exerted at the specific location where the sensor was placed. Due to the high intra and inter-individual variability in pedal operation, the recorded signal presented frequent loss of data.

Consequently, the experimenter decided to send the initial questionnaire to be completed by the participants, in their own time, before the execution of the experiment. To guarantee the following behavior, the density of the traffic jam in the opposing lane was increased and the vehicle that had to be followed was located closer to the participants' own vehicle. To guarantee the stop and go behavior, the density of the traffic crossing the intersection was also increased. The word that made the question in the in-between session questionnaire unclear was highlighted to make sure that the participants understood correctly. The eligibility criteria were modified to exclude participants with dark eyes, glasses and/or beard in order to enhance the quality of the data recorded by the eye-tracker. Additionally, it is recommended to remove from the analysis eye blinks and data 0.2 seconds before and after segments of missing data. When more than 60 percent of such information is removed, the eye-tracker data for the respective session should be removed from the analysis. Finally, the force sensitive resistors mounted on the pedals and the load cell were removed from the experimental setup.

In the third iteration, the experimenter confirmed that the introduced changes in the previous iterations were appropriate. The overt observation, personal informal interview and visual verification allowed for the experimenter to ratify that no major modifications needed to be implemented. Furthermore, the experimenter confirmed that the suggested filters and post-processing procedures for each signal were appropriate for the required analyses. The experimenter also realized that the projection of the environment in this particular type of simulator could induce light evoked pupillary response, which should be taken into account for data processing.

5.5.9 Final design for the conduct of the experiment

The information gathered in the previous section was used to refine the research design of the experiment presented in Section 5.5.1. The procedure of the modified research design can be seen in Table 5.6. The major changes with respect to the previous version are described below.

Table 5.6. Procedure for conducting the experiment

Step number	Procedure
1	Fill out the questionnaires (enhanced version of questionnaires)
2	Watch video: General instructions and Training session
3	Attach sensors to participants (Pedal sensors are not used)
4	Check the proper functioning of all sensors
5	Seat inside the driving simulator (Do not wear the seat belt)
6	Calibration of the eye tracker
7	Relax for 5 minutes inside the driving simulator cabin
8	Baseline recording of the heart and respiration activity for 1 minute
9	Run training session (lengthened driving segment and lowered sound)
10	Fill out the NASA-TLX questionnaire inside the driving simulator cabin
11	Relax for 5 minutes inside the driving simulator cabin
12	Recording of the heart and respiration activity for 1 minute
13	Watch video: instructions for Session 1
14	Run session 1 (increased traffic density to guarantee the following and stop and go behavior)
15	Fill out the NASA-TLX questionnaire inside the driving simulator cabin
16	Relax for 5 minutes inside the driving simulator cabin
17	Recording of the heart and respiration activity for 1 minute
18	Watch video: instructions for Session 2
19	Run session 2 (increased traffic density to guarantee the following and stop and go behavior)
20	Fill out the NASA-TLX questionnaire inside the driving simulator cabin

In the final research design the eligibility criteria was modified to exclude participants with dark eyes, glasses and/or beard. The video with the instructions was split into three segments. The questionnaires were shortened and some questions were reformulated to clarify their meaning. The instruments used for sensing were pre-tested before the participant went inside the driving simulator cabin. The participants were instructed not to wear the seat belt due to motion artifacts introduced in the physiological signals with the subject's movement. During the breaks in the in-between sessions, the participants were indicated to stay inside the cabin while filling out the questionnaires in order to prevent possible damage to the equipment. The participants were also instructed to relax and a baseline measurement from the physiological signals was recorded during the last minute of this relaxation period. In the training session, the driving segment was lengthened, the sound of the traffic in the driving simulator was lowered and during the experimental sessions the density of the traffic situation was increased to guarantee the following and stop and go behaviors. All the sensors on the pedals were removed.

5.6 References

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Chapter 6

Research cycle 4: Full scale laboratory study of driving in haste

6.1 Introduction

In the previous chapter, particular low level manifestations of time pressure that could be used to recognize the state of driving in haste were identified. The majority of these manifestations corresponded to those observed in contexts different from driving a vehicle. This chapter presents a confirmatory analysis in which the hypotheses presented in Chapter 5 are tested, as well as an exploratory analysis in which indicators are further investigated to determine their discriminative power.

6.2 Execution of the experiment and subject sample description

The full-scale experiment was executed according to the research design presented in Section 5.5.9. The length of the experiment was about 90 minutes per participant. In terms of the used sample, 56 healthy subjects (46 males and 8 females, in the age interval of 23 and 37 years) were recruited. Participants were recruited from the Delft University of Technology student and employee community. Two participants who experienced motion sickness were excluded. The participants' mean age was 28.0 years (SD = 3.9) and, on average, participants had their driving license for 9.1 (SD = 4.5) years, with an average annual mileage of 6350 (SD = 8116) kilometers. Three participants reported the use of medication, yet none of them used medication for hypertension or any other cardiovascular disease, and 18 participants wore contacts or glasses during driving. Twenty participants reported prior experience in a driving simulator, with a mean of 1.8 (SD = 1.3) participated experiments per participant. For a complete overview of the driving experience and behavior questionnaire see Table 6.1.

Prior to starting the experiment procedures, all participants provided their written informed consent. This research was approved by the Human Research Ethics Committee of the Delft University of Technology (The Netherlands). Taking into account that there could be pupillary light response due to the luminance of the virtual scenery, a light intensity meter (Extech HD450, range: 400 Lux, resolution: 0.1 Lux) was used to record luminance data for each position in the virtual scenery. The luminance data of each complete session was recorded seven times. This was done in order to correct the measured pupil diameters. Since the sensor had to be mounted at the participant's eye position, these recordings were gathered by a person who was not participating in the study. The signals were sampled and stored at 1 Hz and manually synchronized with the driving simulator for the seven sessions. For each participant and session, the light-evoked pupil diameter was modeled by a linear fit between the pupil diameter and the luminance and subtracted from the measured pupil diameter [1].

6.3 Data analysis

To analyze the data of the full-scale experiment a first confirmatory analysis (hypothesis-driven analysis) was performed in order to test the hypothesized indicators of someone driving in haste that were formulated from existing theories of time pressure, mental/visual workload and other type of stress (Section 5.3). Then, an exploratory analysis, based on the visualization of the data, was carried out with the aim to discover new patterns that could characterize people driving in haste. This visual exploration of the data was done by the researcher without any pre-conceived idea. The confirmatory analysis is described in Section 6.3.1 and the exploratory analysis in Section 6.3.2.

Table 6.1. Driving experience and behavior (number of responses in 56 participants)

	Every day	4–6 days/week	1–3 days/week	About once a week	Less than once a month	Never
Computer games		3	3	12	14	22
Drive a car	7	5	14	13	7	5
	Elementary school	**Secondary school**	**Bachelor degree**	**Postgraduate degree**		
Highest educational qualification	1	0	15	38		
	Motorways	**Urban roads**	**Country road**	**Other main roads**		
Type of road	44	48	13	13		
	Faster	**A bit faster**	**The same**	**A bit slower**	**Much slower**	
Driving speed	2	29	19	4	0	
	0	**1**	**2**	**3**	**4**	**5**
Involvement in accidents	43	9	1	1		
	1 - 2	**2 - 3**	**3 - 4**	**5 - 6**	**7 - 8**	**9 - 10**

6.3.1 Indicators derived from literature: Confirmatory analysis

The signals recorded by the different instruments were synchronized and re-sampled according to Section 5.5.3. All signals were then merged into a single file and filtered as explained in the previous chapter. Each signal was independently processed to derive the hypothesized indicators formulated from the existing theories (Section 5.3.3). A metric (i.e., summary statistics to characterize behavior over time or space such as mean or standard deviation) was then computed for each derived indicator over the complete session. That is, mean values and standard deviations were calculated for each participant per indicator, and for the different self-rating scales and rating of perceived workload (for the list of indicators, see Table 5.1). A paired-sample t-test (two-tail) was used to compare the dependent variables between the NTP and HTP sessions. A normal distribution was assumed for both groups of data [2]. The significance level was set at $p<0.005$. Due to the large number of dependent variables, a conservative alpha value was chosen.

6.3.2 Indicators derived from visual inspection: Exploratory analysis

For the exploratory analysis, all dependent variables were plotted as a function of traversed distance for both the HTP and NTP sessions. Driving performance metrics were determined using spatial sliding windows of 1m. Physiological and interaction metrics were determined using a temporal sliding window of 3s. Particularly HRV, blink frequency, and pupil diameter were determined using a temporal sliding window of 30s, 10s and 1s, respectively. These plots were analyzed to identify possible tendencies in particular segments corresponding to car following, intersections, overtaking and cruising. An example of this type of plot can be seen in Figure 6.3 and 6.4. As a result of the previous analysis, the different segments were isolated into separate groups matching the four possible driving situations (car-following, intersections, overtaking and cruising). Intersections were studied both altogether, as well as further categorized into those corresponding to intersections with and without traffic crossing ahead. Overtaking segments were similarly studied as a whole, as well as further grouped into those with and without opposing traffic flow. To study the combined tendency for each driving situation, the multiple segments corresponding to each of these situations were trimmed and adjusted so that each segment contained the same number of data points and only the data of interest for the specific situation (i.e., the overtaking situation contained only data within ±75m from the obstacle). This allowed for a combined comparison of the data subsets using averaged plots and probability distributions.

Vehicle acceleration per throttle pedal operation and vehicle deceleration per brake pedal operation were plotted as probability distributions using filters based on vehicle velocity bands. In order to do this, the vehicle velocity at the beginning of each pedal operation (either throttle or brake) was obtained and the operations were then classified accordingly into five velocity bands (0-20km/h, 20-40km/h, 40-60km/h, 60-80km/h and 80-140km/h). The five respective probability distributions were subsequently plotted for the maximum vehicle acceleration or deceleration per operation. Finally, the plots and probability distributions containing the combined data for all participants were analyzed to select those corresponding to indicators that appeared to have a distinguishable difference between HTP and NTP. Then, these were plotted again for several individual participants to determine if the indicator indeed showed a clear and separable difference between the driver in NTP and HTP sessions.

Additionally, associations between some of the variables, including some of the possible indicators and results from the driver behavior questionnaire and driving style inventory, were evaluated using the Pearson's product-moment correlation coefficient. All questionnaire-related results were fractionally ranked prior to statistical analysis to cope with their skewed distribution [3]. To obtain the correlation matrix, the difference between the HTP and NTP sessions for the driving performance measures, the physiological measures, and the subjective workload was calculated.

6.4 Findings of the confirmatory analysis

The results from the t-test averaged over sessions of the cardiovascular, respiratory, visual behavior, interaction and driving performance measures, are presented in Table 6.2-6.5.

Excluded data

As mentioned in Section 6.2, the data from two participants were excluded from the analyses. These participants experienced simulator discomfort during the training session and were at that point withdrawn from the experiment. Accordingly, data from 54 participants were used for further analyses. In particular, for the physiological (cardiovascular, respiratory) related measures, four additional participants were excluded from the analyses. The recording unit failed to record continuous data. For the cardiovascular related measures, four more participants were withdrawn because over 20% of their signals presented ectopic beats or noise [4]. Consequently, the data from 50 and 46 participants were used in the respiratory and cardiovascular analyses, respectively. As a result of data loss due to the eye tracker being unable to capture the relevant facial features, a total of 26% of the eye tracker data were removed from the analyses. Additionally, five complete sessions of eye tracker data were removed due to eye tracker data loss exceeding 60%.

Time pressure manipulation check

To check whether the manipulation induced the subjective experience of time pressure, participants were asked to indicate whether they felt there was not enough time to drive, whether they felt they had to hurry up, and how much time pressure they felt. Responses were collected based on a five-point Likert scale from 1 *strongly disagree* to 5 *strongly agree* for the first two statements and from 1 *No pressure at all* to 5 *Very high pressure* for the last statement.

A t-test performed on the responses collected from the subjects after the experiment confirmed that the time pressure manipulation was successful since participants in the high time pressure condition experienced more pressure ($M = 3.7$, $SD = 0.9$) than participants in the low time pressure condition ($M = 1.3$, $SD = 0.55$), $t(54) = -18.4$, $p < 0.005$. Furthermore, they experienced a higher need to hurry up and higher lack of time to perform the driving task.

Table 6.2. Means (standard deviations in parentheses) of the questionnaire-based subjective measures for the NTP, and HTP sessions, p-values, and the Pearson correlation coefficient (r1) between the NTP and HTP sessions

	Session		Significance	Correlation
Dependent variable	**NTP**	**HTP**	**p value***	**r1**
Subjective measures				
Mental demand (0-100)	38.89(22.50)	59.44(20.39)	**4.51E-12**	0.68956
Physical demand (0-100)	22.78(15.80)	38.15(21.96)	**3.43E-08**	0.61315
Temporal demand (0-100)	20.00(16.37)	71.39(16.18)	**8.08E-26**	0.29036
Performance (0-100)	67.96(25.43)	47.50(25.47)	**3.24E-05**	0.15438
Effort (0-100)	33.06(18.92)	63.98(16.23)	**1.42E-15**	0.34051
Frustration (0-100)	21.02(19.63)	48.89(27.10)	**1.99E-11**	0.50314
Workload index (NASA-TLX) (0-100)	33.95(10.91)	54.89(12.98)	**9.62E-19**	0.55387
Driving fast (1-5)	1.70(0.74)	3.74(0.85)	**1.52E-19**	0.11496
Time pressure (1-5)	1.35(0.55)	3.69(0.91)	**1.11E-24**	0.26162
Need to hurry up (1-5)	1.61(0.74)	4.28(0.76)	**9.52E-24**	-0.1062

Table 6.3. Means (standard deviations in parentheses) of the physiological measures for the NTP, and HTP sessions, p-values, and the Pearson correlation coefficient (r1) between the NTP and HTP sessions

	Session		Significance	Correlation
Dependent variable	**NTP**	**HTP**	**p value***	**r1**
Physiology				
Mean respiration rate (1/min)	20.90(3.04)	22.42(3.35)	**5.85E-10**	0.908
Mean respiration amplitude (mV)	10.00(2.60)	10.26(2.78)	2.39E-01	0.837
Mean inhalation time (s)	1.21(0.16)	1.18(0.16)	3.60E-02	0.797
Mean exhalation time (s)	1.63(0.28)	1.54(0.24)	**1.94E-03**	0.693
Duration of each respiratory cycle (s)	2.84(0.43)	2.71(0.38)	**3.84E-03**	0.736
Mean duty cycle (-)	0.43(0.02)	0.43(0.02)	**4.94E-03**	0.609
Mean heart rate (1/min)	77.93(12.43)	81.13(13.42)	**3.86E-07**	0.963
Standard deviation of NN intervals (ms)	53.76(16.71)	53.92(17.17)	8.99E-01	0.887
HRV Low frequency component - LF (%)	0.71(0.11)	0.73(0.09)	4.60E-02	0.603
HRV High frequency component - HF(%)	0.29(0.11)	0.27(0.09)	4.60E-02	0.603
LF/HF ratio	2.91(1.51)	3.26(1.66)	1.35E-01	0.522
Percentage Road Centre (%)	77.13(16.53)	79.67(13.43)	5.84E-02	0.812
Percentage road center without intersections (%)	77.14(16.91)	81.97(14.03)	**1.62E-03**	0.776
Horizontal Gaze Variance (deg^2) - HGV	70.53(28.16)	77.73(23.72)	1.75E-02	0.666
HGV without intersections (deg^2)	48.21(27.59)	35.33(21.19)	**9.19E-06**	0.717
Percentage Dials (%)	11.61(10.89)	10.06(11.47)	2.05E-02	0.910
Percentage Clock (%)	1.25(0.95)	2.25(1.06)	**5.11E-09**	0.459
Mean blink frequency (Hz)	0.31(0.15)	0.27(0.16)	**4.23E-04**	0.923
Mean pupil diameter (mm)	5.20(0.72)	5.39(0.69)	**8.24E-09**	0.961

Table 6.4. Means (standard deviations in parentheses) of the driver-vehicle interaction measures for the NTP, and HTP sessions, p-values, and the Pearson correlation coefficient (r1) between the NTP and HTP sessions

	Session		Significance	Correlation
Dependent variable	**NTP**	**HTP**	**p value***	**r1**
Driver-Vehicle interaction				
Mean number of throttle op (#)	80.02(10.66)	84.00(14.12)	3.41E-02	0.522
Mean number of brake op (#)	22.98(4.91)	25.79(5.24)	**1.61E-04**	0.576
Mean clutch operation (#)	60.34(11.81)	57.09(10.83)	3.09E-02	0.611
Mean number of gear op (#)	65.17(10.09)	60.17(10.39)	**1.08E-03**	0.540
Throttle >0.25 (%)	0.31(0.06)	0.40(0.07)	**7.63E-16**	0.562
Throttle >0.70 (%)	0.11(0.13)	0.42(0.19)	**2.93E-18**	0.470
Max brake pedal position(%)	0.46(0.12)	0.50(0.10)	**2.95E-03**	0.662
Mean brake pedal position (%)	0.07(0.01)	0.08(0.02)	**3.98E-06**	0.426
Max throttle pedal position (%)	0.39(0.09)	0.55(0.10)	**9.90E-19**	0.696
Mean throttle position (%)	0.18(0.04)	0.28(0.07)	**5.12E-21**	0.716
Brake pedal variance (-)	0.03(0.01)	0.04(0.01)	**1.04E-10**	0.517
Mean throttle variance (-)	0.09(0.03)	0.14(0.03)	**1.66E-18**	0.691
Shifting time between throttle and brake (s)	2.56(0.87)	1.68(0.63)	**2.88E-09**	0.430
Shifting time between brake and throttle(s)	2.52(0.77)	1.90(0.66)	**2.63E-03**	0.232
Speed pressing throttle (l/s)	0.29(0.14)	0.50(0.21)	**7.50E-14**	0.776
Speed pressing brake (l/s)	0.32(0.13)	0.46(0.16)	**2.50E-12**	0.792
Speed pressing clutch (l/s)	3.29(0.91)	3.74(0.88)	**2.12E-10**	0.909
Mean steering speed (deg/s)	7.60(0.96)	8.36(1.26)	**1.75E-07**	0.675
RMS acceleration right hand (m/s^2)	1.00(0.37)	1.11(0.45)	**5.38E-05**	0.926
RMS acceleration right foot (m/s^2)	0.36(0.09)	0.50(0.19)	**1.20E-08**	0.740
RMS acceleration left hand (m/s^2)	0.32(0.09)	0.37(0.11)	6.09E-03	0.553
RMS acceleration left foot (m/s^2)	0.64(0.34)	0.75(0.43)	**1.56E-06**	0.967
Jerk of right hand (m/s^3)	51.87(24.31)	61.27(30.95)	**2.44E-06**	0.934
Jerk of left hand (m/s^3)	17.35(5.64)	18.60(6.21)	2.25E-02	0.816
Jerk of right foot (m/s^3)	26.12(9.53)	37.04(17.24)	**1.28E-08**	0.823
Jerk of left foot (m/s^3)	41.24(25.52)	48.22(32.86)	**2.58E-05**	0.970
Mean accel. right foot per brake op. (m/s^2)	0.34(0.19)	0.56(0.27)	**3.87E-09**	0.642
Mean accel. left foot per clutch op. (m/s^2)	1.32(0.84)	1.63(1.09)	**2.80E-06**	0.947
Mean accel. right foot per throttle op. (m/s^2)	0.26(0.13)	0.41(0.25)	**4.77E-07**	0.731
Mean accel. right hand per gear op. (m/s^2)	1.41(0.56)	1.75(0.74)	**7.64E-05**	0.704
Mean accel. right foot - throttle to brake op. (m/s^	0.60(0.22)	0.79(0.35)	**2.50E-08**	0.834
Pressure exerted on steering wheel (V)	0.36(0.25)	0.39(0.28)	7.71E-02	0.914

Table 6.5. Means (standard deviations in parentheses) of the driving performance measures for the NTP, and HTP sessions, p-values, and the Pearson correlation coefficient (r1) between the NTP and HTP sessions

	Session		Significance	Correlation
Dependent variable	**NTP**	**HTP**	**p value***	**r1**
Driving performance				
Completion Time (s)	556.06(38.22)	467.81(35.38)	**4.65E-27**	0.640
SD position in lane (m)	0.97(0.11)	0.93(0.10)	**9.50E-05**	0.787
SD position in lane without obstacles (m)	0.24(0.08)	0.30(0.14)	**1.80E-04**	
Mean lateral position (m)	0.15(0.19)	0.23(0.23)	**2.08E-05**	0.815
Mean engine speed (RPM)	2272.89(271.68)	2629.15(341.39)	**2.91E-16**	0.755
Mean speed (m/s)	12.31(0.85)	14.65(1.14)	**7.37E-26**	0.641
Max. speed (m/s)	24.62(2.32)	30.51(3.61)	**1.44E-18**	0.470
Mean acceleration (m/s^2)	1.35(0.18)	1.73(0.24)	**2.94E-19**	0.559
Max. acceleration (m/s^2)	6.68(0.68)	7.17(0.37)	**6.39E-08**	0.539
Min. car following distance (m)	7.51(3.80)	3.91(3.01)	**4.40E-11**	0.577
Min. car following time (s)	0.64(0.32)	0.28(0.23)	**2.14E-16**	0.702

Subjective workload

The workload for the HTP session (M=54.89, SD=12.98) significantly increased compared to the NTP session (M=33.95, SD=10.91), t (53) = -13.46, $p < 0.005$ (Table 6.2). These effects were most pronounced for the temporal demand, effort, and frustration scales. Figure 6.1 shows the mean score for each NASA-TLX subscale for the two sessions.

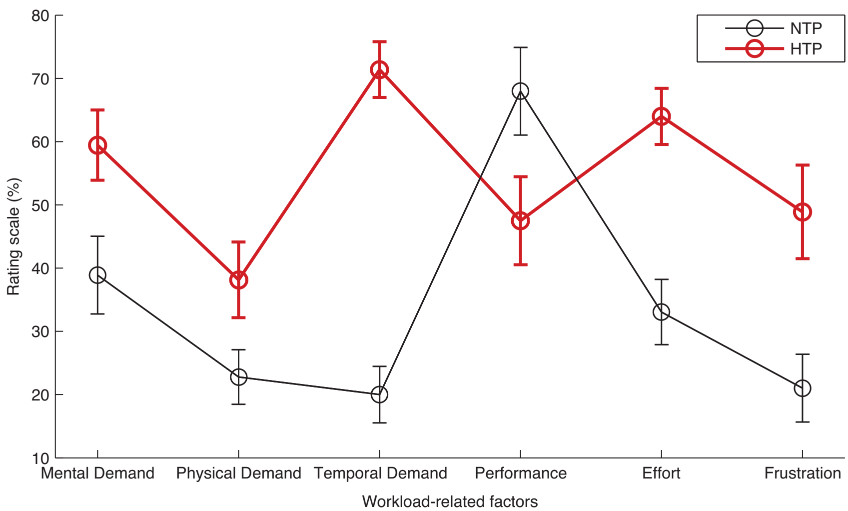

Figure 6.1. Self-reported workload NASA-TLX for HTP and NTP sessions

Effects of time pressure on cardiovascular activity

During the HTP condition participants exhibited a significantly higher heart rate compared to the NTP condition. The HRV did not differ between the sessions. Specifically, in the time domain, SDNN slightly increased for the HTP condition, yet not significantly. In the frequency domain, the normalized spectral power in the LF band and the ratio between LF/HF tended to be higher in the HTP condition compared to the NTP condition. The normalized spectral power in the HF band tended to be lower. However, none of these results were significant.

Effects of time pressure on respiratory activity

The respiratory frequency and mean duty cycle significantly increased, whereas the mean exhalation time and mean total respiratory cycle duration significantly decreased during the HTP condition as compared to the NTP condition. Moreover, the mean respiratory amplitude slightly increased and the mean inhalation time slightly decreased during the HTP condition but not significantly.

Effects of time pressure on visual behavior

The HTP condition resulted in a significant increase in pupil diameter and the percentage of time the participants spent looking at the clock. A significant decrease in blink frequency was also observed during this condition. Horizontal gaze variance and the percentage of time looking at the road center increased but not significantly. However, after removing the segments corresponding to road intersections, the result was a statistically significant increase for the percentage of time the subjects spent looking at the center of the road, as well as a statistically significant decrease for the horizontal gaze variance. In Figure 6.2, heat-maps showing the gaze distribution during car following illustrate the increased spatial tunneling of drivers' gaze. The percentage of time the participants spent looking at the dials decreased in the HTP condition but not significantly.

Figure 6.2. Heat-maps during car following in no time rush (left) and time rush (right) conditions, overlaid on the center simulator visual. Gaze distributions were determined by aggregating gaze data from car following sections of all participants in one-by-one degree bins and are displayed on a logarithmic scale.

Effects of time pressure on driver-vehicle interaction

Regarding the frequency of operations of vehicle controls, the number of brake operations significantly increased and the number of gear operations significantly decreased during the HTP condition. Meanwhile, the number of throttle pedal operations increased, whereas the number of clutch pedal operations decreased – yet not significantly. In terms of the behavior related to pedal displacement, all measurements evaluated showed a significant increase for the HTP condition. These measurements were: the variance during brake and throttle pedal operation, the mean position of the brake/throttle pedals, the maximum position of the brake pedal and the frequency of pressing the throttle pedal in more than 25% and than 70% of its full stroke. A significant decrease in the mean time between switching from the throttle to the brake pedal and from the brake to the throttle pedal was also found during the HTP condition. Regarding the speed in pressing pedals and steering control, a significant increase during the HTP condition was found for all measurements (mean speed of pressing throttle, brake and clutch pedals and steering speed).

The majority of the assessed measurements related to the intensity of the body movements significantly increased during the HTP condition. These measurements included: the Root Mean Square (RMS) of the acceleration for the right/left foot and for the right hand and the RMS of the acceleration for the right foot associated with both the operation of the brake and throttle pedals, RMS of the acceleration for the right foot associated with the motion from the throttle to the brake pedal, RMS of the acceleration for the left foot associated with the operation of the clutch pedal, RMS of the acceleration for the right hand associated with the operation of the gear stick. The RMS of the acceleration for the left hand also increased but not significantly. Similarly, the RMS of jerk for the right/left foot and for the right hand significantly increased during the time pressure condition. The RMS of jerk for the left hand and the mean steering force also increased but the results were not significant.

Effects of time pressure on driving performance

Performance metrics related to longitudinal control including mean engine rpm, as well as mean and maximum speed and acceleration significantly increased during the HTP condition. A significant decrease in safety-related metrics including minimum car following distance/time was also observed during this condition. The mean lateral position significantly increased during the HTP condition, meaning that the drivers were more located towards the left hand side of the lane. Finally, the standard deviation of lane lateral position significantly increased during the HTP condition relative to the NTP condition. However after removing the segments in which the drivers were overtaking other vehicles, the standard deviation of lane lateral position significantly decreased.

6.5 Findings of the exploratory analysis

The outcomes of the exploratory analysis are presented in the following sections. Figure 6.3 and 6.4 show an overview of selected dependent measures as a function of traversed distance.

The results are clustered according to the four previously mentioned driving situations and grouped according to the types of indicators studied (physiological, interaction and driving performance). Note that these results are exploratory and, thus, are subject to further research with experiments designed specifically to test for the particular driving situations. This section presents figures for only those indicators that provided results that could eventually be used for detecting driving in haste.

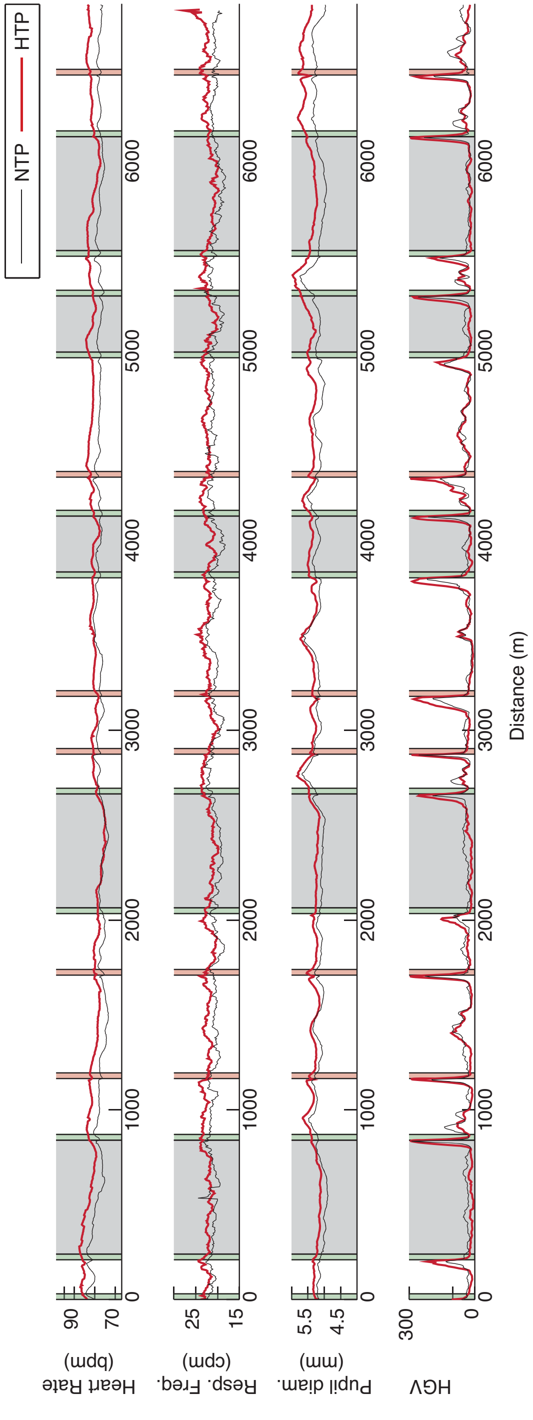

Figure 6.3. Physiological measures as a function of distance for the NTP (black) and HTP (red) sessions. The HGV, pupil diameter, respiration frequency, and heart rate are determined using a temporal sliding window of 3 sec. Note the intersections with and out traffic are indicated by green and red shading, respectively. Car following situations are indicated by grey shading.

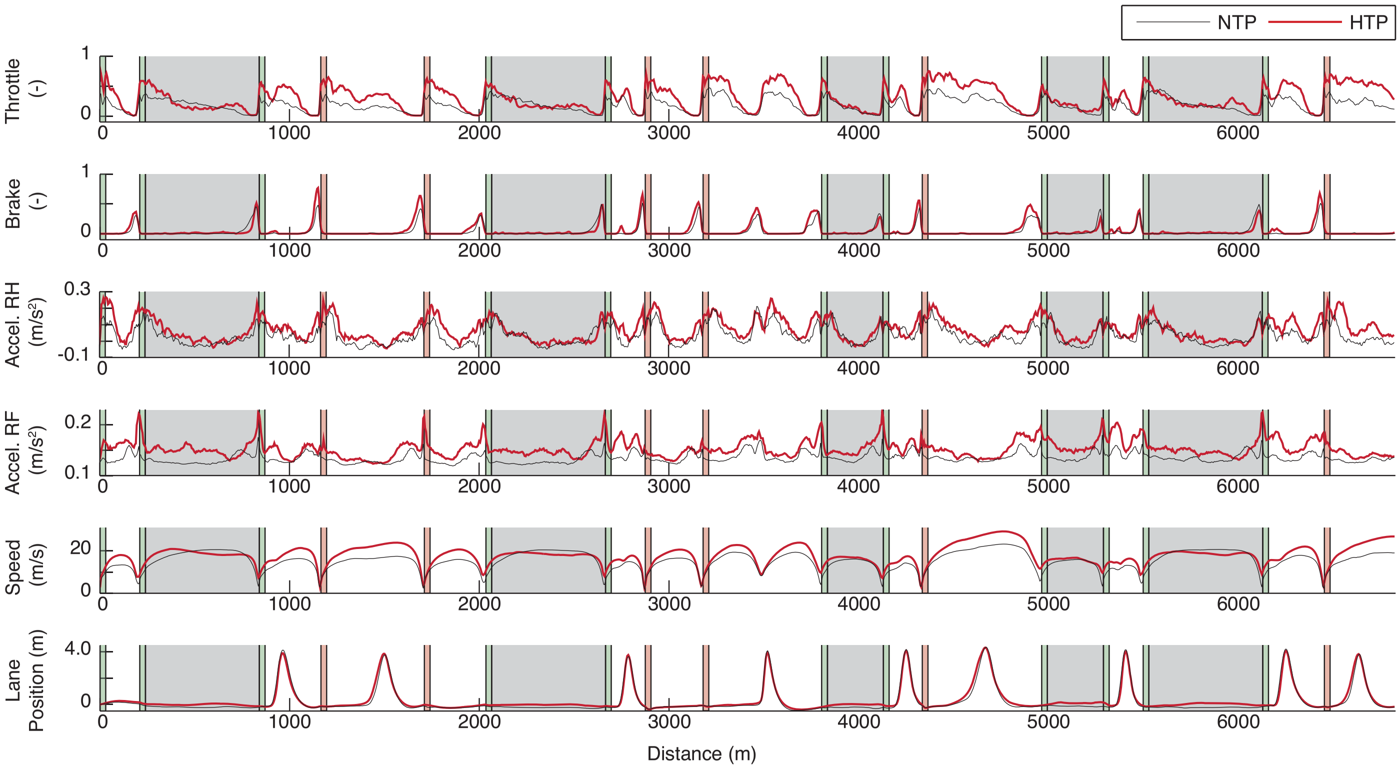

Figure 6.4. Interaction and driving performance related measures as a function of distance for the NTP (black) and HTP (red) sessions. Speed, lateral position, throttle position and brake position are determined using a spatial sliding window of 1 m. Limb accelerations are determined using a temporal sliding window of 3 sec. Note the intersections with and out traffic are indicated by green and red shading, respectively. Car

6.5.1 Car-following situation

During the car-following situation, the tendencies for all of the studied physiological indicators remain relatively similar to those reported for the complete session.

In terms of interaction, the car-following situation results in a lower mean position of the throttle pedal for the HTP condition relative to the NTP condition (Figure 6.5). This result is opposite to what was found for the complete session (see Table 6.4). The variance during throttle-pedal operation remains, as reported for the complete session, mostly higher for the HTP condition (Figure 6.5). During car following, subjects under HTP seem to have a tendency to drive their vehicles at a lower gear as compared to that of subjects under the NTP condition. The tendency for the acceleration of the right hand and foot remains similar to that of the complete session. The results observed for both the acceleration of the left foot and the steering force do not show a clear tendency between both the NTP and HTP conditions.

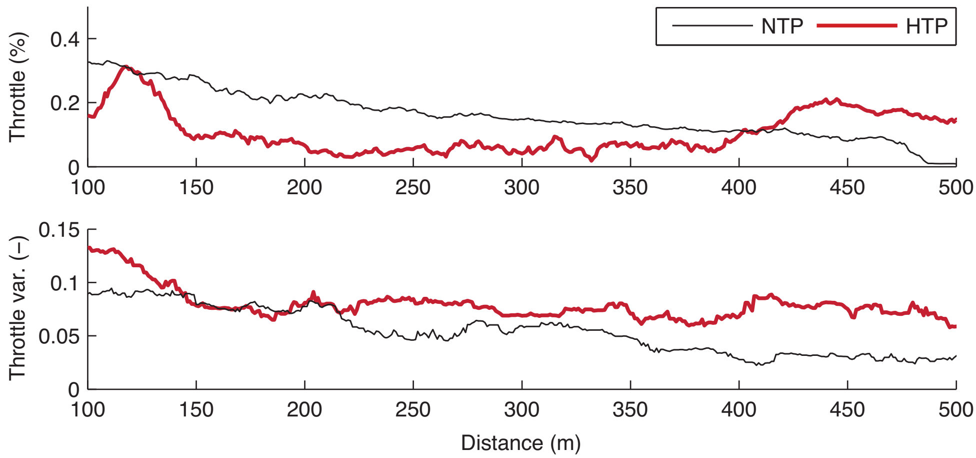

Figure 6.5. Throttle displacement and throttle variance per pedal operation in car-following situations

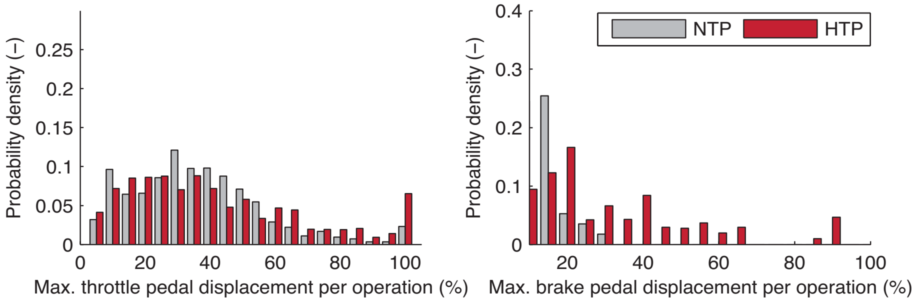

Figure 6.6. Probability distribution of maximum throttle and brake pedal displacement per operation

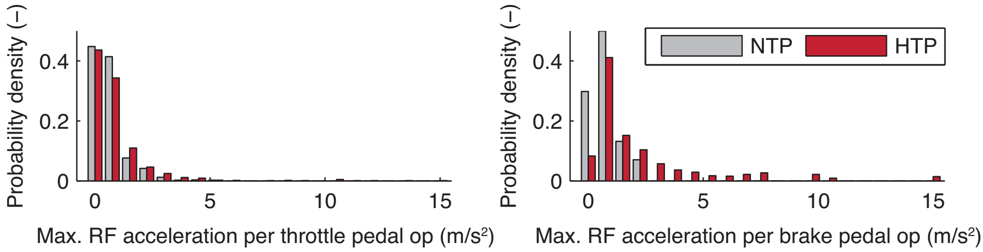

Figure 6.7. Probability distribution for acceleration of the limbs per pedal operation (right foot throttle/brake) in car-following situations

From the data probability distribution plots, the most interesting result is that for the maximum brake pedal displacement per operation (Figure 6.6). Drivers under the HTP condition clearly appear to press the brake farther than those under the NTP condition. Drivers under time pressure appear to be more prone to use the brake pedal during car following situations than those under the NTP condition. The maximum throttle pedal displacement per operation also seems to be higher for the HTP condition relative to the NTP condition (Figure 6.6). Limb acceleration associated to vehicle control operation appears to be slightly higher for the HTP condition relative to the NTP condition. Only for drivers under the HTP condition, the magnitude of the

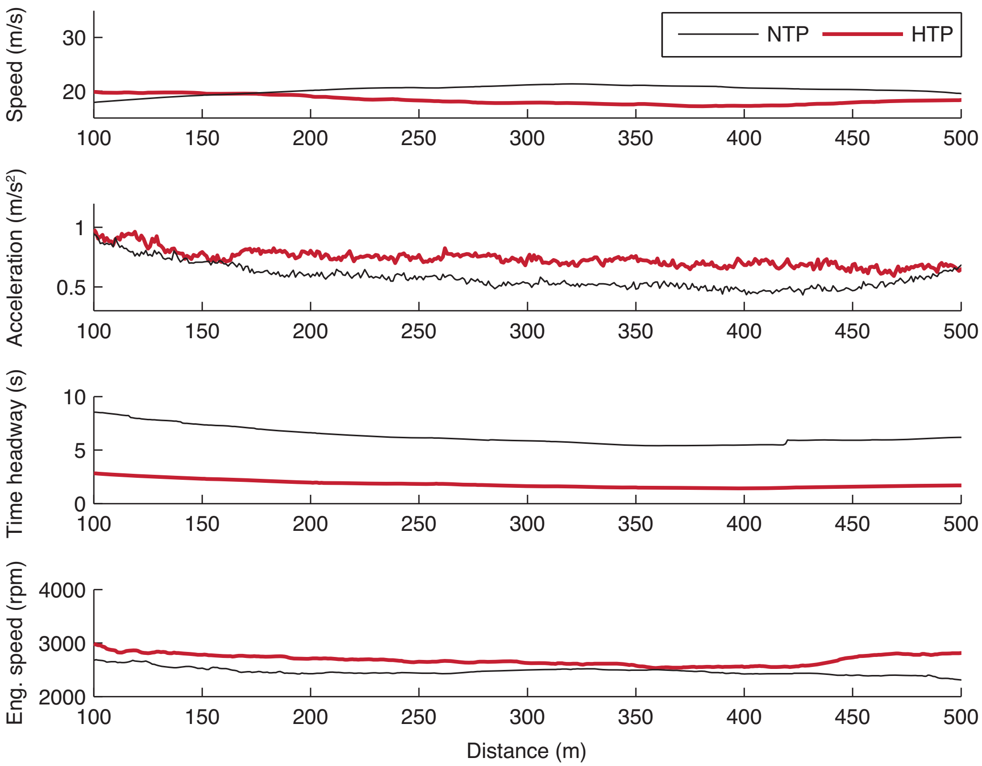

Figure 6.8. Driving performance related measures in car-following situations

acceleration for the right foot, which is associated to brake pedal operation, reaches values around 3m/s² and beyond (Figure 6.7). Note that this exact value may only be valid for the data set obtained from all subjects in this experiment.

In terms of driving performance (Figure 6.8), contrarily to what was found for the complete session, the mean vehicle speed is apparently lower for the HTP condition relative to the NTP condition. The acceleration does not vary its tendency with respect to the complete session and thus remains higher for the HTP condition. Engine speed is also noticeably higher for the HTP condition. Time headway is distinctively lower for the HTP condition compared to the NTP condition. Lateral position is higher for the HTP condition relative to the NTP condition. This means that drivers under time pressure locate their vehicles more towards the left-hand side of their lane. These results are further confirmed with the probability distributions for speed, engine speed, acceleration and lateral position (Figure 6.9). The probability distribution for time to preceding vehicle also confirms that time headway is characteristically lower for the HTP condition compared to the NTP condition (Figure 6.10). From the probability distributions filtered by vehicle velocity bands, the vehicle deceleration per brake pedal operation seems to be considerably higher for HTP drivers than for NTP drivers (Figure 6.11).

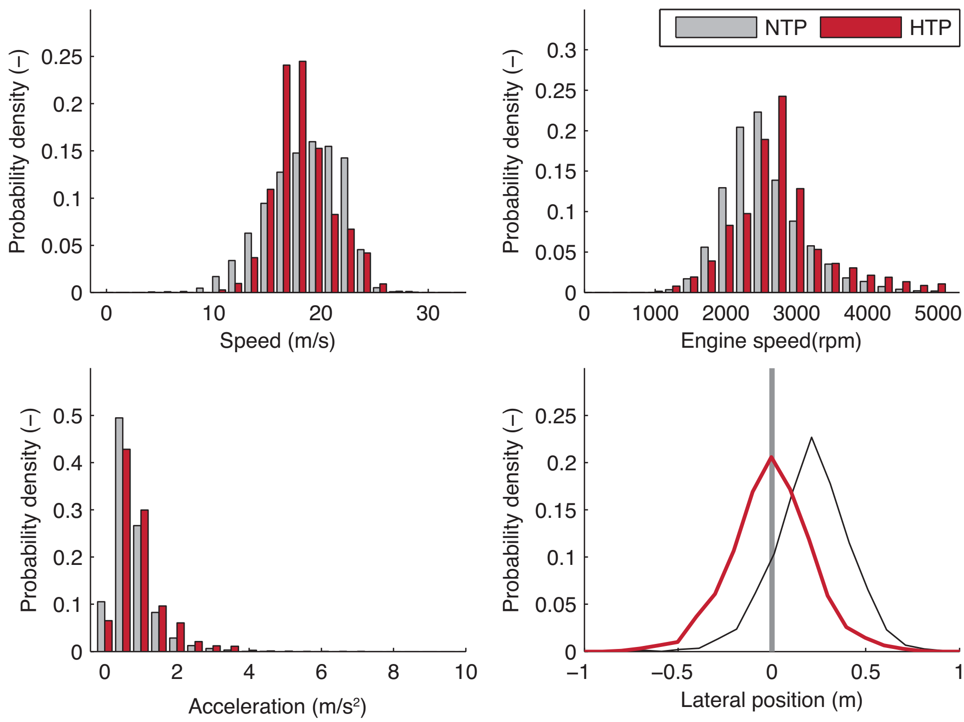

Figure 6.9. Probability distribution for driving performance measures in car-following situations

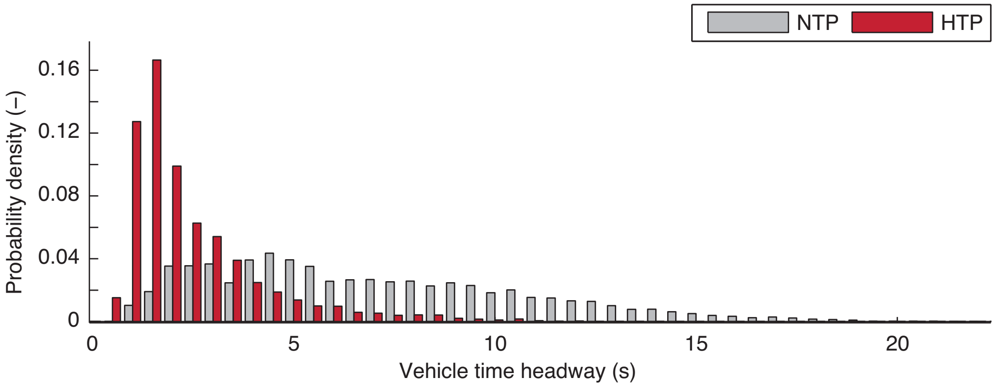

Figure 6.10. Probability distribution of time headway (time to preceding vehicle) in car-following situations

Some of the results described above were further explored for individual participants. The probability distributions for engine speed, vehicle time headway, lateral position and force exerted on the steering wheel are shown in Figure 6.12 and 6.13. The distributions shown in this figure correspond to different participants and were taken out from several randomly plotted data sets, many of which present similar results. The separation between the NTP and HTP conditions for the engine speed and the time headway between the leading and following vehicle, is clearly exhibited. The separation between both conditions is larger for vehicle time headway than for engine speed. The probability distribution for the lateral position, for individual participants, reveals a recognizable difference between both driving conditions. Nevertheless, there is a considerable overlap between the distributions. Finally, despite showing clear differences between

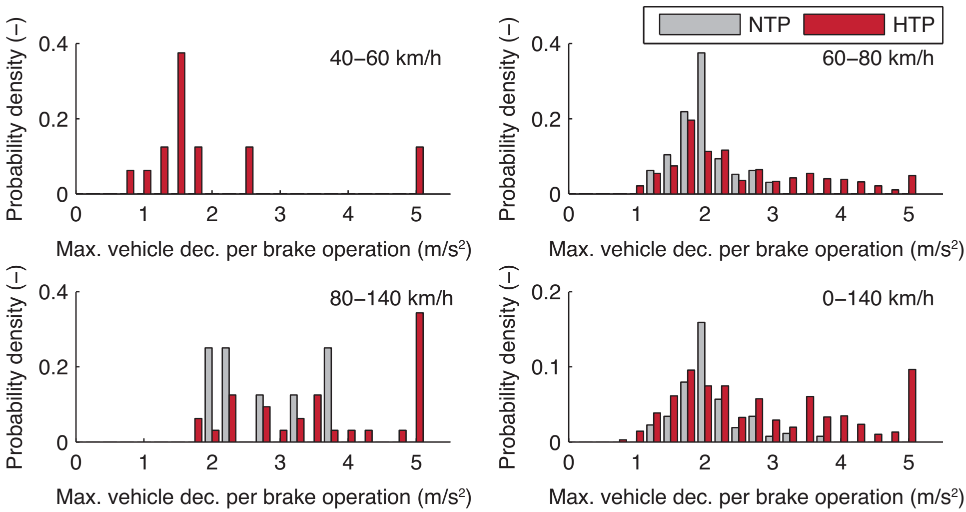

Figure 6.11. Probability distributions for the maximum vehicle deceleration per brake pedal operation per velocity band in car following situations

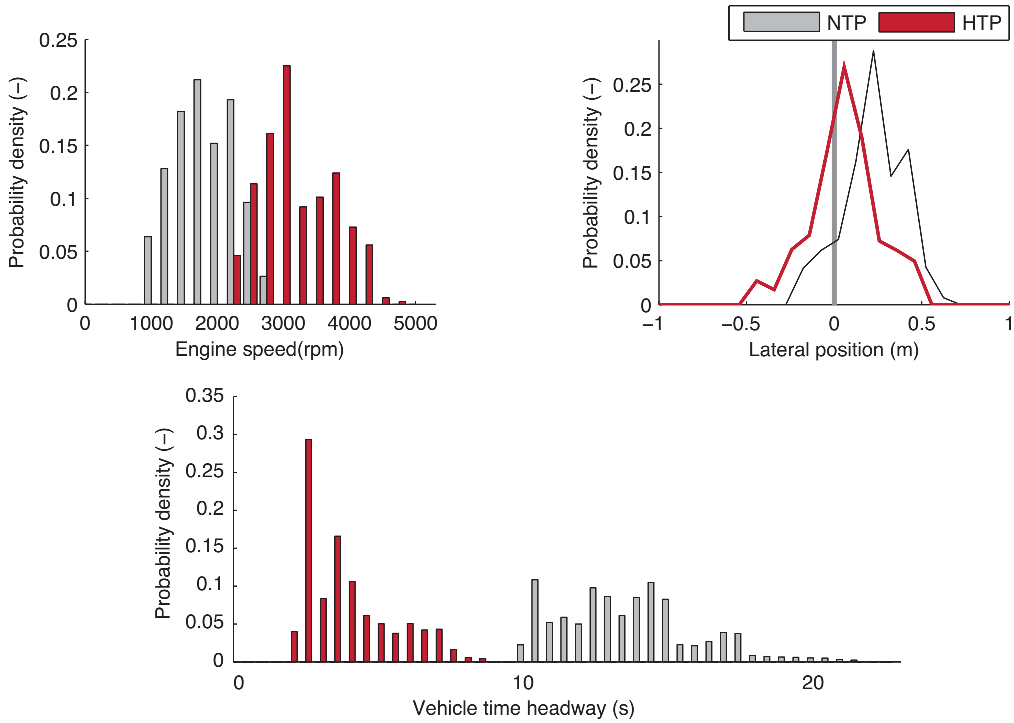

Figure 6.12. Probability distributions for individual participants for engine speed, lateral position, and vehicle time headway in car following situations

the two conditions for individual participants, the probability distribution for the force exerted on the steering wheel presents opposing results among participants. Note that, as was mentioned before, the force exerted on the steering wheel for the combined data set reveals no clear difference between the two conditions.

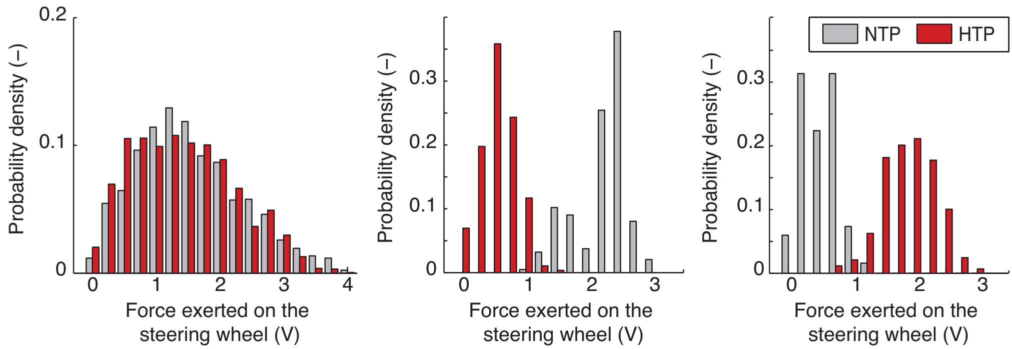

Figure 6.13. Probability distributions of the combined data set of all participants (left) and two individual participants with opposing tendencies (middle and right) for force exerted on the steering wheel in car following situations

6.5.2 Intersections

At intersections both with and without traffic, heart rate maintains the same tendency reported for the complete sessions: heart rate for the HTP condition is significantly higher than for the NTP condition. A slight increase in the heart rate is observed for both HTP and NTP conditions immediately before the intersections with traffic. Heart rate variability, different from what was found for the complete sessions, seems to be lower for the HTP condition in both types of intersections (Figure 6.14).

The results for pupil diameter remain the same as those reported for the complete sessions; the pupil diameter is significantly higher for the HTP condition relative to the NTP condition (Figure 6.15). The pupil diameter appears to decrease immediately before the intersections, both with and

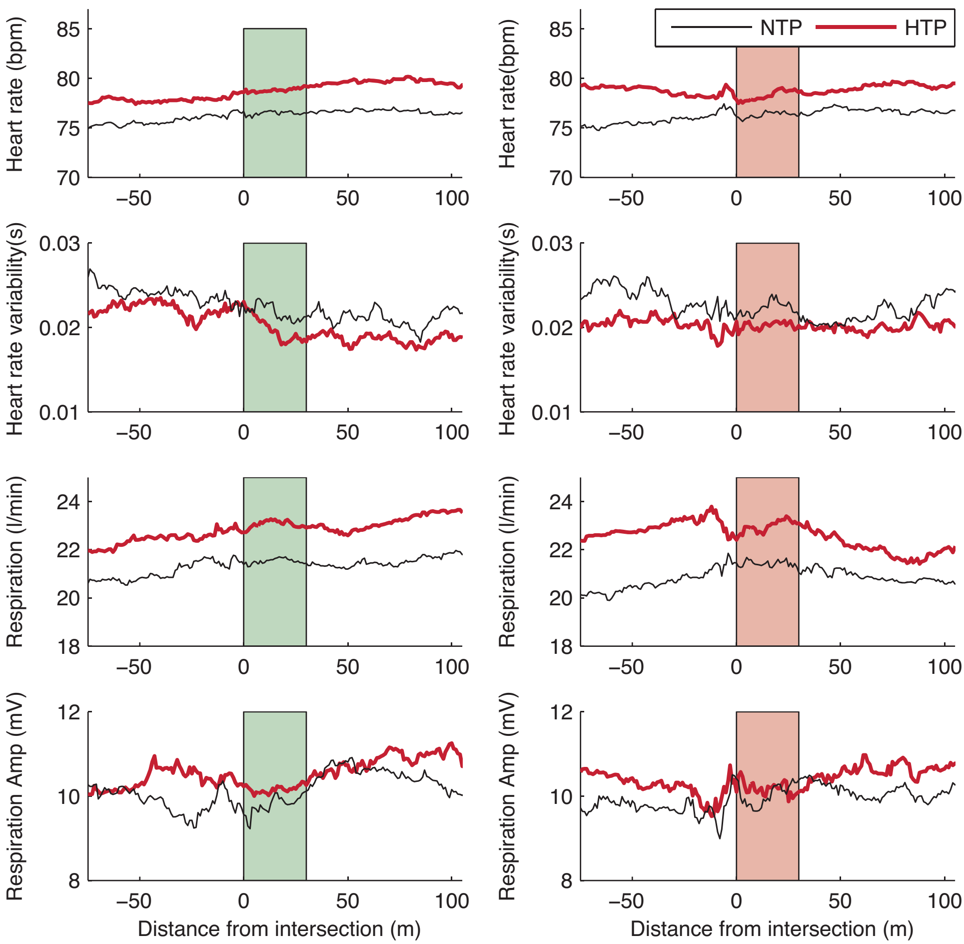

Figure 6.14. Cardiovascular and respiratory measures in intersections without traffic (green-left) and with traffic (red-right)

without traffic, for both the HTP and NTP conditions. This decrease is followed by an increase observed for both HTP and NTP conditions during the second half of the intersections without traffic and during the complete intersections with traffic. The blink rate decreases immediately before both intersection types for both the NTP and HTP conditions (Figure 6.15).

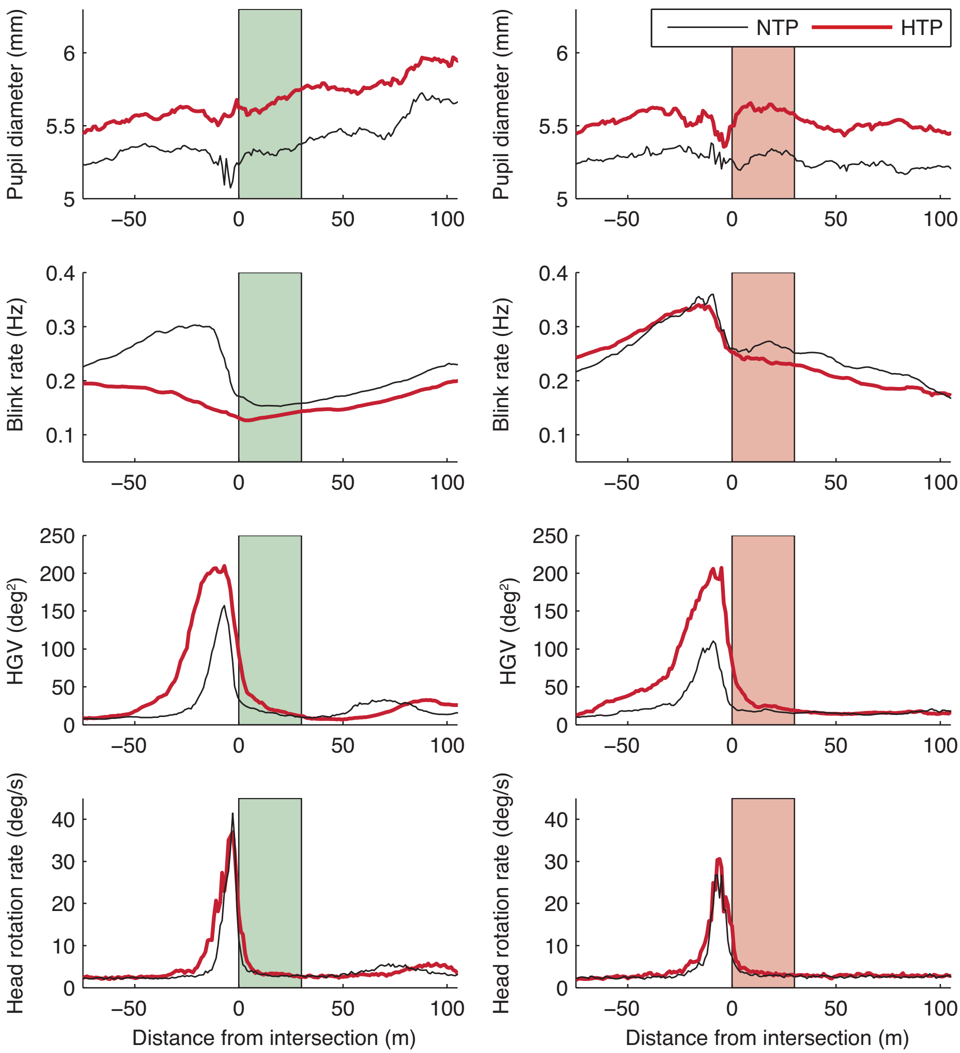

Figure 6.15. Eye behavior measures in intersections without traffic (green-left) and with traffic (red-right)

The horizontal gaze variance increases in both intersection types for both the NTP and HTP sessions, with a larger increase observed for the HTP compared to the NTP session (Figure 6.15). During the former, drivers initiate their visual search as they approach the intersection earlier compared to the latter condition, as can be seen in the increasing horizontal gaze variance starting nearly 60m before the intersection for both intersection types. The head rotation rate is similar for both the NTP and HTP sessions at the two types of intersections. Drivers under time pressure seem to start rotating their heads slightly before drivers under no time pressure. This is more noticeable at intersections without traffic.

Regarding interaction metrics (Figure 6.16), at intersections both with and without traffic, throttle pedal displacement is higher during the HTP condition relative to the NTP condition. The displacement is rather similar for both types of intersection. The brake pedal displacement for the NTP condition at intersections without traffic closely resembles that of intersections with traffic. Differently, the brake pedal displacement for the HTP condition is lower for intersections without traffic as compared to those with traffic. However, drivers under time pressure tend to start pressing the brake pedal considerably earlier before intersections with traffic relative to

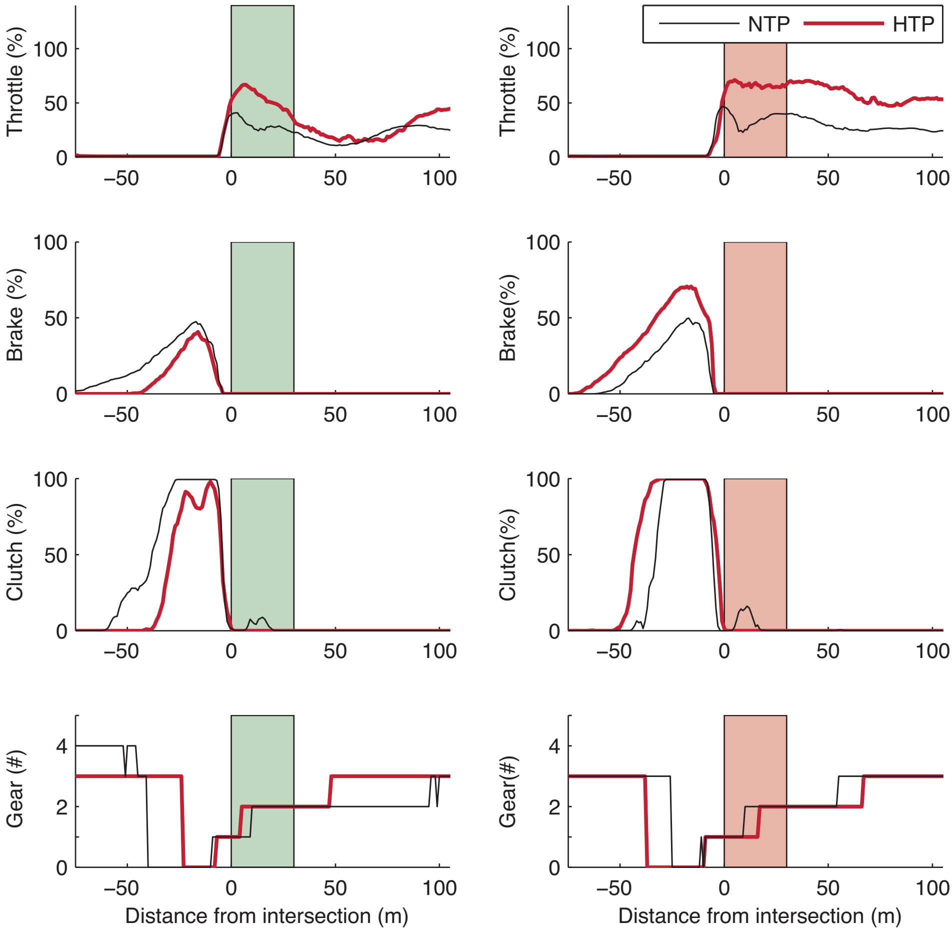

Figure 6.16. Pedal displacement (throttle, brake, clutch and gear) in intersections without traffic (green-left) and with traffic (red-right)

intersections without traffic. Similarly, they tend to start pressing the brake pedal earlier than drivers under no time pressure at intersections with traffic. At intersections without traffic, however, drivers under time pressure tend to start pressing the brake pedal later than drivers under no time pressure. Limb acceleration associated to vehicle control operation appears to be slightly higher for the HTP condition relative to the NTP conditions in both types of intersections. This is most perceptible for the accelerations of the right foot at intersections without traffic.

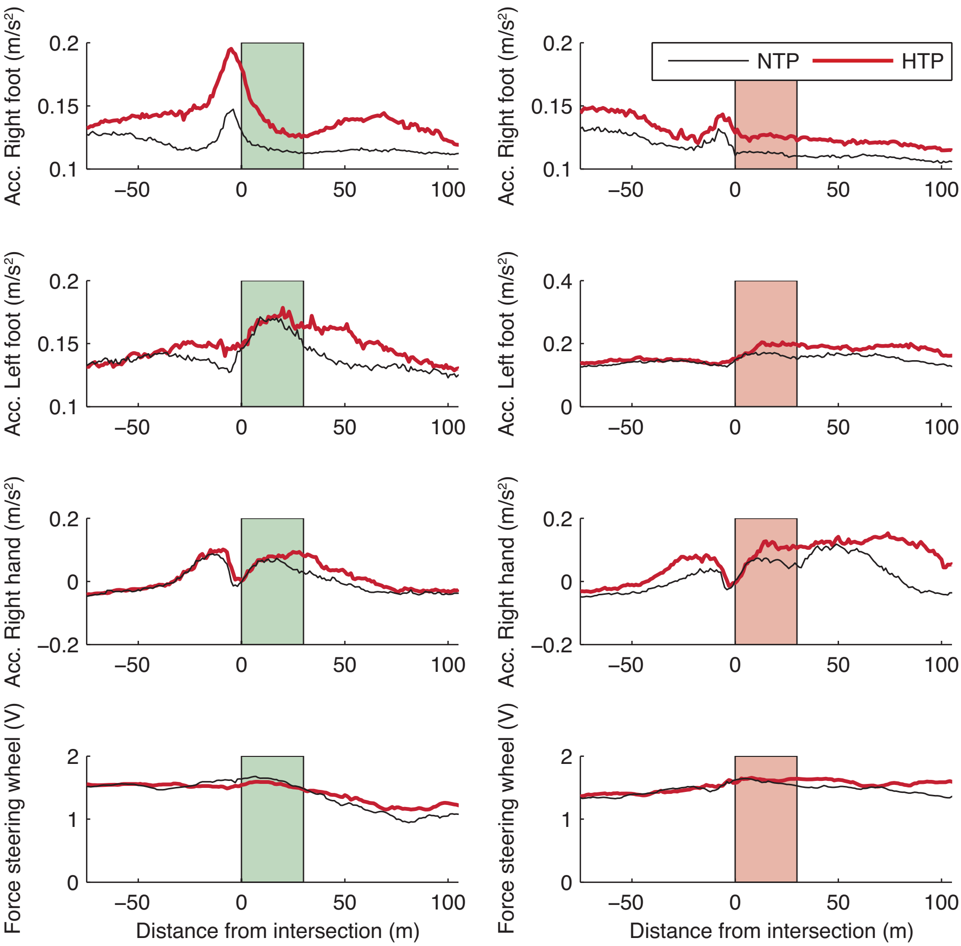

Figure 6.17. Acceleration of the limbs (right foot, left foot, right hand) and force exerted on the steering wheel in intersections without traffic (green-left) and with traffic (red-right)

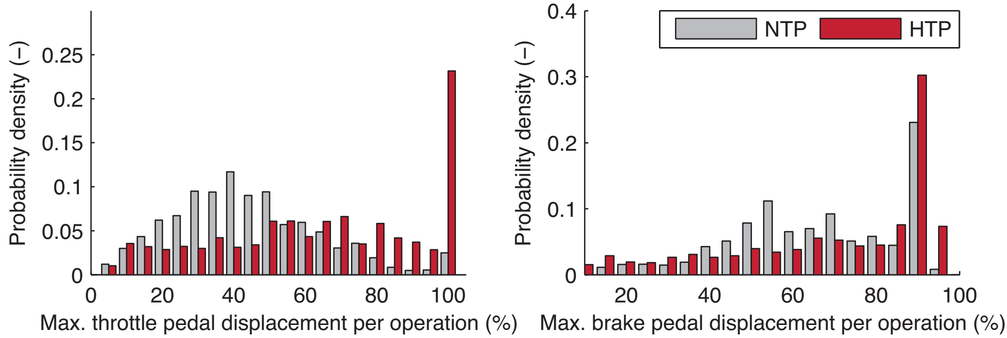

Figure 6.18. Probability distributions for throttle pedal displacement per operation in intersections

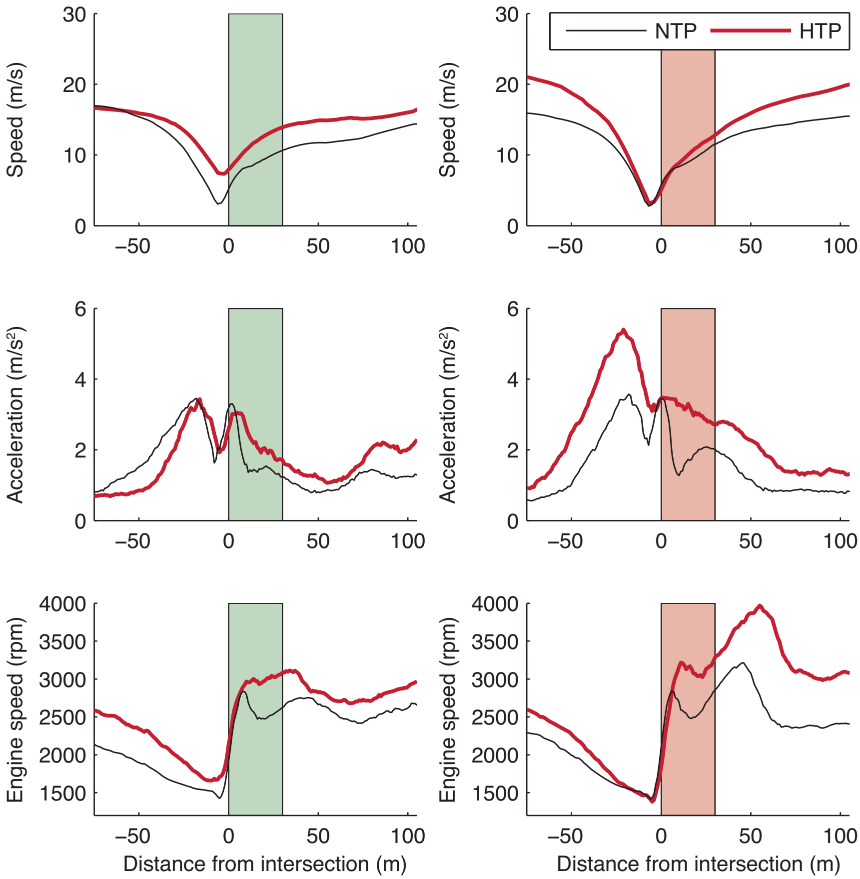

Figure 6.19. Driving performance measures in intersections without traffic (green-left) and with traffic (red-right)

From the data probability distributions (Figure 6.18), the most interesting result is that for the maximum throttle pedal displacement per operation. Drivers under HTP condition appear to press the throttle farther than those under NTP condition. Indeed, the probability of pressing the throttle pedal beyond 80% is considerably higher for drivers under HTP condition relative to those under NTP condition. This holds true for both types of intersection. The maximum brake pedal displacement per operation seems to be higher for drivers under HTP condition. Mainly at intersections with traffic, only drivers under HTP seem to fully press the brake pedal.

As can be seen in Figure 6.19, concerning the driving performance, the mean vehicle speed, the mean vehicle acceleration, and the mean engine speed are higher under HTP condition than under NTP condition in both types of intersection. These results maintain the same tendency reported for the complete session. In addition, the figure also shows that drivers under the NTP condition reduce their speed more than those under the HTP condition when approaching the intersections without traffic. It is also noticeable that the mean vehicle acceleration for HTP drivers is higher for the intersections with traffic relative to those without traffic.

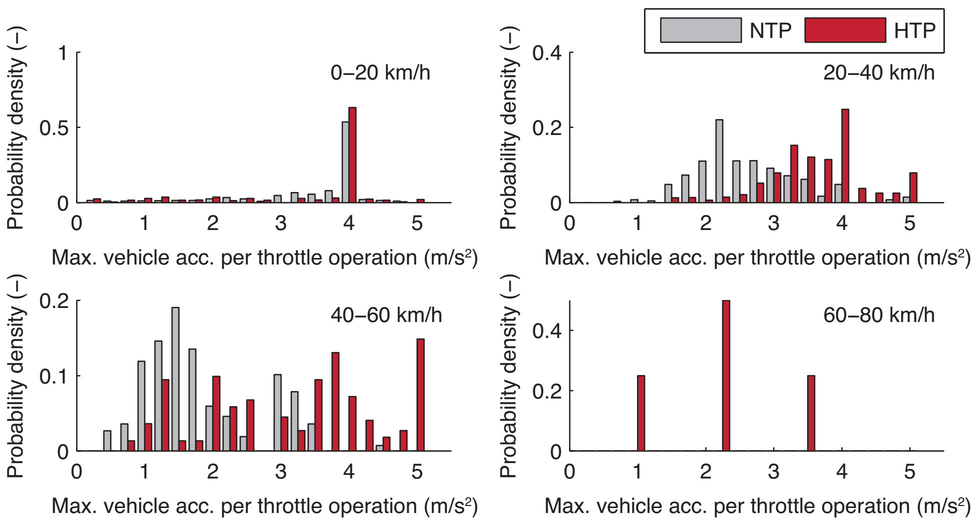

Figure 6.20. Probability distribution for maximum vehicle acceleration per throttle operation per velocity bands in intersections with traffic

From the distribution histograms filtered by vehicle velocity bands (Figure 6.20), vehicle acceleration per throttle pedal operation seems to be higher for HTP drivers than for NTP drivers. This effect is most noticeable for the velocity band ranging from 20 to 40km/h. In particular, for intersections with traffic, this effect is clearly visible with regards to the velocity ranging from 40 to 60 km/h. As vehicle velocity increases towards the velocity band ranging from 60 to 80 km/h, only data for a small number of drivers under the HTP condition is found for both types of intersection. From the distribution histograms filtered by vehicle velocity bands, vehicle deceleration per brake pedal operation does not appear to have a particularly distinguishable pattern between both NTP and HTP driving conditions.

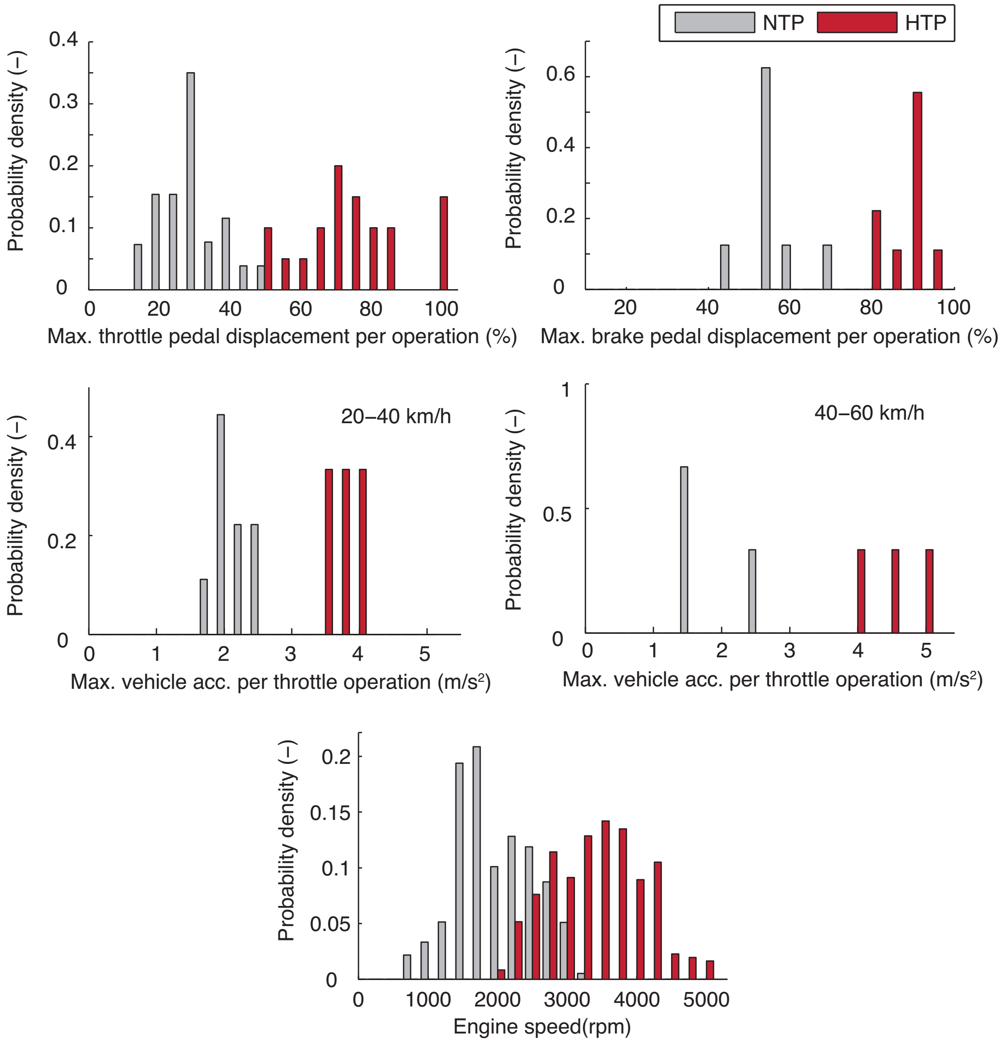

Figure 6.21. Probability distributions for maximum throttle and brake pedal displacement per operation at intersections with and without traffic, maximum vehicle acceleration per throttle operation in the 20-40 km/h velocity band at both types of intersection, maximum vehicle acceleration per throttle operation in the 40-60km velocity band at intersections with traffic and engine speed at intersections without traffic

Some of the results described above were further explored for individual participants (Figure 6.21). The probability distributions for engine speed at intersections without traffic, maximum throttle and brake pedal displacement per operation at both types of intersection (with and without traffic), maximum vehicle acceleration per throttle operation in the 20-40km velocity band at both types of intersection and maximum vehicle acceleration per throttle operation in the 40-60km velocity band at intersections with traffic, are presented in Figure 6.21. The distributions shown in this figure correspond to different participants and were taken out from several randomly plotted data sets, many of which present similar results. The separation between the NTP and HTP driving conditions for engine speed is observable with some overlap. In the remaining distributions, the separation between the two conditions is clearly exhibited. However, due to the limited number of pedal operations per participant during the intersection segments in this experimental setting, these results are still subject to further study.

6.5.3 Overtaking situations

During overtaking situations, heart rate variability, different from what was found for the complete sessions, seems to be lower for the HTP condition relative to the NTP condition both with and without opposing traffic flow (Figure 6.22). This result is more noticeable in the latter situation. An increase in pupil diameter is perceptible as the obstacle is approached in both the overtaking scenario with traffic in the opposing lane and without traffic in the opposing lane (Figure 6.23). The tendencies for the remaining physiological indicators appear to be reasonably similar to those observed for the complete session.

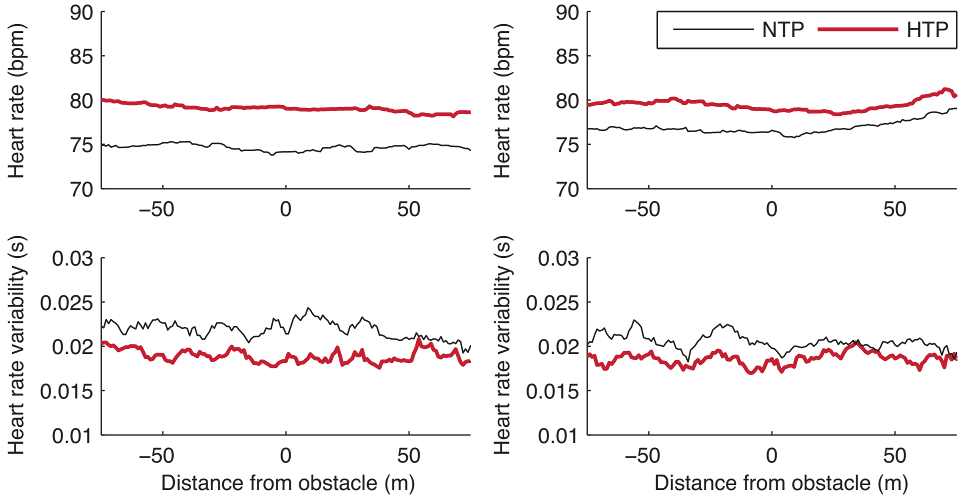

Figure 6.22. Cardiovascular activity measures in overtaking situations without traffic in the opposing lane (left) and with traffic in the opposing lane (right)

Concerning interaction metrics (Figure 6.24 and 6.25), in overtaking both with and without traffic, throttle pedal displacement appears to be higher for the HTP condition relative to the NTP condition. Similarly, steering speed is higher for the HTP condition relative to the NTP condition in both types of overtaking. This difference appears to be larger for overtaking situations with traffic on the opposing lane. Steering angle seems to have a distinguishable pattern between the two types of overtaking situations, being shallower for overtaking situations without traffic. However, it does not seem to present clear differences between HTP condition and NTP condition for either situation. Limb acceleration associated to vehicle control operation appears to be slightly higher for the HTP condition relative to the NTP conditions in both types of overtaking situations.

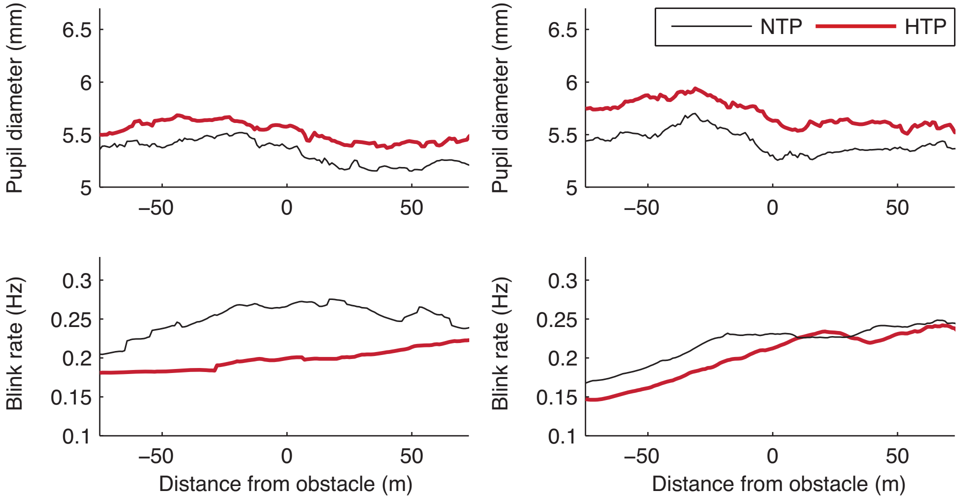

Figure 6.23. Eye behavior measures in overtaking situations without traffic in the opposing lane (left) and with traffic in the opposing lane (right)

Specifically the acceleration of the left foot and right hand clearly reflect a higher value for drivers under HTP. In overtaking with traffic, the force exerted on the steering wheel seems to be higher for the HTP condition with respect to the NTP condition. From the data probability distribution plots, the most interesting result is that for the maximum throttle pedal displacement per operation (Figure 6.26). Drivers under HTP condition press the throttle farther than those under NTP condition for both types of overtaking situations. Actually, the probability of pressing the throttle pedal by more than 80% is largely higher for drivers under HTP condition relative to those under NTP condition.

In terms of driving performance (Figure 6.27), as can be seen on results for the lateral position, when traffic was present on the opposing lane, the HTP drivers initiated their overtaking maneuver later compared to the NTP drivers. In contrast, when no traffic was present in the opposing lane, the HTP drivers initiated their overtake maneuver earlier compared to the NTP drivers. The mean vehicle speed, the mean vehicle acceleration and the mean engine speed are higher for the HTP condition compared with the NTP condition in both types of overtaking situations. These results maintain the same tendency reported for the complete session. From the probability distribution plots, vehicle acceleration per throttle pedal operation filtered by vehicle velocity bands seems to be higher for HTP drivers than for NTP drivers in both overtaking situations (Figure 6.28). This effect is most noticeable for the velocity bands ranging from 20 to 40 km/h and from 40 to 60 km/h; and somewhat noticeable for the velocity bands ranging from 0 to 20 km/h and from 60 to 80 km/h. As vehicle velocity increases towards the velocity band ranging from 80 to 140 km/h, predominantly data for drivers under the HTP condition is found for both types of overtaking.

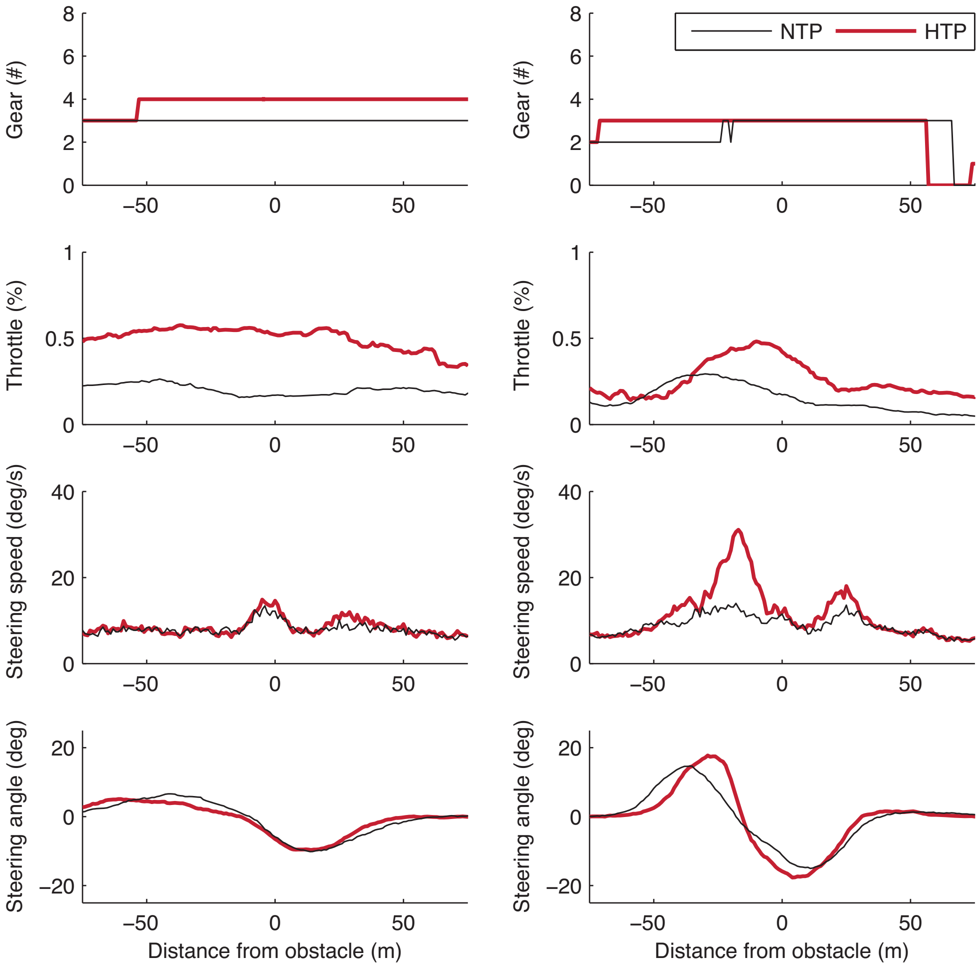

Figure 6.24. Driver-car interaction-related metrics (gear, throttle, steering speed, steering angle) in overtaking situations without traffic in the opposing lane (left) and with traffic in the opposing lane (right)

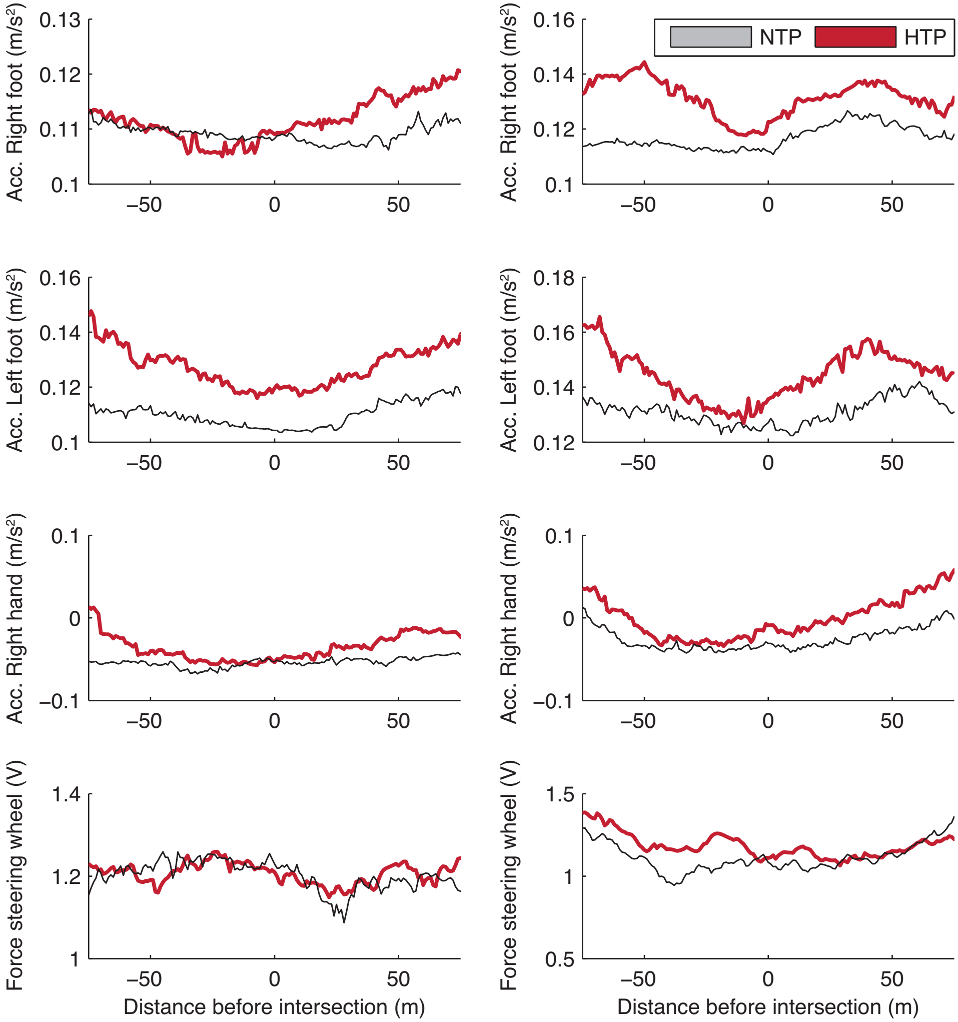

Figure 6.25. Acceleration of the limbs (right foot, left foot, right hand) and force exerted on the steering wheel in overtaking situations without traffic in the opposing lane (left) and with traffic in the opposing lane (right)

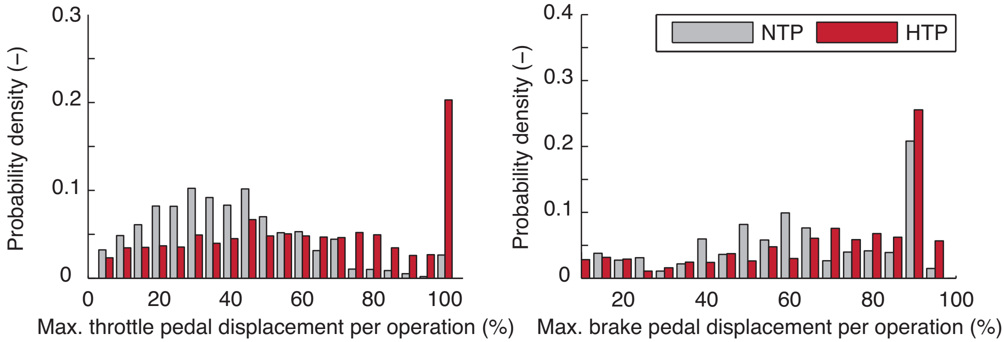

Figure 6.26. Probability distribution for the maximum throttle and brake pedal displacement per operation in overtaking situations

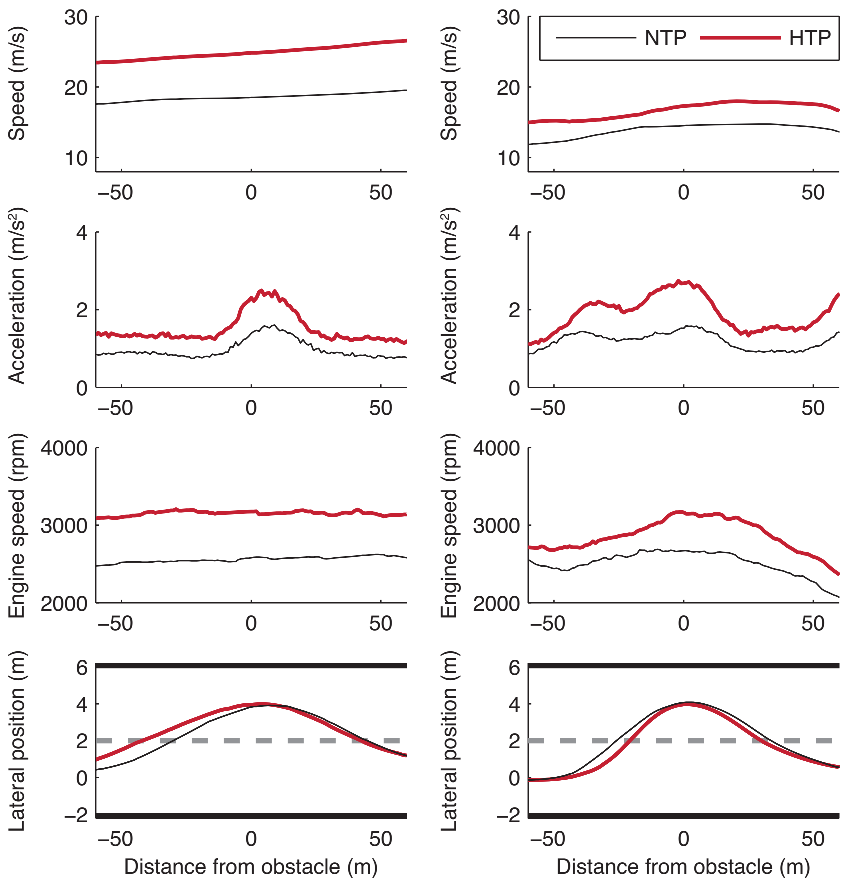

Figure 6.27. Driving performance in overtaking situations without traffic (left) and with traffic (right)

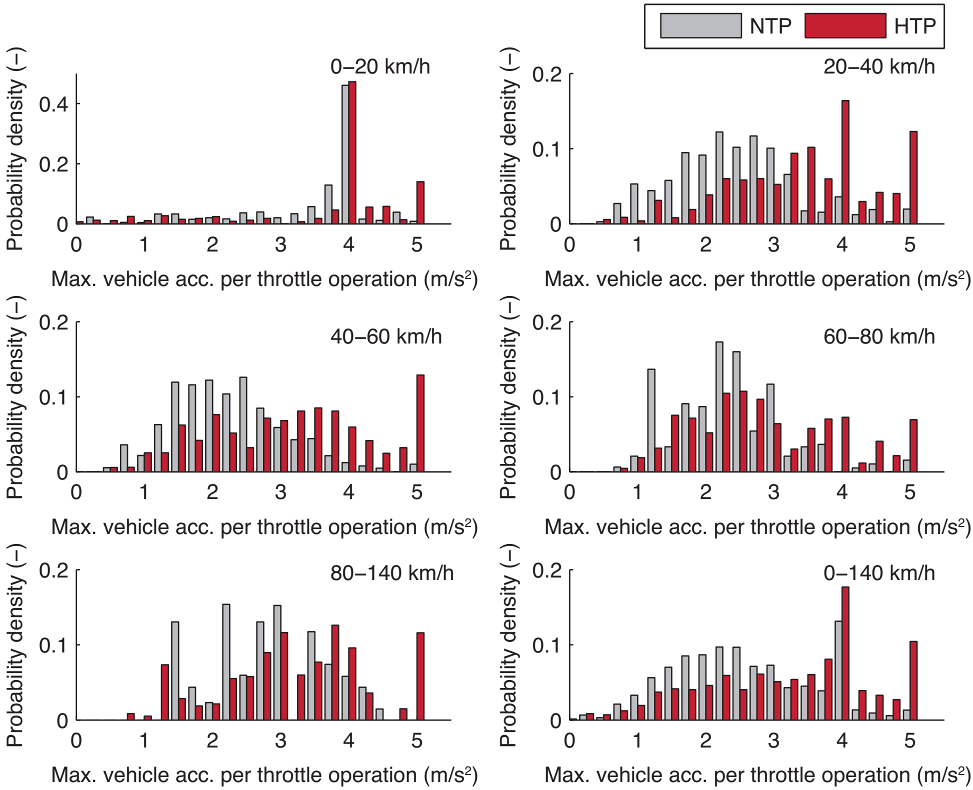

Figure 6.28. Probability distribution for maximum vehicle acceleration per throttle operation per velocity bands in overtaking situations

Some of the results described above were further explored for individual participants (Figure 6.29). The probability distributions for engine speed for both types of overtaking situations (with and without traffic on the opposing lane), maximum vehicle acceleration per throttle operation in the 40-60km velocity band for overtaking with traffic on the opposing lane, and maximum throttle and brake pedal displacements per operation for overtaking without and with traffic on the opposing lane respectively, are presented in Figure 6.29. The distributions shown in this figure correspond to different participants and were taken out from several randomly plotted data sets, many of which present similar results. The separation between the NTP and HTP driving conditions for all the plotted distributions is clear with some overlap between the two conditions for engine speed. Due to the limited number of overtaking situations per participant in this experimental setting, the results associated with pedal displacement are still subject to further study.

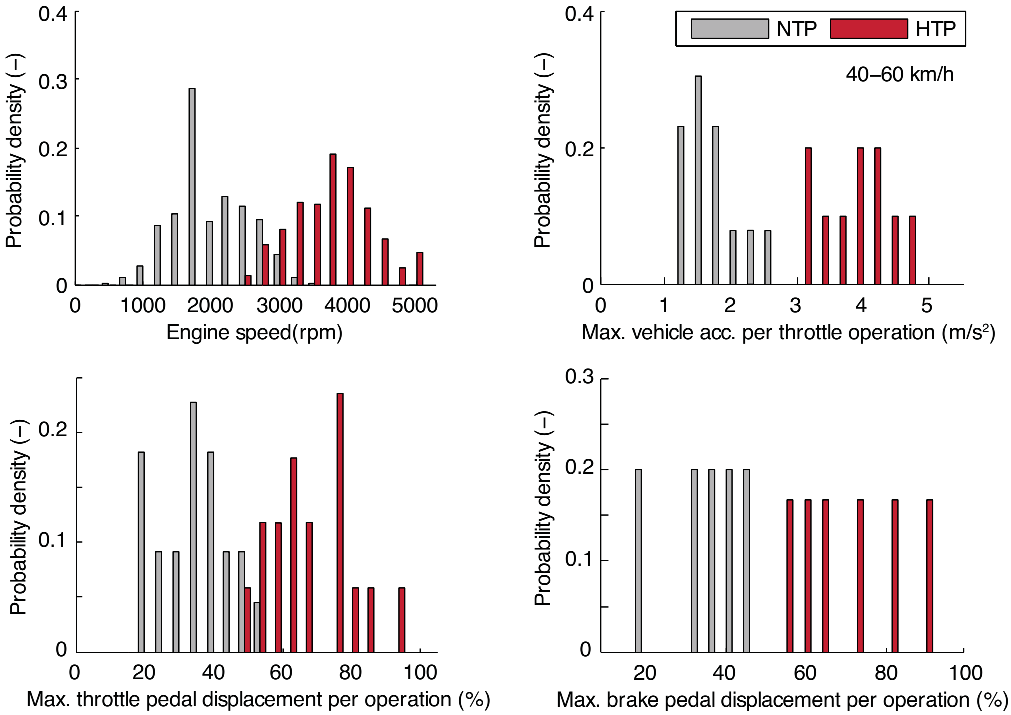

Figure 6.29. Probability distributions for individual participants corresponding to engine speed for overtaking situations, maximum acceleration per throttle operation for overtaking with traffic on the opposing lane, and maximum throttle and brake pedal displacements per operation for overtaking without and with traffic on the opposing lane respectively

6.5.4 Cruising situations

In cruising situations, the physiological metrics appear to maintain the same tendencies as the ones found for the complete session (Figure 6.30). Either the distinguishable tendencies persist or the difference remains unclear.

In terms of interaction (Figure 6.31 and 6.32), the throttle pedal displacement (mean throttle position) and throttle pedal variance are higher for the HTP condition relative to the NTP condition. The data probability distribution for the maximum throttle pedal displacement per operation shows that drivers under HTP condition press the throttle farther than those under NTP condition (Figure 6.33). The probability of pressing the throttle pedal by more than 80% mainly corresponds to drivers under HTP condition. Limb accelerations associated to vehicle control operation (Figure 6.32), including right hand, right foot and left foot, appear to be higher for the HTP condition relative to the NTP condition. The force exerted on the steering wheel appears to be higher for the HTP condition with respect to the NTP condition.

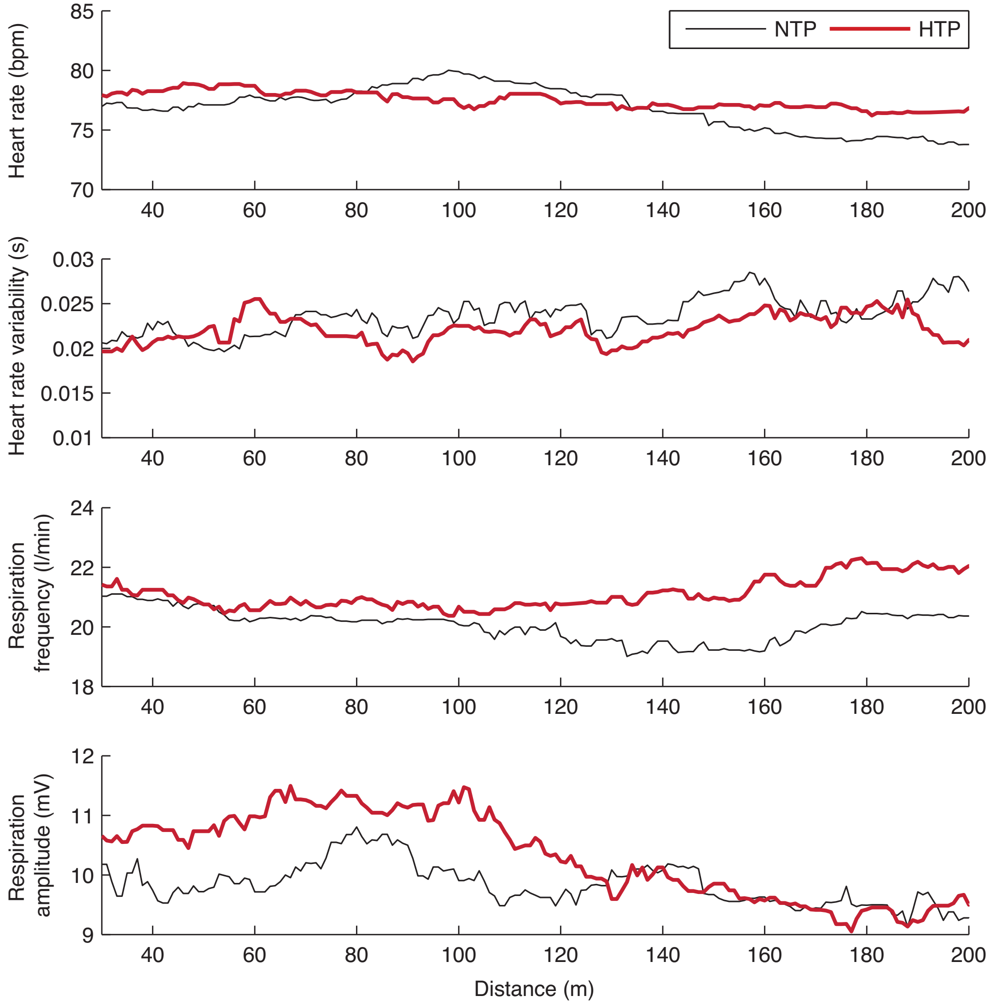

Figure 6.30. Cardiovascular and respiratory measures in cruising situations

The mean vehicle speed, the mean vehicle acceleration and the mean engine speed are higher for the HTP condition relative to the NTP (Figure 6.35). These results maintain the same tendency reported for the complete session. Lateral position does not differ for either condition.

Some of the results described above were further explored for individual participants (Figure 6.35). The probability distributions for engine speed, vehicle speed, vehicle acceleration, maximum throttle pedal displacement per operation and force exerted on the steering wheel are shown in Figure 6.35. The distributions shown in this figure correspond to different participants and were taken out from several randomly plotted data sets, many of which present similar results. The separation between the NTP and HTP driving conditions is clear for all the distributions plotted. Despite showing clear differences between the two conditions, the probability distribution for the force exerted on the steering wheel presents opposing results among participants. Due to the limited number of cruising situations and their relatively short length in this experimental setting, the results for throttle pedal displacement are still subject to further study.

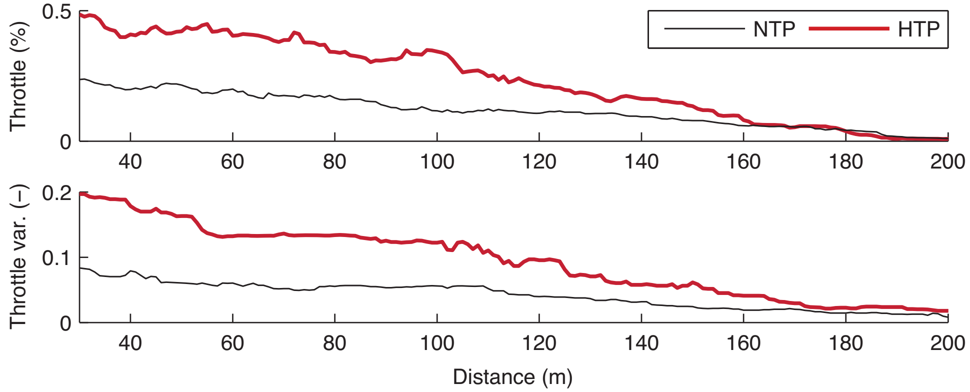

Figure 6.31. Throttle pedal displacement in cruising situations

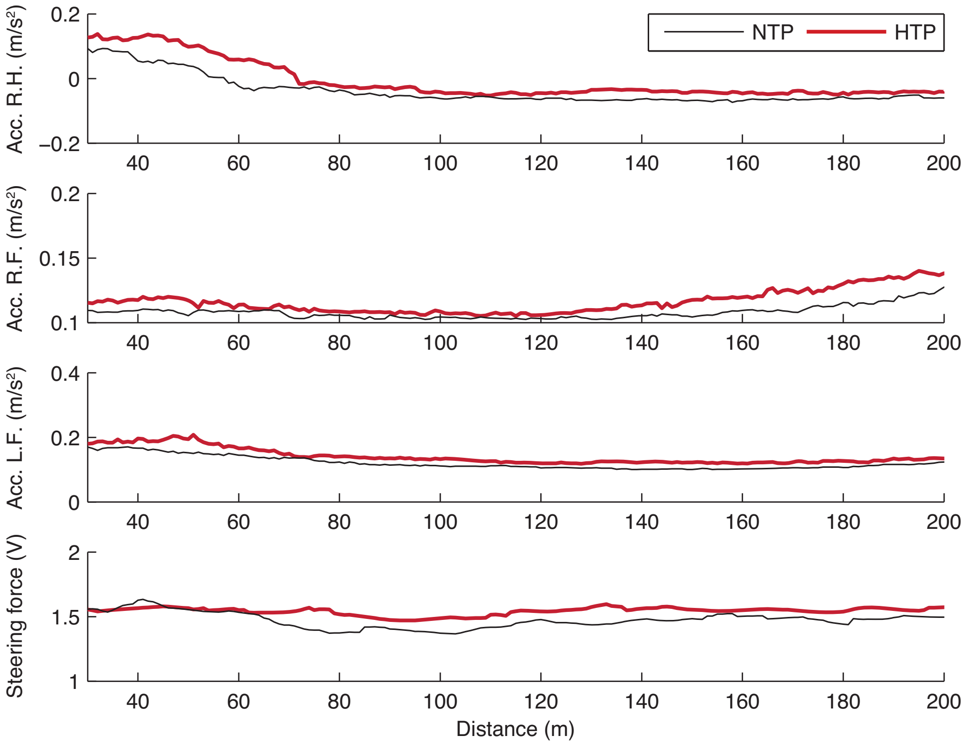

Figure 6.32. Acceleration of the limbs (right hand, right foot, left foot) and force exerted on the steering wheel in cruising situations

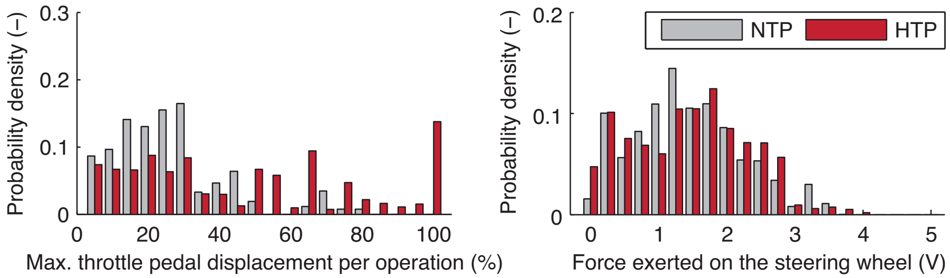

Figure 6.33. Probability distribution for maximum throttle pedal displacement per operation in cruising situations

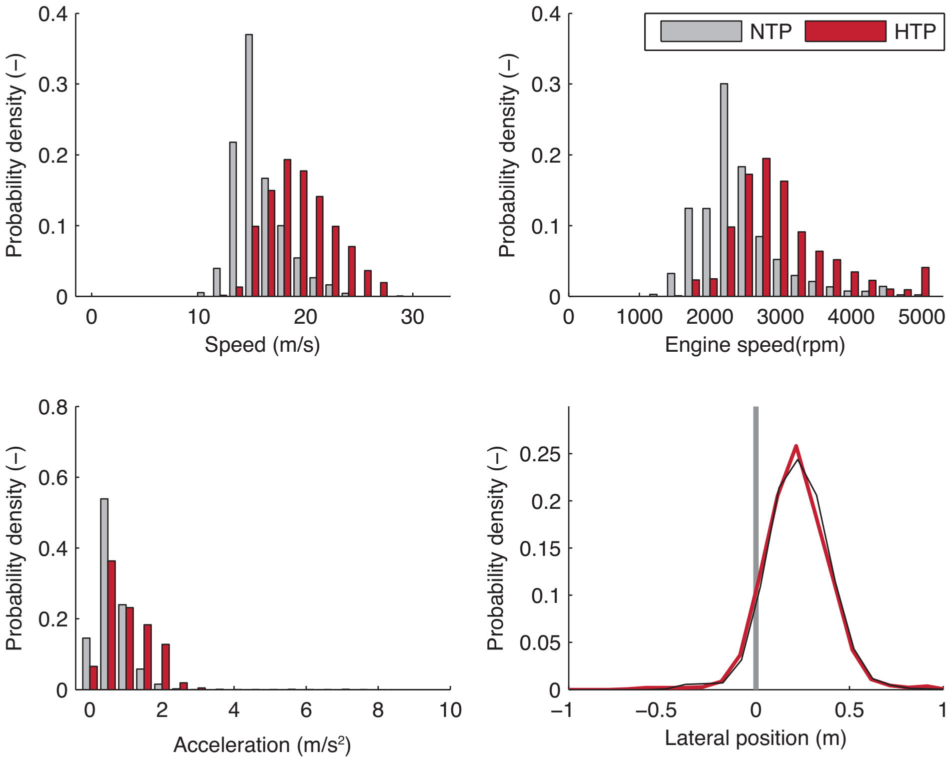

Figure 6.34. Probability distribution of driving performance measures in cruising situations

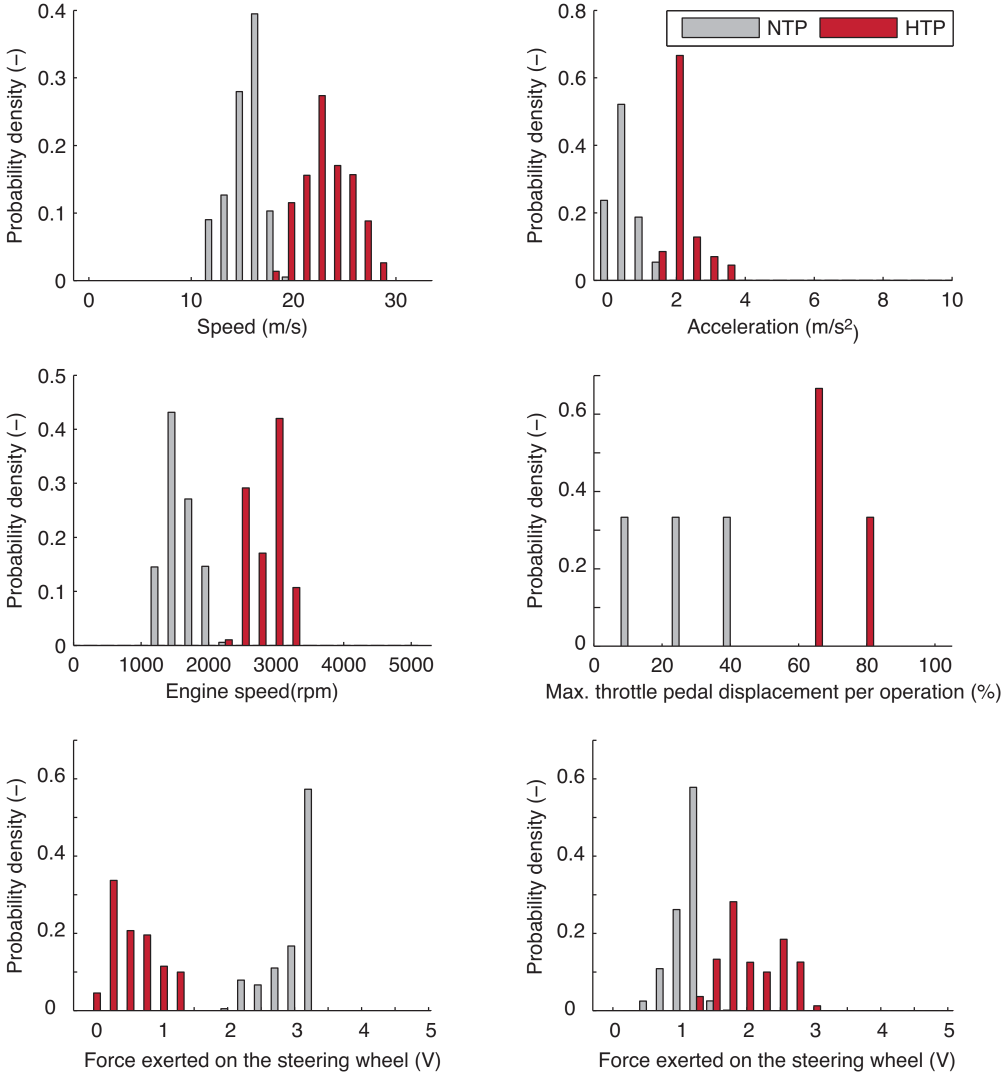

Figure 6.35. Probability distributions for individual participants corresponding to engine speed, vehicle speed, vehicle acceleration, maximum throttle pedal displacement per operation and force exerted on the steering wheel in cruising situations

6.5.5 Correlation between driving styles, subjective workload measures, and physiological and performance measures

The correlation matrix for the MDSI questionnaire, the DBQ, driving performance, physiological and the subjective workload measures, are shown in Table 6.6. In this table the significant correlations between driving styles and physiological measures/driving performance measures can be seen, as well as correlations between subjective and physiological measures of workload. Specifically, in terms of the driving style inventory, reckless and careless driving style correlated with speed, steering speed, DBQ errors and violations. Angry and hostile driving style correlated with speed, RMS acceleration of the right hand and DBQ violations and errors. Patient and careful driving style inversely correlated with steering force and DBQ violations. Anxious driving style correlated with errors.

Regarding the driving style and its relation with the physiological measures, the reckless and careless driving style and the angry and hostile driving style correlate with pupil diameter, respiratory frequency and workload. These two styles are positively correlated. The patient and careful driving style inversely correlated with respiratory frequency and positively correlated with workload. Furthermore, this style negatively correlated with reckless and careless driving style. Additionally, subjective workload (NASA-TLX) correlated with pupil diameter and with the subjective experience of time pressure and the perceived need of driving fast. Similarly the subjective feeling of a need to hurry up correlated with pupil diameter and the subjective feeling of time pressure.

In terms of the physiological signals, heart rate correlated with the RMS acceleration of the right hand and foot as well as with pupil diameter. The correlation between the heart rate and pupil diameter (left) and NASA-TLX and pupil diameter (right) are shown in Figure 6.36.

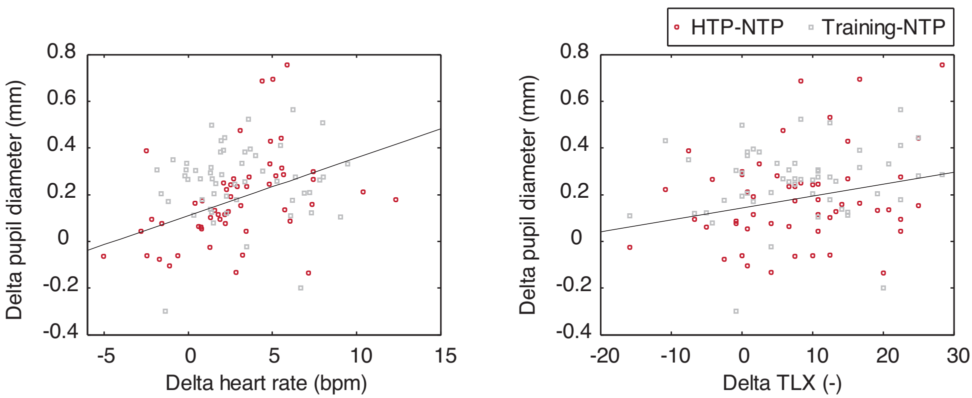

Figure 6.36. Correlation between mean session differences of pupil diameter and heart rate (left) and mean session differences of pupil diameter and NASA-TLX (right) between both sessions. Linear fits calculated from session difference between HTP and NTP are shown in black.

Table 6.6. Correlation matrix (N = 54) for driving performance, physiology, subjective workload metrics, driver behavior questionnaire and multidimensional driving

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Engine speed	-																							
2. Speed	**.47**	-																						
3. Minimum car following distance	**-.32**	-.15	-																					
4. Mean throttle var. per operation	**.38**	**.41**	**-.30**	-																				
5. Steering speed	**.45**	**.42**	-.17	**.39**	-																			
6. RMS acceleration right hand	**.36**	**.41**	-.07	**.42**	**.48**	-																		
7. RMS acceleration right foot	**.58**	**.44**	-.07	**.37**	**.44**	**.72**	-																	
8. Steering force	.05	.04	-.15	.14	.11	.21	.14	-																
9. Percentage road center	.17	-.04	-.23	.05	-.01	.00	.10	-.02	-															
10. Percentage dials	**-.45**	**-.46**	.04	-.26	-.26	-.20	**-.42**	.18	-.07	-														
11. Blink frequency	-.15	.10	.19	-.07	.04	.00	.01	-.21	**-.55**	**-.47**	-													
12. Pupil diameter	**.33**	**.27**	**-.33**	.11	**.46**	**.32**	**.36**	-.02	.22	.04	-.17	-												
13. Respiratory frequency	.16	**.32**	-.14	.27	**.39**	**.36**	.26	.20	-.08	.00	.03	**.54**	-											
14. Heart rate	.02	.26	.03	.18	.19	**.37**	**.57**	.16	-.03	-.06	.01	**.43**	.25	-										
Driving style inventory																								
15. Reckless and careless	.14	**.42**	.05	.10	**.31**	.19	.14	.00	.04	-.04	.01	**.32**	**.35**	.17	-									
16. Anxious	-.01	-.06	.17	.01	.13	.13	.10	-.13	.00	-.13	.09	.09	.20	-.08	.17	-								
17. Angry and hostile	-.01	**.33**	-.03	-.01	.25	**.32**	.25	.09	.13	-.09	.01	**.29**	**.40**	.13	**.62**	.22	-							
18. Patient and careful	-.16	-.03	.10	.01	-.13	.03	.00	**-.28**	.03	-.02	.07	-.11	**-.32**	-.06	**-.31**	.26	-.22	-						
Driver behavior questionnaire																								
19. DBQ violations	**.28**	**.43**	-.04	.19	.36	.15	.11	-.06	.02	-.15	.06	.23	.27	.07	**.74**	.12	**.38**	**-.30**	-					
20. DBQ errors	-.05	-.09	.17	.16	.21	.24	.13	.08	-.09	-.17	.16	-.10	-.02	-.16	**.30**	**.48**	**.27**	-.17	**.39**	-				
21. Workload (NASA TLX)	.13	.10	.08	.16	.31	.06	.21	-.16	-.10	-.09	.07	**.27**	.11	.25	**.42**	.09	**.41**	-.02	**.31**	.16	-			
22. Driving fast	**.27**	**.33**	-.03	.16	.34	.11	.21	-.01	.18	-.07	-.13	**.29**	.12	.07	.07	-.16	.07	.02	.13	.01	**.38**	-		
23. Time pressure	**.27**	.26	-.03	.16	.24	.18	.21	.04	-.03	-.13	.02	.22	.02	.13	.20	.07	.10	-.01	**.34**	.26	**.42**	.22	-	
24. Need to hurry up	.15	.14	**-.27**	.15	.07	-.07	.17	.06	.13	-.17	.03	**.30**	.09	-.05	.17	.07	.10	-.01	.26	.15	.21	.25	**.29**	-

6.6 Discussions

The following sections present an interpretation of the results of this study, based on the model presented in Section 5.2, and in comparison to the findings of previous work in this field. Note that, referring to the model, this study aimed at identifying specific outcomes resulting from a variation in the extraneous load (i.e. time constraint). Other variations within the model (i.e. intrinsic load, individual resources or any additional extraneous loads) were not studied (e.g., the impact of the experience of the driver and the influence of variations in the nature of the task).

6.6.1 Effects of time pressure on cardiovascular activity

In this study, heart rate significantly increased during driving under time pressure condition. Since time pressure has been related to a higher mental effort investment, this result is in line with previous studies in which HR has been reported to increase during mentally demanding tasks [5,6]. Furthermore, during the exploratory analysis, a slight increase in the heart rate was observed for both HTP and NTP conditions immediately before intersections with traffic. Since intersections with traffic inherently demand an extra effort from the driver, this result seems to support the fact that higher mental effort investment leads to higher heart rate. Similar results were reported by Wahlstrom et al. [7], Mazloum et al. [8] and Jiang et al. [9], in which increased time pressure increased heart rate during computer mouse work. Though the results were as expected, it is also well known that respiration causes a change in HR; during inspiration the HR increases whereas the HR decreases during expiration [10,11]. Consequently, further analysis is needed to be certain that the increase in HR is really associated to the level of time pressure in the task and not to the effects of respiration resulting from any degree of physical activity.

Moreover, in this study contrarily to expected, HRV measures in both the time (SDNN) and frequency-domains (LF, HF, LF/HF) did not show statistically significant differences between both driving conditions (NTP vs. HTP). Although SDNN (often referred to as HRV) was expected to decrease as a result of the higher mental effort investment due to increased time pressure, the outcome was relatively similar for both driving conditions, with only a subtle increase for the HTP condition. In the frequency domain, despite the non-significance of the results, all the measures presented the expected tendency: HF decreased, LF and LF/HF increased. One possible explanation for these results lies in the possibility that the simulated task did not induce a significant level of time pressure that could lead to a mental demand noticeable in this physiological marker. However, the mental demand section of the NASA-TLX questionnaire revealed moderate levels and, thus, does not fully support this explanation.

According to De Waard [12], another possible cause for finding no effect of time pressure/mental load on HRV lies in the global nature of the measure and its sensitivity to physical load. It is clear that changes in mental demands are often accompanied by changes in physical demands in terms of increased muscle activity, e.g. increased pressing of response buttons [13]. Nevertheless, there is a lack of consensus as to the actual effect of physical activity on HRV. While some authors claim that physical load in the form of muscle straining can increase HRV because of induced fluctuations in blood pressure [14,15], others have shown that an increase in physical load also results in a decreased HRV and an increased HR [16-18]. The former could explain the results found (subtle increase in HRV) given that, for this study, the time-pressure driving task resulted in higher movement intensity. This, however, would only be valid if higher movement intensity is comparable to higher muscle straining. These inconsistent findings confront the convenience of HRV measures to directly assess the effects of time pressure in tasks involving both physical and mental effort. Furthermore, it is important to note that most studies reporting a decrease in HRV involve a high workload or effortful mental operations in working memory during the task [19]. De Rivecourt et al. [20], for instance, show a continuing strong increase of heart rate in combination with a decrease of HRV during simulated flight in which workload increased strongly as a function of time-on-task.

In fact, while several studies have shown that relatively large heart rate and variability differences can be found between baseline rest periods and task performance [11,18,19]; studies also report that no significant difference can be observed between different levels of task demand [11,21]. The question remains as to whether HRV measures are sensitive enough to differentiate situations with only low or intermediate levels of mental load/time pressure, such as the ones found in the current study. Mulder [18,22] has further emphasized that it is not task difficulty what triggers a response in HRV but rather the invested effort. Interestingly, during the exploratory analysis, different from what was found for the complete sessions, heart rate variability seemed to be clearly lower for the HTP condition in both types of intersections as well as in overtaking situations both with and without opposing traffic flow. Since intersections and overtaking maneuvers naturally demand additional conscious investment of effort from the driver in order to prevent a collision [23], these results seem to support the fact that invested effort is what actually triggers a response in HRV. During an increased task demand, an individual may decide not to react to or adapt and use a different strategy to meet the demands [19]. Either response would result in no apparent effect in HRV measures or only a minimal reduction in HRV [18]. This could be the reason behind not finding significant results for the complete driving task.

Additionally, in relation to the biological mechanisms within the human body, another possible explanation for the results of the current study arises. Mulder et al. [22] state that depending on the magnitude of task load changes and its duration, the pattern of cardiovascular activity can change: either a clear type of defense reaction can be seen or the baroreflex pattern can dominate. The characteristic initial response to workload is often called a defense response or a preparatory response for fight-or-flight. This initial response is associated with the activation of the sympathetic system, which is related to an increase in HR and blood pressure and a decrease in HRV [18]. Nonetheless, when the required effort level is maintained continuously for more than 5 to 10 minutes, the baroreflex system (short-term blood pressure regulation system which helps to maintain blood pressure at nearly constant levels) starts to counteract the initial effects mentioned above, resulting in a decrease in HR (which could still be neutralized by the effects of increased physical activity) and an increase in HRV [22,24,25]. Hence, the result obtained in HRV measures could be the consequence of the interaction between the defense and baroreflex responses along the duration of the task. As a result, the interpretation of HRV changes in terms of mental effort must be related to the regulation mechanisms mentioned: if only the defense-type reaction is in play, HRV index is very valid for invested mental effort; whereas if compensatory mechanisms (baroreflex responses) are becoming more important, interpretation of HRV is not sufficiently reliable [26].

Similarly, associated to another intrinsic variable, the insensitivity of HRV has also been related to the intrusion of respiratory activity, where respiration can influence the HRV in a direction opposite to the effects of mental effort [11]. This intrusion of respiration on the results of HRV is due to the fact that, in the frequency-domain, activity in the high band (HF) is partly caused by respiration [11]. Angelone and Coulter [27] similarly demonstrated that HRV decreases in the high frequency (HF) band as a result of an increase in the respiration frequency during task performance. Moreover, when main respiratory frequency comes within the mid-frequency band (LF in the present study), a substantial increase in HRV is observed [27].

According to the results obtained in the present study, certainly heart rate seems to provide an index of overall workload (including both physical and mental demand), while heart rate variability could be more useful as an index of cognitive/mental workload [12,28]. The latter only seems to hold true provided that such cognitive/mental load is considerably high, which is definitely not the case for the current study since the mental demand section of the NASA TLX questionnaire revealed only a moderate level.

6.6.2 Effects of time pressure on respiration

Respiration frequency significantly increased during driving under the imposed time-pressure condition. Assuming that time pressure indeed results in some degree of mental effort, the results obtained for the current research are in line with those previously reported by other authors. Respiration is well known to provide valuable information about mental effort. Despite the fact that there is a wide variety between the parameters and methods used by the different studies reported, the results are outstandingly similar. Wientjes [29] demonstrated that the subjects change their respiratory pattern when the task becomes more difficult. Specifically, authors have reported increases in respiration frequency when subjects perform more difficult laboratory tasks [30,31]. Others have further reported that respiration frequency increases under stressful attention conditions [32] and as a result of increased memory load or increased temporal demands [33]. Only under certain circumstances (high mental demand), the act of focusing attention on a task may have an inhibitory effect on breathing resulting in a decrease in respiratory frequency [34].

However, as with other physiological measures, respiration pattern is not exclusively sensitive to mental effort and can also be affected by, for instance, physical activity [29]. An increase in physical activity results in increased respiratory frequency [29]. It is known that the time-pressure driving task resulted in higher movement intensity; thereby an increase in physical activity could have influenced the results of this study to some extent. In other words, the increased respiratory frequency during the HTP condition of this study could be the sum of the effects of both increased physical activity and higher mental effort.

Moreover, in the current study, depth of breath (also known as respiratory amplitude) showed a tendency to increase during the time-pressure condition but the results were not significant. Effortful or stressful mental tasks as well as activities associated with higher levels of cognitive demand or with sustained attention, however, have been associated with shallow breathing or a decrease in depth of breath [35,36]. Since physical activity is known to cause an increase in depth of breath [37,38], it is possible that this could be masking the effects of time-pressure on this particular measure for the current study. Furthermore, an increase in respiration frequency combined with an increase in depth of breathing (result obtained for the current study) seems to be associated with states of excitement/arousal linked to emotions such as anger or anxiety [39]. Monod and Kapitaniak [40] proposed that time pressure leads to highly emotional reactions, more specifically a raise in anxiety, because it involves a conflict between the imposed completion time for a task and the time it actually takes to perform the task. As a result, the increase in depth of breath found for the current study could be explained by the presence of some degree of anxiety or other characteristics of the individual (e.g. coping style or personality) as has been indicated by other authors [39,41,42].

Changes in the breathing pattern timing, as expected, resulted in a significant decrease for Ttot during the time-pressure task. Similar results were reported by Wientjes [43], who found that during mild types of challenge (e.g. neutral audiovisual stimulation, mental arithmetic, memory load, attention-demanding tasks), there is a shortening of the duration of the respiratory phases (Ti, Te and expiratory pause time) or Ttot, thus the increase in respiration frequency. Furthermore, the increase in time pressure for the current study resulted in a significant increase in Ti/Ttot. The latter, known as inspiratory duty cycle, is a dimensionless number reflecting the relationship between Ti and Te changes. An increase in duty cycle is linked to a shift towards greater emphasis on the inspiratory phase of the breathing cycle [44] or, in other words, a lengthening of Ti relative to TE and the pauses after inspiration and expiration. Although duty cycle is influenced by physical and mental load, Veltman and Gaillard [11] showed that mental load has a stronger influence. Similarly, Boiten et al. [38] concluded that inhalation time during difficult mental arithmetic tasks was even shorter than during heavy bicycle exercise tasks, thereby confirming the higher dependency of this parameter to mental demand over physical activity. Further analysis, in fact, revealed that Ti presented a non-significant tendency to decrease.

However, likewise with respiratory frequency and depth of breath, special care must be taken at drawing conclusions from these results. Etzel [41] established that particular patterns of respiration accompanied specific emotions; for instance fear/anxiety correlated with, among others, increased inspiration time relative to expiration time. Recalling that there may be presence of some degree of anxiety or other characteristics of the individual (e.g. coping style or personality), it could be possible that the outcomes observed for the current experiment are related to emotional factors rather than to the effect of time pressure on the driving task. In general, it should be noted that breathing pattern assessment based on the parameters measured might not be sufficient or subtle enough to detect differences between the effects of time pressure and emotional states [39]. Strong similarities exist between the respiratory patterns in cognitively oriented tasks and tasks designed to elicited specific emotions [39].

In summary, the available evidence suggests that physical and mental demands, resulting from increased time pressure, almost invariably produce an identifiable effect on the breathing pattern, but that the nature of such alterations depends strongly on the type and the intensity of the demands. In other words, the relatively shallow breathing pattern that is usually found during states of concentrated attention and that was expected for the current study, can apparently be modified or counteracted by influences related to loss of control or increase in emotional excitement [39], as seems to be the case for this study.

6.6.3 Effects of time pressure on eye activity

The eye activity-related measures calculated in this study included: pupil diameter, blink frequency, horizontal gaze variance and percentage of time looking at road center, dials (speedometer) and clock. A significant increase in pupil diameter was observed during the time-pressure task. This is in accordance with other studies that provide similar results. Kahneman [45] concluded that increased task processing demands and augmented resource investment were reflected in increases in pupil diameter. Likewise, Beatty [46] reports that pupil diameter increases with increases in perceptual, cognitive and response-related processing demands. De Rivecourt [20] also suggests that an increase in pupil diameter could be the result of an increase in mental effort. Palinko [47,48] further implies that pupil diameter can be used as a physiological measure of cognitive load in driving simulator studies. Recalling that time pressure has been related to a higher mental effort investment in the task [6] and that time pressure is considered to be a factor that influences the level of mental workload [49-51], the significant increase in pupil diameter during the time pressure task is well in line with what has been reported previously.

Additionally, the exploratory analysis revealed a further increase in pupil diameter perceptible as the obstacle is approached in both overtaking situations with and without traffic in the opposing lane. Possibly, the increased demand of this particular situation requires a higher resource investment, which then results in the observed increase in pupil diameter. Nevertheless, pupil size is known to depend not only on cognitive load but also on lighting conditions: ambient illumination or screen luminance [20,47,52]. The pupil's primary function is to regulate the amount of light falling on the retina [47]. When there is too much light, the sphincter pupillae muscle group will contract the pupil to reduce influx. When there is not enough light, the pupil will dilate by the activation of the dilator pupillae muscle group. This pupillary light reflex is much larger in magnitude than cognition induced pupil changes [53] and, hence, it is a potentially large confounding effect. As it was not possible to maintain constant visual field luminance across the experimental conditions of the current study (for this task, illumination intensity was a function of the virtual environment and changes with the participant's location in the virtual world), these two effects were separated in order to accurately estimate cognitive load due to time pressure. Even after luminance correction, pupil diameter significantly increased for the current study. In fact, the difference between both cases was rather subtle. This is in line with the results reported by Recarte and Nunes [54], which showed that pupil size was sensitive to increased mental workload induced by secondary cognitive tasks during driving, and this effect could be clearly shown despite the variability due to daylight variations on a natural road environment.

Still, this is not fully conclusive since, in addition to the light reflex and the cognitive load response, the pupil also exhibits small dilations or contractions in response to changes in the color content of a visual stimulus without changing either local or global luminance [55]. Kun-Palinko [48] indicate that even gazing at relatively small targets, such as distant vehicles, can result in pupillary light response that can obscure the task evoked pupillary response. Similarly, pupil dilation in response to mental workload can be biased due to emotional responses or orienting reflex [56]. The exploratory study further seems to reveal another possible source of inaccuracy for this indicator. The apparent decrease in pupil diameter immediately before the intersections under all the studied conditions is most probably the result of a loss in data due to the head rotation required for visual inspection at the intersection. Data loss often occurs for remote mounted eye-trackers when the system is unable to track a participant's facial features, pupil, or corneal reflections due to obstruction of the eye-tracker cameras or large head movements [57,58]. Thus, further research is needed in order to determine whether this measure is indeed a good indicator of a time pressure condition.

In terms of the number of eye blinks, a significant decrease was observed for the complete HTP condition relative to the NTP condition. Though this result has been reported by previous studies, confounding results are often found in literature. While Recarte and Nunes [59] found a blink-rate increase attributable to the time spent driving and an even more marked increase attributable to the performance of cognitive tasks during the drive; several studies report this measure to decrease when the visual demands of the task increase [60,61]. As indicated by Recarte [62], however, the problem lies on the interpretation rather than on the inconsistency between results. These authors suggest that a blink-rate increase can be expected either from fatigue (decreased activation) or from the mental effort of a secondary task (increased activation); and that the strong visual component of the driving task could lead to a general blink inhibition effect as a simple mechanism to reduce the probability of missing relevant information [11,61]. Hence, both mental and visual workloads yield opposed outcomes: increased blink rate for higher mental workload and blink inhibition for high visual demand; and blink frequency is the result of the two additive effects although with different sign (the more mental workload, the more blinks; the more visual demand, the less blinks). Then, since the blink inhibition process needs attentional resources, only when there is an additional cognitive task demanding such resources (which was not the case for the current research) it is possible that there is interference with the blink inhibition process, resulting in increased blink rate.

It is important to mention that of all the sensory modes, visual perception is attributed to be the main source of information during driving because 90% of information that is processed is of visual origin [63]. Yet, for visual perception to be effective, attention is essential [54] and is, therefore, always present in a higher or lower degree depending upon the overall task. Consequently, taking into account that driving normally implies a high visual demand and that there was a significant decrease in blink frequency in this experiment, it seems logical to assume that the imposed time pressure condition resulted in a relatively higher visual load for the current study as compared to the mental load. The exploratory analysis for intersections seems to further confirm this with additional decrease in blink frequency immediately before both intersection types for both the NTP and HTP conditions probably due to the drivers' need to gather all relevant information nearby in order to prevent a collision while crossing the intersection. The question remains as to whether these results will hold for different driving tasks involving, for instance, time pressure in combination with a more mentally demanding activity.

Now, regarding pupil response, its effect, contrarily to blink frequency, reflects the highest of the activation states (visual or mental workload) or perhaps an average value of the brain activation areas associated with the task performance [62]. Thus, pupil response by itself cannot be used to accurately determine if a subject is driving under time pressure. Besides, since blink frequency varies in opposing directions depending on the activation state, the use of either of these two measures as indicators of time pressure is subject to further research.

Moreover, during the time-pressure task, the percentage of time the subjects spent looking at the center of the road increased whereas the percentage of time spent looking at dials (more specifically the speedometer) decreased. Both of these changes, despite having the tendency reported by previous studies, were not significant. Meanwhile, the percentage of time the subjects spent looking at the clock significantly increased during the time-pressure task. Recarte et al. [54,64] similarly reported a marked reduction in inspection frequency of mirrors and speedometer corresponding to higher mental workload. These results can be explained from the perspective of an optimization in visual resource allocation such that when attentional resources required for processing several information sources at once become scarce, the expected strategy is to disregard the less relevant sources [54]. Hence, during the time-pressure condition (for the current experiment) participants increased the priority assigned to the road ahead while they reduced inspection of peripheral areas, which, generally speaking, were not as relevant for safe driving.

High attentional workload is also known to produce attentional focus narrowing, meaning that drivers spend more time looking centrally and less time looking at the periphery [54]. However, since the relevance of central and peripheral areas on a road scene depend on each particular traffic situation and on the drivers' intentions, the horizontal gaze variance and percentage of time looking at road center were calculated again after removing the segments corresponding to the road intersections. This particular sub-task naturally demands an increase in horizontal gaze variance and requires looking to either or both sides, thus masking the real effect of these variables for the general task. Indeed, the exploratory analysis seems to confirm this since horizontal gaze variance increases in both intersection types for both the NTP and HTP conditions. The result, after removing the intersections from the complete session data, was a statistically significant increase for the percentage of time the subjects spent looking at the center of the road, as well as a statistically significant decrease for the horizontal gaze variance. For the current study, the latter result further supports the existence of an attentional focus narrowing during the time-pressure task. The exploratory study also revealed that drivers under HTP condition seem to initiate their visual search as they approach the intersection (both with and without traffic) earlier compared to drivers under NTP condition. This is supported by both an early increase in horizontal gaze variance as well as an early rotation of the head prior to the intersection situations. This is most probably the result of the HTP drivers' need to anticipate for events ahead due to his/her higher vehicle speed. Indeed, the effect appears to be more noticeable at intersections without traffic where many HTP drivers try to avoid a full stop at the intersection.

As a last remark, the statistically significant increase in the percentage of time the subjects spent looking at the clock well corresponds with the abovementioned optimization in visual resource allocation. Indeed, it is reasonable to conclude that the clock becomes a highly relevant tool for the execution of the driving task under a time-pressure condition. Coeugnet et al. [65] reported similar results by showing that, under time pressure, drivers devote greater attentional resources to time monitoring.

In summary, the eye activity measures assessed during the present study seem to be highly task dependent, with the direction of the effect varying according to characteristics of the specific activity. Consequently, although mental workload and visual demand appears to have an effect on such measurements, no single one can be directly interpreted as the result of a particular driver condition such as time pressure.

6.6.4 Effects of time pressure on human interaction

The findings of the current study showed, as predicted, that the time pressure condition indeed results in an overall increase in the subject's kinematic activity. The majority of the assessed measurements related to body-motion significantly increased, including: steering speed, root mean square (RMS) of the acceleration for the right/left foot and for the right hand, mean velocity of the throttle/brake/clutch pedal displacement, RMS of the acceleration for the right foot associated with both the operation of the brake and throttle pedals, RMS of the acceleration for the right foot associated with the motion from the throttle to the brake pedal, RMS of the acceleration for the left foot associated with the operation of the clutch pedal, RMS of the acceleration for the right hand associated with the operation of the gear stick. There was also a noticeable increase in the RMS of the acceleration for the left hand, though the result was not statistically significant.

On the one hand, a possible explanation for the latter result is that the movements of the left hand are mostly associated with steering and for the current task the number of steering maneuvers was rather limited related to the complete session. Indeed, the exploratory study for the overtaking situation (both with and without traffic on the opposing lane) shows a clearly higher value of the acceleration for the left hand for drivers under the HTP condition relative to those under the NTP condition. The results associated to an increase in the measurements related to body-motion, on the other hand, provide further support for findings from previous studies [7,8,66] which concluded that time pressure in computer-related tasks resulted in higher mean velocity of the wrist movements or higher speed in typing. In the field of driving, Khaisongkram [67] found that hurry conditions present fast brake pedal operation during the braking tasks and higher maximum acceleration in each pedal operation during going states.

Actually, the outcomes related to body-motion in our study correspond to the acceleration of actions which prior literature suggests as the first coping mechanism used by most individuals under a time pressure condition [68]. The results obtained possibly indicate that drivers were motivated to complete the given assignment while maintaining a preferred level of task difficulty and hence, under the time pressure condition, speed choice was indeed the primary solution to the problem of keeping task difficulty within their selected boundaries.

A significant decrease in the mean time between switching from the throttle to the brake pedal and from the brake to the throttle pedal was also found during the time pressure condition. This, again, is in line with the abovementioned acceleration of actions. It also coincides with the results by Raksincharoen et al. [69] who report a decrease in pedal switching time from brake to accelerator pedal in hurry driving relative to the case of the normal driving.

Furthermore, the RMS of jerk for the right/left foot and for the right hand significantly increased during the time pressure condition. The RMS of jerk for the left hand also increased but the result was not significant. These increases in the rate of change of acceleration for the limbs can be associated with an increase in limb and body stiffness corresponding to the general stress coping mechanism of the motor system suggested by Van Gemmert and Van Galen [70]. Recalling that time pressure leads to anxiety due to the fact that, by definition, the imposition of a deadline would always be expected to place an extra demand [40,71], indeed anxiety's impact on performance has been explained based on the idea of "freezing degrees of freedom" [72]. Studying degrees of freedom of the human body contributes to understanding how the body controls the numerous separate and independent body joints to produce coordinated motion. Early learning is characterized by attempts to "freeze" inessential degrees of freedom in order to reduce task complexity and, hence, motor movements appear rigid, uncoordinated, and stiff [73]. Then, as skill develops through practice, novices start to release previously frozen degrees of freedom, ultimately resulting in smoother, faster, and more fluent motor performance. Under pressure, however, Bernstein suggested that skilled performers often try to "re-freeze" degrees of freedom in an effort to reduce task complexity [74]. This subsequent return to novice-like "freezing" strategies yields motor movements with motions that are rigid and jerky. Consequently, the jerkier motion observed during the time pressure condition for the current experiment could probably be the result of muscle stiffness as coping mechanism to reach the final goal. Additional biomechanical measures, such as limb stiffness or limb motion trajectory, could reveal interesting information related to how the human motor system adapts to and compensates for more stressful task conditions.

Moreover, in terms of pedal displacement, all measurements evaluated showed a significant increase for the time pressure condition. These measurements were: the variance during brake and throttle pedal operation, the mean position of the brake/throttle pedals, the maximum position of the brake/throttle pedals and the frequency of pressing the throttle pedal in more than 25% and 70% of the full pedal stroke. These results suggest an increase in the intensity of the movements and, thus, probably an increase in muscle activity. Several previous studies have reported an increase in electromyographic (EMG) activity when high time pressure was imposed on computer-related tasks [7,75,76]. Maule et al. [71] likewise found that time-pressured participants were more anxious and more energetic. Remarkably, however, the exploratory analysis revealed an opposite result during the car following situation: a lower mean position of the throttle pedal for the HTP condition relative to the NTP condition.

This result does not rule out the suggested increase in the intensity of the movements since the magnitude of the acceleration for the limbs remains evidently higher for the HTP condition. Then, a possible explanation for this outcome is that drivers under time pressure press the pedal farther than under no time pressure, yet they also fully (or somewhat fully) release the pedal more often. In other words, rather than holding the pedal at a relatively steady position, drivers under time pressure press and release the pedal up to higher and lower positions. Thus, the average of these extreme values results in a lower mean throttle position. This was further confirmed by the fact that drivers under HTP condition appear to be more prone to use the brake pedal during car following situations and clearly appear to press the brake farther than those under NTP condition. Also, the variance during throttle pedal operation and the maximum throttle pedal displacement per operation seem to be higher for the HTP condition relative to the NTP condition.

Moreover, the exploratory analysis showed some interesting tendencies related to the brake and throttle pedal displacement at intersections. The brake pedal displacement for the NTP condition at intersections without traffic closely resembles that of intersections with traffic. Differently, the brake pedal displacement for the HTP condition is lower for intersections without traffic as compared to those with traffic in which drivers are highly inclined to fully press the brake pedal. Additionally, drivers under time pressure tend to start pressing the brake pedal considerably earlier before intersections with traffic relative to intersections without traffic. Similarly, they tend to start pressing the brake pedal earlier than drivers under no time pressure at intersections with traffic. At intersections without traffic, however, drivers under time pressure tend to start pressing the brake pedal later than drivers under no time pressure. These tendencies are probably the result of the increased vehicle speed associated to the first coping mechanism stated before for drivers under the HTP condition. Indeed, when drivers approach an intersection at a higher speed, it is rather expectable that they start executing the deceleration actions prior to those who approach the situation a lower speed since a moving object at a higher speed requires a longer distance to stop. It is also expectable that the brake pedal displacement is larger for such HTP drivers.

Furthermore, the difference in behavior observed between the two types of intersection is likely to be associated with intention of drivers under the HTP condition to avoid a full stop at intersections without traffic. Drivers under this condition actually are more prone to reduce their speed only immediately before entering the box junction rather than to fully stop or considerably diminish their speed before the crosswalk. In terms of the maximum throttle pedal displacement per operation, drivers under the HTP condition seem to press the throttle farther than those under NTP condition at both types of intersections. The interesting result, however, is that the probability of pressing the throttle pedal beyond 80% is almost exclusively for drivers under the HTP condition relative to those under NTP condition. This is valid for both types of intersection and, since it is also observed for cruising and overtaking situations (both with and without traffic on the opposing lane), is therefore a promising indicator for the purpose of this study.

The probability distributions corresponding to different individual participants further revealed interesting results towards the definition of indicators that can differentiate a HTP driver from a NTP driver. The observed results certainly seem to prove that indicators such as maximum throttle/brake pedal displacement per operation, as well as force exerted on the steering wheel, show, at least for some participants, a clear separation between the two conditions. Although the current experimental setup did not provide enough information to fully study this kind of results, the outcomes do support the idea that indicators need to be further studied within individual drivers rather than for combined groups of people. Most probably, the impossibility of finding similar and absolute driving behaviors observable among all drivers leads to masking of effects when all results are studied together. This masking is easily observable in the probability distributions for the force exerted on the steering wheel, where the combined data for all participants often does not show a clear separation between the two driving conditions. When further analyzed for individual participants, however, a sharp division between conditions is often found, yet with opposing tendencies: while some drivers under the HTP condition exert more force on the steering wheel relative to their NTP condition, the contrary is true for other drivers. Thus, when combined, the two results average between each other and no single tendency is evident.

Similarly, even when the same tendency is present between participants, the range of values for particular indicators varies considerably from driver to driver. Hence, merging data for two participants often results in averaged results that eliminate the separation between distributions. Furthermore, not only the within and between driver variability affects the interpretation of results, but driving situations (e.g. car following, overtaking with and without traffic on the opposing lane, intersections with and without traffic and cruising) also reveal different effects in terms of separation between distributions. In other words, an indicator that could eventually be used to recognize drivers under HTP during car following situations (e.g. maximum brake pedal displacement per operation) would probably be useless for situations such as overtaking or cruising. These findings are in compliance with the complexity of driving patterns found by Ericsson [77]. According to this author, driving pattern is a complex phenomenon that may vary strongly and is influenced by several variables as the driver, the street environment, the traffic flow and the car type, and the driving patterns. Then, since different drivers have different driving styles that cause variation in driving patterns and since different influencing factors might interact with each other forming a more complicated pattern of causes and effects, further research is needed to better understand driver variability and its implications on the identification of drivers under a time pressure condition.

Moreover, in line with the increased intensity of operations mentioned earlier, yet contrarily to expected, the number of operations for the clutch pedal and for the gear stick decreased during the time pressure condition of the current study. While only the latter decrease was statistically significant, these results dissent from previous studies which have proved that high time pressure causes an increase in the number of mouse clicks, for instance, during computer interaction tasks [76]. Meanwhile, the number of throttle and brake pedal operations does match those results since they both increased during the time pressure task. Only the increase in the number of brake pedal operations was statistically significant. A possible explanation for these results is that the frequency of operations indeed increases as time pressure increases but only for those tasks in which productivity is enhanced by such action. For example, during a typing-related task, more keystrokes in less time undeniably result in increased typing speed, thus contributing to higher efficiency towards reaching the final goal within the given time.

During driving, however, subjects seem to believe that this is not the case (the number of operations does not contribute to reaching the goal in less time) and rather may be trying to optimize the use of resources following the theory proposed initially by Miller [78], and reformulated by several other authors [68], who listed a number of strategies for coping with time pressure and information overload. The most frequently used are filtering (processing some parts of the information more, and others less), acceleration, and omission (ignore particular parts of the task). In this order of ideas, simultaneously to accelerating actions and filtering irrelevant information by narrow focusing (which was previously discussed for the eye-related measures), drivers could be omitting or limiting the use of those vehicle controls that are not essential for the completion of the task. Accordingly, the number of operations for the clutch pedal and for the gear stick shows a tendency to decrease, whereas the number of brake/throttle pedals operations, which are actually fundamental for safe driving while moving at higher speed, does increase.

Finally, the mean steering force was found to increase for the current study, yet not significantly. Similarly, Gerard et al. [75] concluded that time pressure increases key strike force and Hughes et al. [66] found that additional time pressure and mental workload may result in typists exerting even more unnecessary force. Jaskowski et al. [79] also reported that time-pressure enhances general arousal, leading to increased response force. The results for the current study were not significant probably as a result of the high variability between drivers. In relation with steering indicators, during the exploratory analysis, the steering angle was found to have a distinguishable pattern between the two types of overtaking situations (with and without traffic on the opposing lane), being shallower for overtaking situations without traffic. However, it does not seem to present clear differences between HTP condition and NTP condition for either situation. This result is thus probably more useful for identifying situations rather than for establishing a driver condition.

From all the above, it can be seen that time pressure, and perhaps the mental load associated with it, influences human kinematics (the motion of the body) and kinetics (the forces and moments that the human body exerts) in a particularly and identifiable way. Still, however, similar influences may result from other physically demanding activities within the vehicle (e.g. picking up the cell phone or having a discussion with a passenger) and, thus, further research is needed before most of these measures can be used for detecting a time pressure condition in car driving. Also, while brief periods of increased workload are known to make people feel more energetic [80], it has also been proved that situations involving long periods of continuous time-pressured decision making may actually lead to increased fatigue (reduced energy) [71].As a result, the interpretation of some of these results needs to be handled with care for long-term tasks.

6.6.5 Effects of time pressure on driving performance

In general, the effects of time pressure on driving performance were as expected and reflected the results revealed during the focus group studies reported in Chapter 3. Performance metrics related to longitudinal control, including mean engine RPM, as well as mean and maximum speed and acceleration, significantly increased during the increased time pressure task for the complete session. During the exploratory study, the mean vehicle speed for the car following situation, contrarily to what was found for the complete session, was found to be lower for the HTP condition relative to the NTP condition. A possible explanation for this outcome lies in the fact that drivers under the HTP condition do not seem to maintain a regular speed somewhat close to that of the leading vehicle but they rather decrease their speed below that of the vehicle ahead, thus allowing for the leading vehicle to increase its headway distance. This situation is then followed by an increase of speed above that of the leading vehicle until the distance between the two vehicles is reduced again and the cycle starts over. The average of this variation in speed is possibly what leads to a lower mean vehicle speed.

The maximum vehicle speed in car-following situations, however, still increases for drivers under the HTP condition. These results most possibly correspond to the acceleration of actions expected as the first coping mechanism used by most individuals under a time pressure condition [68]. Drivers were motivated to complete the given assignment and consequently, under the time pressure condition, an increase in vehicle speed and acceleration was the primary solution to the problem of reaching the goal in less time while keeping task difficulty within their selected boundaries. Similarly, Khaisongkram et al. [67] found that vehicle speed, and longitudinal acceleration were most indicative of a hurried driving behavior during a car following, braking, cruising, decelerating, and a stopping task. Coegnet et al. [81] also found that time pressure promotes fast driving. Van der Hulst et al. [82] further concluded that time pressure causes a motivational pressure to maintain high speed and short safety margins.

Correspondingly, the current experiment also resulted in a statistically significant decrease in safety-related metrics including the minimum car following time during the time pressure condition. These results suggest, as was also found by other authors [65,83], that externally imposed time pressure overrules other goals in driving and induces an increased level of risk in the driving strategy. This risk-taking compensatory behavior leads to speed-accuracy trade-offs, an outcome stated by Wickens and Hollands [84]. The observed increases in the standard deviation of lane lateral position, accordingly, indicated that under time pressure drivers indeed exhibited more corrections in lane position due to increased speeds. Note that, for the complete session, the time pressure condition resulted in a statistically significant decrease in the standard deviation of lane lateral position.

However, after removing the overtaking situations (which inherently require an intentional deviation from the lane), the result was the already mentioned increase in the standard deviation of lane lateral position. Lateral deviation, which indicates degraded vehicle control as it increases, has been reported previously to be a sensitive performance measure [85-87]; increasing for hurried drivers who tend to make more corrections due to higher speeds [88]. Furthermore, an increase in visual demand has also been associated to increased lane keeping variation [89]. Since there is a clear and direct relationship between the speed at which a driver is traveling and the visual demand of the driving situation [90,91], it plausible to assume that the time pressure condition for the current experiment resulted in an increase in the visual demand of the task and thus, in an increase in the variability in lane position associated to it.

While no driver maintains the vehicle perfectly at a selected lateral position in the lane, the mean lateral position for the current experiment differed between the no time pressure and time pressure conditions. During the latter, drivers were significantly located more towards the left hand side of the lane, whereas during the former condition drivers were more located towards the right hand side of the lane. This effect was particularly evident for the car following situation analyzed during the exploratory study. Thus, illustrating the drivers' willingness to decrease their safety margin as a strategic shift to reach the goal within the given time. Drivers seem to believe that assuming a riskier behavior by driving closer to the border of the counter lane allows them to reach their destination faster, perhaps by allowing them to anticipate events and react in advance. This also explains why during cruising situations, according to the exploratory results, lateral position is nearly the same for both driving conditions: drivers are only moving forward on a freeway with no obstacle ahead and, hence, no situation to react to.

Another interesting result in terms of lateral position for overtaking situations was also found during the exploratory study. When traffic was present on the opposing lane, the HTP drivers seemed to initiate their overtaking maneuver later compared to the NTP drivers. In contrast, when no traffic was present in the opposing lane, the HTP drivers initiated the overtake maneuver earlier compared to the NTP drivers. This result further supports the idea that drivers under time pressure react earlier than drivers under no time pressure whenever possible, as certainly happens when no traffic is present on the opposing lane. Else, when traffic on the opposing lane prevents them from overtaking the obstacle, drivers under the HTP condition seem to adopt a considerably shorter following distance until they can finally execute the overtaking maneuver, thus initiating the movement later compared to the NTP drivers.

The abovementioned results imply that performance metrics related to both longitudinal and lateral vehicle control are candidate measures for identifying driving under time pressure. Still, however, further research is needed because their response could easily be found for several other situations with increased visual demand or a different source of stress. Additionally, despite the fact that vehicle acceleration has been found to be a promising indicator for driving under time pressure, the exploratory study further revealed that acceleration/deceleration analyzed for a complete driving task often fails to provide clear differences between drivers under HTP condition relative to drivers under NTP condition. This is due to the fact that a high value of acceleration cannot be defined without linking it to the speed at that particular moment. The vehicle acceleration is less as speed increases because it takes longer to get a change in speed. For example, assuming that the gas pedal is pressed to its maximum position, it takes less time to change the vehicle's speed from 10-20km/h than it is to change it from 100 to 110km/h. Thus, the use of distribution histograms of vehicle acceleration/deceleration per throttle/brake pedal filtered by vehicle velocity bands seems to be promising for identifying the state of driving under time pressure. More research is needed to establish the real potential of this finding.

The probability distributions corresponding to different individual participants further revealed interesting results towards the definition of indicators that can differ an HTP driver from an NTP driver. The observed results certainly seem to prove that indicators such as engine speed, time headway, vehicle speed/acceleration and vehicle acceleration per throttle pedal operation per velocity bands, show, at least for some participants, a clear separation between the two conditions.

6.6.6 Correlation among measurements

The correlation matrix showed remarkable significant correlations between driving styles (i.e. reckless and careless, angry and hostile, patient and careful and anxious) and physiological/driving performance measures; as well as correlations between subjective (i.e. NASA-TLX) and physiological measures of workload. The result in terms of driving styles provides evidence regarding the variability between drivers and its possible impact on physiological/driving performance measures discussed previously. Moreover, on one hand, the correlations between variables seem logical since, as could be rationally expected, the reckless and careless driving style and the angry and hostile driving style positively correlated with one another, whereas the patient and careful driving style negatively correlated with the first two styles. On the other hand, the particular correlations found between driving styles and performance metrics well represent what could be generally expected from each type of driver. Reckless and careless driving style, for instance, correlated with speed, steering speed, DBQ errors and violations.

Jonah [92] provides a comprehensive review in which similar results, especially in terms of speeding, errors and violations, can be found. Also, correspondingly, Taubman et al. [93] defined this type of driver as the driver seeking for stimulation, sensation, and with a tendency to take risky driving decisions and engage in high velocity driving. The angry and hostile driving style, defined as a driver that has a tendency to behave aggressively [93], correlated with speed, RMS acceleration of the right hand and DBQ violations and errors. Patient and careful driving style, corresponding to a driver who has the tendency to be polite towards other drivers and to drive carefully [93], inversely correlated with steering force and DBQ violations. Anxious driving style, related to a driver who displays signs of fear in given driving situations, express doubts and lack of driving confidence and has a tendency to commit driving errors due to being easily distracted [93], correlated with errors.

Moreover, the correlation of the subjective workload (NASA-TLX) with the subjective experience of time pressure and the perceived need of driving fast, as well as the correlation of the subjective feeling of a need to hurry up with the subjective feeling of time pressure, further confirmed that some level of time pressure was indeed induced on the participants. Increased heart rate and subjective NASA-TLX reports were correlated to increased pupil diameter. While the correlation between the NASA-TLX and pupil diameter was only moderate, it does provide evidence of a physiological response worth exploring further. The lack of a stronger correlation could be affected, for instance and as has been discussed in a previous section, by the differences in luminance and pupillary response resulting from the driving task itself. Gable et al. [94] have reported similar results. Recalling from Sections 6.6.1 and 6.6.3, both heart rate and pupil diameter increase as a response to workload (visual and cognitive demand) and, hence, it is expected that positive correlation exists between them when workload, as confirmed with the NASA-TLX questionnaire, is present. The correlation of heart rate with the RMS acceleration of the right hand and foot is also an expected result associated to the natural response of the heart to an increase in physical activity.

6.7 Validity of the driving simulator

Considerable evidence indicates that driving-simulator measures are predictive for on-the-road driving performance [95]. Yet, disadvantages of simulation also exist and depend on the equipment and the problem under study. One of the most common disadvantages to using simulation is simulator sickness [96]. Our simulator did not provide some types of visual information, such as stereopsis, glare, and accommodation distance, nor did it support vestibular motion feedback. The lack of these features increases the risk of drivers to develop simulator sickness symptoms, which may also negatively affect the use of simulators. Nonetheless, research shows that this issue is less of a problem for young drivers [97] and that it can be reduced by using limited horizontal field of view, avoiding sharp curves or stops during driving, and by using short sessions (≤10 min) with sufficient rest breaks [95]. During the current study, these characteristics were taken into account for the design of the experiment and only two participants reported symptoms of simulator sickness and were consequently removed from the analysis. Furthermore, particularly the lack of support for vestibular motion feedback could have led to an erroneous perception of motion and, hence, could have resulted in faster driving in the simulator relative to what could be expected in real life. Research by other authors similarly indicates that the speed is greater, that the variability in lateral position is larger, and that the mental effort required to perform a secondary task is larger in the simulator compared to real-world performance [98,99]. This increase in speed is true for both of the driving sessions for the current experiment and, therefore, any tendency in the experimental data would still be observable in the real environment.

Additionally to the limitations mentioned above, the validity of simulators is sometimes questioned because, by definition, driving simulators provide only a representation of reality, not reality itself [100]. Validity, however, goes beyond appearance. It typically refers to the degree to which behavior in a simulator corresponds to behavior in real-world environments under the same conditions [101]. Only eventually validity is, as stated before, affected by the level of fidelity which is indeed related to the physical correspondence of components, layout, and dynamics with those experienced in a real setting [96]. For validity, two types can be distinguished, (i) absolute and (ii) relative validity. The former refers to the degree to which a simulator generates the same numerical values of driving performance that are observed in the real world. On the other hand, the latter refers to the degree to which any changes in those measures of driving performance are in the same direction as those in the real world. In this particular study, the simulator's relative validity is of greatest interest because the goal was to identify tendencies and visualize relations between variables under two driving conditions (e.g., acceleration reduction), rather than to establish specific numerical values for such variables (e.g., amount of acceleration reduction). According to Young et al. [102], the best method for determining the validity of a simulator is to compare driving performance in the simulator to driving performance in real vehicles under the same driving tasks.

Driving under time pressure is known to lead to deterioration in driving performance and an increase in crash risk [103] and, thus, validation against the real environment was not performed. Still, driving simulators have proved to be excellent instruments in studies where relative comparisons are important [100]. Godley et al. [104], for instance, found that participants reacted to the rumble strips, in relation to their deceleration pattern on the control road, in very similar ways in both the instrumented car and simulator experiments, establishing the relative validity. However, participants generally drove faster in the instrumented car than the simulator, resulting in absolute validity not being established. Several other studies have investigated speed, as well as other situations including intersections, tunnels, reaction times, braking behavior, steering wheel movements and driving errors, and typically conclude that simulators are not perfect substitutes for the on-road setting, but that people's behavior is similar in simulators and on the-road. In other words, despite failing to meet requirements for absolute validity, the majority of the studied measures show relative validity [105].

6.8 Limitations of the study

The present study only investigated the consequences of time pressure on longitudinal driving on a two-lane urban road and sunny weather. The effects of road curves, roundabouts, intersections with turns, hills, larger number of lanes, rural road, highway, traffic congestion, or any other traffic or weather situation could result in different findings. The study was also executed with young and healthy individuals and, therefore, generalization of the present results to the entire driver population should be done only with careful consideration. Driver personality traits should also be further explored to better identify determining factors for time pressure in driving, including time constraints, uncertainty and goal importance for each individual. The type of vehicles used during the experiment was limited to a small family car and, during the car following situations, the leading vehicle speed was not variable.

Results for truck drivers following a motorcycle with variable speed, for instance, could be considerably different. In our study, the driving task lasted for less than 12 minutes. It is not clear whether the results would be the same for continuous long-term driving or if this time lapse could perhaps be a short time of exposure to a stressor. Apart from effects that may accumulate over time, physiological processes may change during prolonged exposure to the same task. Since the order of the HTP and NTP conditions was not randomized due to the use of adaptive time constraints, the physiological differences between the sessions might not be related to the exposure to the experimental stressors. However, participants were given a break between the sessions to ensure that the physiological signals returned to baseline. Though the learnability effect was not controlled, participants of this study did not seem to enhance their driving performance. Studies conducted in a laboratory setting have the advantage that the experimental conditions are carefully controlled. Yet, it is also a limitation that the absolute validity is not guaranteed per se and, thus, generalization of the results must be cautiously studied.

6.9 Conclusions

In this chapter, the reduced set of detectable behavioral indicators were analyzed and evaluated through the execution of an experiment using a driving simulator and a custom sensing system specifically devised for the assessment of the required data. The main aim of the present study was to identify detectable effects of time pressure on the physiological activity, driver interaction with the controls of the vehicle and driving performance during longitudinal driving.

Most physiological measures were found to respond differently to an increase in time pressure. Specifically, heart rate, respiratory frequency, duty cycle, blink frequency and pupil diameter, have a discriminatory power that could eventually be used to identify HTP drivers from NTP drivers. These measures have been related to the higher mental effort investment resulting from the driver's perceived lack of time to complete the task. In addition to mental demand, pupil diameter and blink frequency have also been related to the visual demand which is inherent to the driving task and increases as a result of some of the effects of time pressure (e.g. speed). However, further research is needed before any of these measures can actually be used for detection purposes. On one hand, these measures seem to be affected by specific driving situations (e.g. overtaking, car following, etc.). This means that no single value can be used as a threshold between NTP and HTP conditions, but rather different values should be used depending upon the situation. On the other hand, physiological measures highly depend on individuals and, therefore, vary considerably from person to person and even within the same person.

Additionally, the response of most of these measurements with respect to time pressure may be masked by external factors. Physical load, for example, affects heart rate and respiratory activity. Respiratory activity, in turn, influences heart rate. Environmental light conditions can result in a potential confounding effect with regards to pupil dilation, a sign of both a decrease in lightening conditions and an increase in visual and mental demand. Finally, concerning blink frequency, special care must be taken because its response, contrarily to what happens to pupil diameter, may vary in opposing directions depending on the activation state (visual or mental demand). In a driving task, visual and mental demands are always present to a higher or lower degree depending on the situation and level of time pressure. Indeed it could be possible that no effect was observable on HRV for the current study due to moderate level of time pressure that was induced. As a result, considering that the effects observed in the physiological measures highly depend on the level of visual and mental demand, the use of these measures is subject to further research in order to fully understand their behavior relative to all possible driving situations.

Some interaction related measurements in terms of the subject's kinematic and kinetic activity also show distinguishable differences between HTP and NTP conditions. However, these differences were mainly noticeable when analyzed per individual participant and were rarely observable for the combined data set of all participants. The majority of the assessed measurements related to body-motion significantly increased during HTP condition, including: speed in the operation of the controls of the vehicle and acceleration of the limbs associated to these operations. Moreover, the pedal displacement was clearly distinguishable between HTP and NTP drivers. Drivers under HTP condition press the throttle pedal farther than those under NTP condition. This observed result was even clearer when the analysis was done in an individual basis. The above outcome supports the idea that indicators should be studied within individual drivers rather than for combined groups of people. The impossibility of finding distinguishable results for some of the measurements such as force exerted on the steering wheel lies in the fact that the opposite behavior observable among all drivers leads to masking of effects when all results are studied together.

Similarly, even when the same tendency is present between participants, the range of values for particular indicators varies considerably from driver to driver. Hence, their combination often averages results, eliminating the separation between distributions as it was the case for the speed operation of the vehicle controls. Furthermore, not only the within and between driver variability affects the interpretation of results, but driving situations (e.g. car following, overtaking with and without traffic on the opposing lane, intersections with and without traffic and cruising) also reveal different effects in terms of separation between distributions. Then, since different drivers have different driving styles that cause variation in driving patterns and since different influencing factors might interact with each other, further research is needed to better understand driver variability and its implications on the identification of drivers under a time pressure condition. Moreover, the tendencies found in the number of operations for the controls of the vehicle were different from what was expected: instead of increasing, they often decreased. This result seems logical considering that the frequency of operations increases as time pressure increases but only for those tasks in which productivity is enhanced by such action. In this order of ideas, drivers could be omitting or limiting the use of those vehicle controls that are not essential for the completion of the task. Still, however, similar influences may result from other physically demanding activities within the vehicle (e.g. picking up the cell phone or having a discussion with a passenger) and, thus, further research is needed before most of these measures can be used for detecting a time pressure condition in car driving.

In terms of performance-related metrics, the effects of time pressure were generally as expected. The response of mean engine RPM, as well as vehicle mean and maximum speed and acceleration, most possibly correspond to the acceleration of actions expected as the first coping mechanism used by most individuals under a time pressure condition. The results observed in terms of the minimum car following time and lateral positions of the vehicle also correspond to the fact that externally imposed time pressure overrules other goals in driving and induces an increased level of risk in the driving strategy. This risk-taking compensatory behavior, in turn, leads to speed-accuracy trade-offs, observable in the standard deviation of lane lateral position. Again, though a difference between the two conditions exists, the combined results for all participants often do not reveal separable distributions between the HTP and the NTP conditions. The results studied per participant and per driving situation, as was already mentioned in the previous paragraph, provide differentiable results between the two driving conditions.

Specifically, the findings of this study suggest that indicators such as engine speed, time headway, vehicle speed/acceleration and vehicle acceleration per throttle pedal operation per velocity bands, show, at least for some participants, a clear separation between the two conditions. These means that performance metrics related to both longitudinal and lateral vehicle control are candidate measures for identifying driving under time pressure. Still, however, further research is needed because their response could easily be found for several other situations with increased visual demand or a different source of stress. Furthermore, a high value of acceleration cannot be defined without linking it to the speed at that particular moment. Thus, the use of probability distributions for vehicle acceleration/deceleration per throttle/brake pedal filtered by vehicle velocity bands are promising for identifying the state of driving under time pressure. More research is needed to establish the real potential of this finding.

Additionally, contrarily to our belief, there is no single indicator that is fully independent from the driving context and fully insensitive to the differences among drivers. Besides, we could not find sufficient evidence suggesting that indicators closer to the source (i.e., the driver) were enough and the best for identifying driving in haste. Most probably the combination of indicators from different domains would result in a better recognition of this risky state and hence should be further explored.

6.10 References

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Chapter 7

Conclusions, propositions, reflections, and future research

7.1 General conclusions

The ever-increasing usage of cars and occurrence of complex driving situations have led to a dramatic increase of the total number of accidents with injuries and fatalities. Traffic accidents are seen as serious social and technological problems with a global dimension. It is known from the literature that non-regular psychological and physiological states of drivers, such as being in haste, may result in risky driver behavior. Recognizing this state would allow for taking countermeasures and, thus, could contribute to the prevention of a considerable number of traffic accidents around the world. Consequently, the global objective of this PhD research has been to identify indicators of sufficient discriminative power in terms of recognition of driving in haste, which could eventually be used in the development of algorithms for detecting this risky state in real-life driving situations and conditions. With this objective in mind, this promotion research project has been decomposed into four subsequent and interrelated research cycles.

In the first research cycle, our aim was to explore and aggregate general observable manifestations of driving in haste based on the study of the related professional and scientific literature. Information and data about manifestations (symptoms) of driving in haste were aggregated by means of various structured lists of keywords and cited references. The data carried by the written text were interpreted, coded and assumptions were made in an inductive way. Finally, the occurrence frequencies of the findings were recorded and investigated. Each manifestation found was associated to one of four source domains, including (i) the physiological status of the driver, (ii) the interaction of the driver with the car, (iii) the behavior of the car, and (iv) the overall driving performance (car-environment interaction).

Relative to the physiological status of the driver, the studied papers reported on various manifestations of the phenomenon such as: (i) changes in cardiovascular activities (heart rate, blood pressure), (ii) variations in the respiratory activity (respiration frequency), (iii) variations in other body reactions (muscle tension, skin temperature) (iv) changes in electric conductivity (sweating), as well as (v) performing overt behaviors such as rude gestures, swearing and yelling, and (vi) showing unusual facial expressions (frowning). In terms of the interaction of the driver with the car, these manifestations were related to: (i) the intensity of operating the functional controls of the car (for instance, force on the gearstick, push on the brake, throttle, and/or clutch pedals, (ii) the movements applied on the steering wheel, (iii) the amount of force exerted on the steering wheel, and (iv) the velocity of switching the pedals. In addition, (v) excessive operation of warning-related controls (such as horn honking and flashing headlights) was also mentioned in some studies. Concerning the domain of behavior of the car, among the reported observable manifestations were: (i) motion velocity profile of the car, and (ii) acceleration and deceleration profile of the car. Finally, the observable manifestations related to the overall driving performance included various risky behaviors such as: (i) running yellow/red lights, (ii) disobeying traffic road signs and warning signals, (iii) tailgating, (iv) overtaking dangerously, and (v) cutting others off in a lane. Additionally, (vi) failing to yield to pedestrians, and (vii) frequently changing lanes were also reported in the literature.

During the second research cycle, these observable manifestations gathered from the literature review were further countered and/or complemented with manifestations derived from professional drivers and experts in the fields of driving, behavioral psychology and human medicine obtained in focus group studies. While some of the statements mentioned by the groups indeed corresponded to statements found in the literature, others were only verified by some experts. Thus, a correspondence analysis was used to make visible how much and what kind of bodies of knowledge actually underpinned the aggregated knowledge. In other words, the frequency of mentioning manifestations was used to establish the relevance of the statement towards describing the phenomenon of driving in haste. Since it was initially believed that indicators closer to the source would be best and enough for identifying driving in haste, high correspondence manifestations were set as the most promising ones. These included: heart rate, blood pressure (cardiovascular activity), gaze variance (visual behavior), skin temperature/conductivity, respiratory frequency, intensity of body movements and intensity in the operation of the car controls. However, the congruency and correspondence analyses provided considerably high indices for some observable manifestations in the car behavior and car-environment interaction domains and thus, measuring them was not radically discarded.

In the third research cycle, due to the fact that haste resulting from different stressors (e.g. physiological urges, time constraint, etc.) could end in different observable manifestations, the phenomenon of driving in haste was further reduced to the phenomenon of driving in haste due to a temporal constraint, also referred to as time pressure. Subsequently, based on findings from previous literature, an experimental study with a small subject sample was conducted in order to determine a reliable motivation and level of time manipulation for inducing the feeling of being in haste in a driving simulator study. It was found that any of the motivation strategies used, be it imagining a fictitious scenario, competing or rewarding, would equally result in a detectable form and level of feeling haste in all the participants. Indeed, the driving simulator, which is new to most participants, seems to be by itself an effective stimulus to perform well and, hence, designing an experiment that engages subject's attention and curiosity (i.e. intrinsic motivation) together with a time constraint for completing a task ought to be enough to ensure a detectable level of hurriedness on the driver. This small study, despite not having statistical significance, provides evidence about the successful induction of haste that the few previous empirical studies in this research area could not provide.

The fourth research cycle aimed at achieving final establishment and assessment of the set of detectable behavioral indicators for the state of driving in haste resulting from a time constraint imposed on the driving task. In order to clarify important concepts and definitions for the current study, a framework that describes the processes and mechanisms associated with human performance under haste due to a time constraint was constructed based on some previously proposed transactional models of stress. Then, based on literature specific to time pressure and its effects on human behavior, physiology and body dynamics, the observable manifestations found as a result of the previous research cycles (mainly in the physiological and interaction domains) were reduced only to those that could originate from a time constraint. Indicators associated to the driving performance domain, derived from focus groups studies and the previous literature review on haste, were included on the list of possible indicators due to the fact that existing solutions for driver state recognition are often primarily based on these indicators. A set of hypotheses in terms of expected tendencies resulting from driving under time pressure was also derived based on the questionnaires and focus group studies (qualitative research techniques) reported in the second research cycle. Finally, the discriminative power of this reduced set of indicators was analyzed and evaluated through the execution of a full-scale experiment using a driving simulator and a custom sensing system specifically devised for the assessment of the required data. Prior to the execution of the full-scale experiment, nonetheless, a pilot study was carried out to refine the experimental design. Detectable effects of time pressure were recognized on physiological activity, driver interaction with the controls of the vehicle and driving performance.

Most physiological measures were found to clearly respond to an increase in time pressure. Particularly, heart rate, respiratory frequency, duty cycle, blink frequency and pupil diameter, proved to have a discriminatory power that could eventually be used to identify HTP drivers from NTP drivers. These measures, however, seem to be affected by specific driving situations (e.g., overtaking, car following, etc.), as well as to external factors (e.g. physical load affects heart rate and respiratory activity, environmental lightning conditions confounding effects regarding pupil dilation, etc.), and variations in the nature of the task (e.g. increased mental demand relative to visual demand) or even level of time pressure. Thus, no single value can be used as a threshold between NTP and HTP conditions, but rather different values should be used depending upon the situation. Additionally, physiological measures highly depend on individuals and, therefore, vary considerably from person to person and even within the same person. These results disproved the initial belief that there existed at least one indicator that was completely independent of the driving context and insensitive to differences between drivers. Consequently, before any of these measures can actually be used for detection purposes, further research is needed in order to fully understand behaviors of such indicators relative to all possible driving situations.

Some interaction-related measurements in terms of the subject's kinematic and kinetic activity also provided promising distinguishable differences between HTP and NTP conditions. Though, these differences were mainly evident when analyzed per individual participant and were seldom observable for the combined data set of all participants. Specifically, speed in the operation of the controls of the vehicle, acceleration of the limbs associated to these operations and pedal displacement allowed to distinguish between HTP and NTP drivers. Again, these results were often more clearly observable when the analysis was done in an individual basis. Thus, refuting again the initial belief that there existed at least one indicator that was completely insensitive to differences between drivers and, on the contrary, supporting the idea that indicators should be studied within individual drivers rather than for combined groups of people. Indeed, it was found that the impossibility of finding distinguishable results for some of the measurements such as force exerted on the steering wheel lies in the fact that there exist opposing behaviors observable among all drivers, which in turn leads to masking of effects when all results are studied together. Similarly, even when the same tendency is present between participants, the range of values for particular indicators varies considerably from driver to driver. Hence, their combination often averages results and eliminates the separation between distributions, as was the case for the speed operation of the vehicle controls. Further research is needed to better understand driver variability (driving style) and its implications on the identification of drivers under a time pressure condition. Furthermore, not only the within and between driver variability affects the interpretation of results, but driving situations (e.g. car following, overtaking with and without traffic on the opposing lane, intersections with and without traffic and cruising) also reveal different effects in terms of separation between distributions. These results similarly disproof the initial belief that there existed at least one indicator that was completely independent of the driving context. Despite the promising results, interaction-related indicators should be studied carefully since similar influences may result from other physically demanding activities within the vehicle (e.g. picking up the cell phone or having a discussion with a passenger) and, thus, further research is needed before most of these measures can be used for detecting a time pressure condition in car driving.

In terms of performance-related metrics, the results were similar to those of interaction-related indicators. Again, though a difference between the two conditions exists, the combined results for all participants often do not reveal separable distributions between the HTP and the NTP conditions. The results studied per participant and per driving situation, however, do provide differentiable results between the two driving conditions. Specifically, the findings of this study suggest that indicators such as engine speed, time headway, vehicle speed/acceleration and vehicle acceleration per throttle pedal operation per velocity bands, show, at least for some participants, a clear separation between the two conditions. These means that performance metrics related to both longitudinal and lateral vehicle control are candidate measures for identifying driving under time pressure. Still, however, further research is needed because their response could easily be found for several other situations with increased visual demand or a different source of stress. Additionally, a high value of acceleration cannot be defined without linking it to the speed at that particular moment. Thus, the use of vehicle acceleration/deceleration per throttle/brake pedal filtered by vehicle velocity bands is a promising indicator for identifying the state of driving under time pressure. More research is needed to establish the real potential of this finding.

Although further research is still needed before the identified indicators can be used for the recognition of driving in haste, a considerable number of indicators with sufficient discriminative power for such recognition were provided. However, even though the given indicators could eventually be used in the development of algorithms for the detection of this state in real driving conditions, the main contribution of this research is that, through both qualitative research techniques as well as empirical research, it sets the basis for future research in the field of recognizing the phenomenon of driving in haste. In general, the results of the current study reveal that, despite having a recognizable response towards driving under time pressure relative to driving under normal conditions, indicators closer to the source are not enough for recognizing when a person is driving in haste. Additionally, the effects of haste on human behavior can vary according to the stressor and different stressors may result in some different indicators. Moreover, there is no single indicator that is completely insensitive to the context and to the driving situation, nor is there a single indicator that is completely insensitive to differences between drivers. Indicators vary between persons in relation to their driving style, as well as within persons (even for the same driving situation). Consequently, rather than aiming at the development of a recognition system based on time windows, researchers should focus on the study of indicators per context and/or driving situations. This in order to establish more specific indicators and thresholds, as well as to establish whether certain situations share conditions that can be grouped for detection purposes. Finally, researchers should invest effort in the study of combination of indicators, both between and within the different domains (i.e. physiological, interaction and driving performance), to cope with the limitation induced by the fact that different stressors that elicit driving in haste may trigger similar responses on certain indicators which in turn could result in erroneous detections (false positive). Unfortunately, based on the results of the current study, a minimal combination of indicators that is best to recognize the state of being in haste cannot be provided. The explanation behind this is that while the exploratory study was good enough to prove that indicators should be studied per driving situations, it did not provide sufficient data to establish the level of discriminatory power per indicator. This, in turn, prevented any attempt to compare indicators with each other and thus to select those that could eventually be combined.

7.2 Research propositions

Below, we present the technical propositions derived in this research:

As evidenced in the case of revealing observable manifestations of driving in haste, a review of the literature should be combined with other research methods, such as focus group sessions, if researcher wants to generate reliable preliminary hypotheses.

Literature is limited to what has already been studied and thus is tied specifically to the goal of the researcher, which sometimes is not in line with your particular objective. Adopting results from such studies may limit the aggregation of significantly new knowledge to the field since the synthesis of the findings relies only on the researcher. The use of focus group for knowledge exploration, contrarily, provides insights into the perceptions and opinions of multiple people, which in turn increases the chances of finding novel information. Additionally, focus group studies are useful to make data triangulation, that is, to assess the findings of a first aggregative study (e.g. literature review) in the mirror of the findings of a second study (i.e. focus group study), and to identify overlaps and complements.

The use of a driving simulator is in itself a source of intrinsic motivation for subjects taking part in the study of driving in haste, hence there is no need to use other external motivations in combination with a time constraint at completing a task.

In the current study, the use of any motivation strategy, be it gaming, role playing, competition, gaming plus money reward and competition plus money reward and reducing significantly the time available to complete the driving task, equally induced a detectable form and level of the state of being in haste. The different motivations resulted in similar observable manifestations of haste and levels of perceived time pressure. The only aspect common to all experimental conditions, in addition to the time constraint, was the driving simulator and the fact that the participants were volunteers. Thus, it seems logically to assume that the motivation of the participants in this experimental setup was based on their intrinsic stimulus to complete the task.

It is necessary to consider the environment of driving because the studied indicators are different in specific driving situations and vary according to the associated mental/visual/physical demands (e.g., overtaking, car following, etc.) and external factors (e.g. environmental lighting conditions, etc.).

The demands of driving under time pressure are a sum of both an intrinsic and an extraneous load consisting of (i) the nature of the driving task with its associated physical and mental demand and (ii) the circumstances under which this task is performed (in this case the time constraint), respectively. Hence if either load varies, the demand of the task also varies. In this study, the nature of the task was variable along the session depending on the driving situations. The exploratory analysis revealed that those variations in the demand of the task were reflected in the indicators in the form of different tendencies or values. Moreover, frequently these tendencies or values could not even be used to differentiate between both driving conditions (NTP and HTP). This means that no single threshold exists that can be continuously used for identifying driving in haste. Instead, the threshold should be continuously adapted based on the influence of the context in the response of the indicator.

Contrarily to the belief that speed is sufficient to identify driving in haste, its ability to discriminate between NTP and HTP driving conditions in specific driving situations, such as driving in a traffic jam, is limited.

As a response to the first coping strategy (I.e., acceleration of actions) when subject to time pressure, vehicle speed is generally expected to increase. However, in this study, the opposite tendency was found in some situations. For instance, the mean vehicle speed for the car following situation was lower for the HTP condition relative to the NTP condition. This outcome possibly lies in the fact that drivers under the HTP condition do not seem to maintain a regular speed somewhat close to that of the leading vehicle but they rather decrease their speed below that of the vehicle ahead, thus allowing for the leading vehicle to increase its headway distance. This situation is then followed by an increase of speed above that of the leading vehicle until the distance between the two vehicles is reduced again and the cycle starts over. The average of this variation in speed is possibly what leads to a lower mean vehicle speed.

The maximum vehicle acceleration/deceleration per throttle/brake pedal operation is not a sufficient indicator of driving under time pressure, because it cannot be assessed without considering the actual speed of the vehicle.

Although high acceleration is a natural response to time pressure, a high value of acceleration by itself is not necessarily an indicator of haste. It cannot be defined without linking it to the speed at that particular moment. Linking acceleration to speed seems logical since the vehicle acceleration is less as speed increases because it takes longer to get a change in speed. For example, assuming that the gas pedal is pressed to its maximum position, it takes less time to change the vehicle's speed from 10-20km/h than it is to change it from 100 to 110km/h.

The threshold value of each indicator of driving in haste should be set on an individual basis because the studied indicators vary considerably from person to person and even relative to the same person.

The results of the current study revealed distinguishable differences between HTP and NTP conditions for several indicators in all the studied domains. Though, these differences were mainly evident when analyzed per individual participant and were seldom observable for the combined data set of all participants. Further analysis showed that the impossibility of finding distinguishable results for some of the measurements (e.g., force exerted on the steering wheel) lied in the fact that the opposite behavior observable among all drivers led to masking of effects when all results were studied together. Similarly, even when the same tendency was present between participants, the range of values varied considerably from driver to driver and their combination often averaged results, eliminating the separation between conditions. Establishing a single indicator threshold value based on combined data set could result in misleading identification of driving in haste for part of the population.

7.3 Reflections on the current research

In this section we briefly reflect on the content presented in this thesis.

A driving simulator was used in order to identify indicators of driving in haste. The use of this method for collecting data in combination with a custom sensing system, allowed us to collect longitudinal behavior data, as well as data from the interaction of the driver with the vehicle controls and the driver's physiology. However, the use of driving simulators has some validity issues. As mentioned in Section 6.7, driving simulators possess relative validity. This means that the direction of the behavioral response may be similar to real driving conditions, whereas the magnitude of this response may differ. The effects of time pressure in the physiology response, driver interaction response and driving performance, may consequently be assumed to differ with respect to their magnitude compared to real driving behavior.

Another limitation of this study is that mainly longitudinal behavior on urban roads was studied. The only lateral behavior considered was the one corresponding to overtaking situations. We did not investigate longitudinal behavior in other types of roads such as freeways or rural areas. Additionally, this research considered a limited number of driving situations.

A fundamental reflection is that in this study, extensive research on the influence of haste on physiology, interaction and driving performance was studied. Although we showed that haste generated by time constraints led to significant changes in some of the physiological and visual behavior indicators, not every indicator revealed an identifiable difference between conditions. It was proposed that this might be due to the physiological and behavioral variability between people and because the indicators seem to be context dependent (e.g. two lane vs. one lane road) and situation dependent (overtaking vs. car following). Furthermore, gender, driving experience, age and ethnicity may also be assumed to have a substantial effect.

Moreover, in this research, the driver task lasted for approximately 12 minutes. Consequently, it is not yet clear whether the behavioral responses may vary due to the prolonged exposure to the same task causing fatigue in the driver and thus, revealing different tendencies in the responses.

In addition to the above limitations, in this research we did not induce different levels of time pressure. Consequently, we could not establish whether the response of certain indicators could change its intensity as a result of the level of perceived pressure.

Finally, in the current study, we did not have control over the level of mental demand relative to visual demand. Hence, we could not establish which demand was dominating. This is especially critical for some physiological indicators in which the effect due to visual and mental demand varies in the same direction or opposite direction.

7.4 Recommendations for future research

In this final section we discuss directions for future research following from the results presented in this dissertation. Specifically, this document describes how research towards the recognition of driving in haste can be complemented.

In the previous section, it was stated that due to the fact that driving simulators were used to gather the information regarding indicators of driving in haste, some validity issues exist. The extent to which the results can be compromised is not clear. Therefore it is recommended to perform a validation study using data collected in real driving situations through the use of an instrumented vehicle.

Another reflection mentioned was that this research had a limited number of driving situations (overtaking, car following, cruising and stop and go behavior in intersections) and a limited context (urban road with moderate traffic). It is therefore recommended to expand this research including other driving situations such as stop and go behavior in traffic lights, roundabout negotiation, and lane shifting maneuvers, among others. Other driving contexts such as highways and rural roads should be taken into account.

In the above section, it was mentioned that mainly longitudinal behavior was considered. Consequently it is recommended to perform research on identifying indicators of driving in haste in lateral driving behavior. This research should be performed for more driving situations as well as for more driving contexts such as highways and rural roads.

Furthermore, we did not establish the influence of physical activity on physiological data. It is therefore recommended to perform future research on the influence on the physiological behavior of the driver caused by other activities executed in the car, such as talking on the phone.

Influences of age, ethnicity, driving experience and gender were also mentioned in the previous sections as possible biases for the physiological, interaction and driving performance responses. Therefore, we recommend to study whether these characteristics moderate the above responses when driving in haste.

Additionally, we did not study long-term exposure to driving under time pressure. Hence, studies with longer periods of driving should be designed in order to understand the effects of fatigue on the indicators of driving in haste.

Similarly, influences of different levels of time pressure were not studied. Studies with variations in the motivation or in the time constraint should be performed to further understand the phenomenon of driving in haste.

Finally, as mentioned in the previous section, the levels of mental and visual demands were not controlled during the current study. Since this could have significant impact on the behavioral responses, it is imperative to understand the effects of both mental and visual demand over the indicator in order to be able to define the expected outcome. For instance, assuming that blink rate is expected to increase as a result of high mental demand and to decrease as a result of high visual demand, it is the combination of both of these demands what determines the effects. If mental demand is higher the expected outcome is an increase in blink rate, whereas if visual demand is higher the expected outcome is a decrease.

Summary

Background of the research

With the increase of the daily use of vehicles and the frequent occurrence of complex driving situations, the number of accidents leading to injuries and fatalities has increased dramatically. A study made by the World Health Organization (WHO) revealed that as many as 50 million people were injured and over 1.24 million fatalities occurred worldwide annually [1]. As these figures imply, traffic-related accidents can be considered a serious social and technological problem with global dimensions. Hence, traffic safety has become a high priority issue not only for governmental agencies, but also for the majority of vehicle manufacturers and other stakeholders. In order to enhance the safety of mobility, a number of projects have been proposed, ranging from enhancement of infrastructure to vehicle-based safety systems [2].

Conventional approaches to improving vehicle safety mainly focus on passive safety (e.g. airbags, seatbelts, pre-tensors, laminated windshields and collapsible steering columns), aiming to minimize the severity of injuries caused in traffic accidents, rather than to prevent them. In present-day vehicles, the above-mentioned passive safety systems have been complemented by active safety systems. These latter systems, in addition to minimizing the effects of a crash, also work towards avoiding them. These include the following systems: electronic stability control, traction control and dedicated driver assistance (e.g., adaptive cruise control, lane departure warning, collision warning and mitigation parking assistance, etc.). Due to the fact that driver behavior is the most prominent factor contributing to traffic accidents and because it is better to avoid accidents than just to reduce the severity of injuries, the idea of active safety systems has received much attention and various advanced driver assistance systems (ADASs) have gained popularity in the last years [3].

Current ADASs typically provide assistance to the driver in one or more main tasks in the driving process: i.e., perception, analysis-decision and action [4]: they help the driver in recognition of the environment, judgment of the situation or in actions to be performed. Most of the systems developed until now are working as a process parallel to the driver, considering only the inputs from the environment and the vehicle. In other words, they perceive and analyze the driving situation, and then take an action the way the driver should. In most of them, there is no consideration of the driver in the loop, and, consequently, the system is not aware of the driver's characteristics, the driver's state, and the driver's behavior. Recently, in an effort to reduce the number of false alarms set off by these systems, more advanced so-called *human-centered ADASs* have been proposed that, in addition to monitoring the environment and the state of the car, monitor the driver in order to know his/her intentions (turn, stop, change lanes, etc.), conditions (fatigued, intoxicated, alert, irritable, etc.), and limitations (visual acuity, reaction time, etc.).

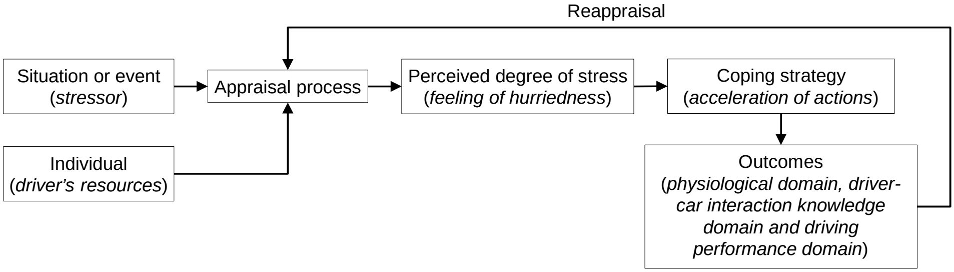

Figure 7.1. Transactional Stress/Coping Model used to define haste

Currently, not too many systems can adapt to the drivers' characteristics yet. However, now that advanced information technology, miniaturized technological components, and sensing and control technologies are increasingly deployed in everyday products, it is believed that systems that adapt to the characteristics, emotional states, and different conditions of the human being will not only be more sophisticated, but also become more widespread in the future [5]. In the upcoming ubiquitous network society, the driver monitoring functions will be crucial in driving support systems, and safety systems will probably be able to fully understand the driver and respond to their individual needs. In order to make this happen, driving assistive instruments should be able to recognize the characteristics, actual mood, and different conditions of the user. Indeed, the first step towards an intelligent user monitoring system is to automatically detect and interpret the state of the driver.

Some detection/monitoring systems have already been developed for the most studied dangerous states, namely, fatigue, distraction and drug impairment. Although these states are top-ranking in accident causation statistics in the world, misbehavior of the driver can take many other forms. Many of them appear when the driver is driving in a hurry. This state is commonly known as haste. The state of haste is a mental condition in which a person perceives a need to hurry or rush. It has been recognized that rushing, rather than speeding, is a major cause of motor accidents. This is because most collisions occur below the speed limit. For example, children have been tragically run over by vehicles reversing out of house compounds. As studies in for instance Europe and Japan have shown, haste has cost many lives on the road [6,7]. Driving in haste increases the risk of accident as a result of speeding, faster acceleration, hard braking, dangerous overtaking and tailgating [8].

Haste is a complex phenomenon that arises from several factors, of which the most important ones are: (i) physiological conditions (e.g. need to urinate), (ii) social pressure (e.g. obligation to maintain cultural norms for speedy behavior), (iii) motivational states (e.g. irritability, angriness), and (iv) time-related conditions (e.g. being late for an appointment). All these factors, that can be defined as stressors, place a demand on the person and induce feelings of stress [9]. Based on Lazarus and Folkman's Transactional Model of Stress and Coping, these stressors trigger an appraisal process in which a human being assesses the degree of threat that this stressor imposes on his/her wellbeing, and determines the ability of managing or coping with this threat with the resources he/she has available [10]. The form of stress, triggered by any of the abovementioned factors and experienced as a feeling of hurry with a need to perform actions rapidly as the first coping mechanism, is what is referred to more specifically as haste in this research (Figure 7.1).

Although haste is commonly associated with the physical condition of executing actions rapidly, haste can also manifest itself in other behavioral changes if the execution of rapid actions is restricted. In order to understand these other behavioral changes, literature on driving in haste had to be further studied.

Forerunning research of driving in haste

Several studies claim that driving in haste usually causes risky behaviors. However, most of the papers do not address the specific manifestations of driving in haste and merely focus on the most obvious risky behaviors such as speeding, tailgating and high acceleration. Besides, most of the studies are based on questionnaires using videos or images about driving situations in which the questioned drivers have to judge whether they are supposed to be in a hurry or not and what their reaction would be. Although the answers given to these questionnaires by participants may in general be true, some participants' responses may not be honest and leave room for biases. The proneness of respondents to produce fake answers is well-documented by [11]. The results of questionnaire-based studies have to be carefully considered and verified using more objective approaches such as driving simulator studies or naturalistic observation. Using questionnaires for deriving hypotheses and driving simulators for testing them seems to be effective for an a priori confirmation of indicators of driving in haste.

Moreover, although a few engineering-rooted studies have used driving simulators to identify specific manifestations of haste and to predict this dangerous state, these studies do not go beyond vehicle information (e.g. speed, acceleration, etc.) for the characterization of this state. Considering that in the overall process of driving a car, the behavior of the driver is transferred to the car through the driver interaction, and that the behavior of the car and its interaction with the environment is already a reaction to the drivers' behavior, vehicle information (indirect driving parameters) alone does not seem to be sufficient to detect dangerous states of the driver. Rather, it is reasonable to think that combining indirect driving parameters with direct driver-related measures (i.e. indicators related to the driver physiology and driver-car interaction knowledge domains) may increase discriminative power and thus enable more accurate detection of the risky state. In fact, considering indicators closer to the source only (direct driver-related measures) could be sufficient since indirect driving parameters are responses to direct driver-related actions. Additionally, although some studies of driving in a hurry give a useful basis for understanding the effects of driving in haste, the results are still exploratory and subject to the drivers' opinion. Little is known about the individual characteristics that moderate the effects of driving in haste. More empirical studies evaluating the relation between driving style and driving in haste are still needed for further understanding the impact of these characteristics in the manifestations of haste.

Research problems

From the reviewed literature, the first impression and assumption was that in the future more human centered ADAS would be needed. In this type of systems, the driver monitoring function will become crucial for detecting the drivers' intention and state, as well as for judging a particular dangerous situation. Therefore, it will be necessary to study all possible driver states and activities of the driver that may cause traffic accidents. Since, from all the dangerous states that contribute to traffic accidents, driving in haste frequently occupies the top position of the results of the investigations of driver's mental and physical states immediately before accidents, in this research, it is assumed that the development of a system for the detection of driving in a hurry will considerably contribute to reduce traffic accidents. The understanding of the phenomenon, in terms of how it is developed and its manifestations, is necessary for the development of a technical support system. In order to get a comprehensive understanding of the phenomenon and to explore optimal detection possibilities, the knowledge derived from psychologists and engineers about driving in haste needs to be combined, even if the current trends in the literature do not indicate efforts in this direction.

Now, if being in a hurry can be conceived as a form of stress induced by a particular stressor, it could be expected that the driver responds to this type of stressor in a manner similar to that with which he/she does to other types of stressors (such as heat, noise, etc.): through an extraordinary mental or physical effort or by exhibiting changes in performance. This stressor, as any other would, will possibly affect the way the driver performs (behavioral), the way he/she feels (emotional) and the way the bodily functions respond (physiological). Consequently, driving in haste can be expected to produce some recognizable symptoms in the drivers' physiology and his/her interaction with the vehicle. Our main assumption is, thus, that the behavior of the driver in a hurry is different from his/her usual behavior in a normal driving situation, and that the emerging changes in the behavior propagate from the driver through the car towards the environment. However, until now, researchers have focused on the detection of driving in a hurry by using only a few vehicle behaviors, which are the most obvious symptoms. Consequently, the methods based on these behaviors are attempting to detect the driver state in an indirect way or, in other words, using the behavior of the vehicle, which is simply a propagation of the drivers' actions.

This particular research, on the contrary, focuses on the problem of recognizing driving in haste based not only on information about the vehicle behavior but also on information about the drivers' physiology and his/her interaction with the car. More specifically, the problem lies in identifying the effects of driving in haste on the physiology of the driver, his/her interaction with the car and the driving performance. However, in order to study the phenomenon of driving in haste, this situation must be recreated either in real or in virtual scenarios. It is difficult, though, to study the phenomenon in real life since there are too many triggering factors and too many variables that cannot be controlled. Besides, intentionally inducing haste in drivers on a real road can lead to unsafe situations and is, therefore, unethical. Reproducing haste in a laboratory setting appears to be the most feasible alternative approach. Then, assuming that the phenomenon of driving in haste could be generated in an artificial environment, this research also faced the issue of reproducing driving in haste in a driving simulator.

Overall research objective

Since driving in haste leads to a considerable number of traffic accidents around the world and since research in the area is rather limited both in terms of quantity (studies are rather limited in number) and quality (most of the existing studies are questionnaire-based and the others have limited sample sizes), the overall objective of this PhD research was to identify indicators with sufficient discriminative power for the recognition of driving in haste that could eventually be used in the development of algorithms for the detection of this state in real driving conditions

More specifically, the aim was to further understand the phenomenon of haste in order to: (i) induce this state for the execution of a study using a driving simulator, as well as to (ii) identify, based on studies reported by other authors and knowledge derived from experts in the fields of driving, behavioral psychology and human medicine via focus group studies, possible observable manifestations or indicators of driving in haste, and finally (iii) empirically assess the discriminative power of the indicators identified for the recognition of driving in haste by means of the design and execution of an experiment using a driving simulator.

Hypotheses and assumptions

From the above, the main assumption for the current study was that the behavior of the driver in a haste situation would be different from his/her usual behavior in a normal driving situation and that the emerging changes in the behavior would propagate from the driver through the car towards the environment. That is, the behavioral state of the driver would be reflected not only on the human body, but it would also have observable influences on the behavior of the car, the interaction of the driver with the car, and the interaction of the car with the environment.

Moreover, the global hypothesis for the current study was that there existed at least one indicator that was completely independent from the driving context and completely insensitive to differences between drivers. In other words, prior to the conduct of the study, it was believed that it would be possible to find one indicator that would have sufficient discriminative power for the recognition of driving in haste independent of whether the driver was one or another, and whether he/she was driving on a freeway or approaching an intersection with traffic crossing ahead.

A secondary hypothesis for the current study was derived from the fact that, in the overall process of driving a car, the behavior of the car (i.e. vehicle information such as speed, acceleration, etc.) is a reaction to the drivers' behavior and, thus, indirect driving parameters are responses to direct driver-related actions. Consequently, since both indirect and direct measures provide similar information, it was expected that indicators closer to the source, that is indicators coming from the physiology of the driver and his/her interaction with the vehicle controls, were best for identifying driving in haste. In fact, it was initially expected that indicators closer to the source alone were already enough for the intended purpose.

Another hypothesis was related to the induction of haste in drivers in a laboratory setting using a driving simulator. The premise was that driving in haste, with the stressor being time-related, could be induced using the time pressure construct defined as a time constraint plus a motivation to perform the driving task in the given time. In other words, it was expected that haste resulting from a time-related stressor could be intentionally prompted by reducing the time available to complete the task as long as the participant was motivated to do so.

Overall research approach

In order to recognize when a driver is in a hurry, it is necessary to synthesize bodies of knowledge from behavioral science and engineering science. However, collecting and merging information and research data from multiple fields introduces a complexity in the research. In order to handle this inherent complexity a multi-methodological framing was applied to set up the research design. The whole PhD research was broken down into four interrelated research cycles, as shown in Figure 7.2. Each cycle had particular objectives and framing methodology. For this purpose, the methodological framing theory, proposed by Horváth [12], has been applied. The first three research cycles, which aim at gathering knowledge about the indicators present when driving in haste situations and about the induction of haste in a driving simulator, have been methodologically framed as research in design context (RDC). The fourth cycle, which deals with the selection of indicators, their combination, and their association with measurement technologies, has been framed as design inclusive research (DIR).

The use of this methodological framing is explained by the fact that the first three research cycles aimed at gathering insights and understanding the phenomenon in a specified context (i.e. driving), whereas in the fourth research cycle an experimental arrangement was used for detecting and testing the indicators and this also served as an evolving research tool. The specific objective of the first two cycles of the research project was to define a set of recognizable behavioral indicators in the discussed context. We investigated which phenomena were strongly associated with the state of driving in haste, and how the various manifestations of these phenomena could be described in terms of indicators. In the research cycle three, due to the fact that it was difficult to study the phenomenon of "driving in haste" in real life since there were too many triggering factors and too many variables that should be controlled, we investigated how to induce an emotional state in subjects in such a way that we could be certain that subjects actually experienced

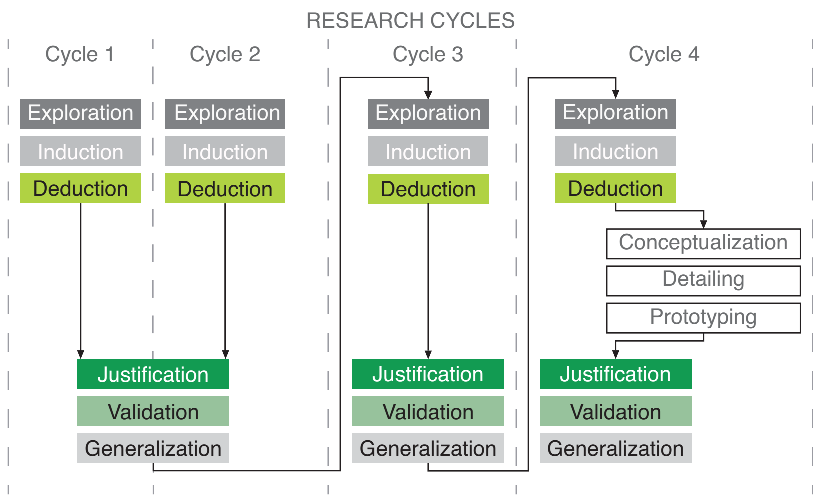

Figure 7.2. Organization of the research cycles

haste. In the fourth research cycle, the indicators were further studied and refined in order to identify those with the sufficient discriminative power for recognizing the state of driving in haste.

Research cycle 1: Exploring observable manifestations of driving in haste

Our forerunning literature analysis has indicated that there were many reports on observed or assumed manifestations on being in haste or acting in haste. Therefore, we stated as a specific objective of this research cycle to explore and aggregate general observable manifestations of driving in haste associated with: (i) the physiological status of the driver, (ii) the interaction of the driver with the car, (iii) the behavior of the car, and (iv) the overall driving performance. We planned to use the result of this secondary research not only to gather existing information and knowledge, but also to extrapolate from this existing body of knowledge and to synthesize new insights and relationships. We intended to reuse this information about the observable manifestations of driving in haste in a posterior research cycle, which is dedicated to the identification of detectable behavioral indicators for the recognition of driving in haste.

As indicated above, the major research method applied in this research cycle was a complementing qualitative and quantitative literature review. In the practice, a multi-keyword-based Internet-search was completed considering both scientific publications and web-site contents. Information and data about manifestations (symptoms) of driving in haste were aggregated by means of various structured lists of keywords and cited references. In the qualitative phase of the study, the data carried by the written text were interpreted, coded and assumptions were made in an inductive way. In the quantitative phase of the study, the occurrence frequencies of the findings were recorded and investigated.

In terms of driver physiology, the studied papers reported on various manifestations of the phenomenon such as: (i) changes in cardiovascular activities (heart rate, blood pressure), (ii) variations in the respiratory activity (respiration frequency), (iii) variations in other body reactions (muscle tension, skin temperature) (iv) changes in electric conductivity (caused by sweating), as well as (v) performing overt behaviors such as rude gestures, swearing and yelling, and (vi) showing unusual facial expressions (frowning).

Moreover, various observable manifestations of driving in haste were reported on in terms of the driver interaction with the car. These manifestations were related to: (i) the intensity of operating the functional controls of the car (for instance, force on the gearstick, force exerted on the brake, throttle, and/or clutch pedals), (ii) the movements applied on the steering wheel, (iii) the amount of force exerted on the steering wheel, and (iv) the velocity of switching the pedals. In addition, (v) excessive operation of warning-related controls (such as horn honking and flashing headlights) was also mentioned in some studies.

Concerning the domain of vehicle behavior, among the reported observable manifestations were: (i) speed profile of the car, and (ii) acceleration and deceleration profile of the car.

Finally, the driving performance related observable manifestations included various risky behaviors such as: (i) running yellow/red lights, (ii) disobeying traffic road signs and warning signals, (iii) keeping short distance between cars, (iv) overtaking dangerously, and (v) cutting others off in a lane. Additionally, (vi) failing to yield to pedestrians and (vii) frequently changing lanes were also reported in the literature.

Research cycle 2: Interrogating for observable manifestations of driving in haste

In order to extend the set of the observable manifestations of driving in haste obtained in the first research cycle, we planned an interrogative research. The interrogative study was conducted with various individuals in the form of focus group sessions (FGSs). The participants of the FGSs were common car drivers, experts of behavioral psychology and human medicine, and traffic engineering professionals. Their assignment was to report on their past experiences with, and to express their opinion on the manifestation and identification of observable manifestations of driving in haste. We were especially interested in the identification of the instrumentally detectable behavioral indicators of driving in haste. Our objective was to explore and synthesize additional knowledge about the observable and detectable manifestations of driving in haste with the involvement of the invited car drivers and experts. As in the preceding research cycle, four aspects, namely the physiology of driver, the interaction of the driver with the car, the behavior of the car, and the driving performance were considered. The interrogative study was also done with the objective of being able to make a data triangulation, that is, to assess the findings of the first aggregative study in the mirror of the findings of the second interrogative study, and to identify overlaps and complements.

Concerning the overall conduct of the first and the second research cycles, the following should be noted. As described, the explorative parts of these research cycles were completed as a literature study and as a focus group study, respectively. The confirmative parts of the two research cycles were combined and conducted as described above, with the necessity and usefulness of data triangulation in mind. This research design made it possible to make both research cycles epistemologically and methodologically complete [13]. We found that there was a reasonably large overlap between the observable manifestations gathered from the literature review and the focus group sessions, and a complementing set of manifestations could be generated based on the additional and not-negated findings.

The focus group sessions were used as a qualitative methodological approach to gathering data about driving in haste. In each of the five focus group sessions, which were conducted as open-ended and semi-structured discussion forums, the participants were asked to express their opinions about the attitudes, behaviors, actions, etc. of drivers being in haste. To increase the awareness of the session participants, to facilitate a focused discussion, and to record each comment of the participants in the focus group sessions, we developed: (i) a visual dictionary, (ii) a video with traffic situations, and (iii) an image-based questionnaire.

After each focus group session, the recordings were transcribed. The information provided by the participants and the notes taken by the moderator on paper were typed. The data gathered in the different sessions were combined in a single file. These raw data were pruned and semantically analyzed. Considerable effort was put into data pruning in order to make the large amount of recorded material and writings manageable, and to develop a descriptive theory about the relevant indicators of driving in a haste situation.

The procedure for analyzing the data gathered in the focus group study involved the following main actions (Figure 7.3): (i) transcribing the data, (ii) arranging the gathered raw data (verbal expressions) in groups according to their meaning (semantic groups), (iii) characterizing each group by an expressive textual descriptor, (iv) sorting the descriptors (possible observations regarding the haste state) according to the domains (i.e., driver, driver-car interaction, car behavior, car-environment interaction) in order to compare it with the literature (v) identifying

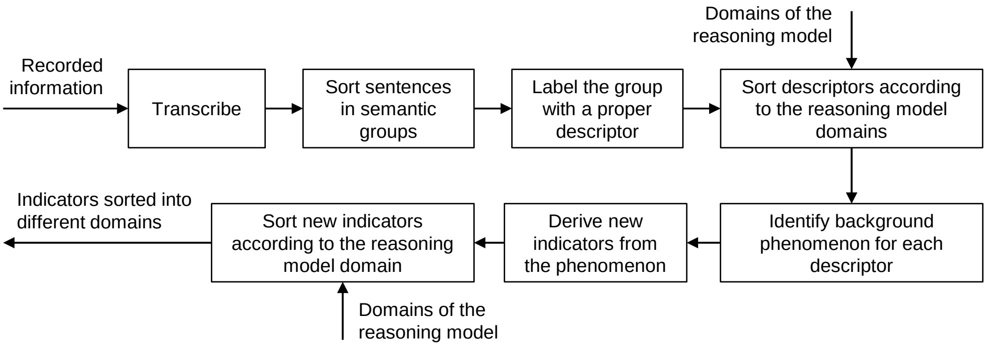

Figure 7.3. Procedure of the data analysis generated in the focus group study

the background phenomena based on the consideration of the descriptors, (vi) deriving new indicators from each phenomenon, and (vii) sorting these indicators according to the different domains, and making an assessment of these indicators. Table 7.1 contains a sample of the list of sorted indicators. The indicators shown in this table belong to the driver-car interaction domain only.

A congruency analysis revealed that while some of the statements mentioned by the groups indeed corresponded to statements found in the literature, others were only verified by some experts. Thus, a correspondence analysis was used to make visible how much and what kind of pieces of knowledge did actually underpin the aggregated body of knowledge. In other words, the frequency of mentioning certain observable manifestations was used to establish the relevance of the statement to describe the phenomenon of driving in haste. An initial hypothesis of this study was that indicators closer to the driver domain were considered sufficient for identifying driving in haste. Accordingly, manifestations with high correspondence were selected for further study. These included: (i) heart rate, (ii) blood pressure (cardiovascular activity), (iv) gaze variance (visual behavior), (v) skin temperature/conductivity, (vi) respiratory frequency, (vii) intensity of body movements, and (viii) intensity in the operation of the car controls. However, the congruency and correspondence analyses also revealed that some observable manifestations in the car behavior and car-environment interaction domains could be potential candidate for identifying driving in haste.

Table 7.1. Sample of derived indicators of driving in haste for the driver-car interaction domain

Semantic group	Freq	Background Phenomena	Derived indicators
The driver presses the pedals harder	22	Tendency to make dynamic/aggressive interaction with the vehicle	Force exerted on the pedals - Force exerted on the gas pedal - Force exerted on the brake pedal - Force exerted on the clutch pedal - Force exerted on the steering wheel - Speed of switching between pedals - Speed of moving the steering wheel - Speed of moving the gearstick - Force exerted on the gearstick - Force exerted on the steering wheel - Force exerted on the horn - Pressure exerted on the steering wheel
The driver makes sudden movements of the steering wheel (turning the steering wheel harder)	9		
The driver uses the clutch frequently	7	Tendency to operate frequently the vehicle.	Frequency of using clutch pedal - Frequency of pressing brakes - Frequency using the steering wheel - Frequency of pressing gas pedal - Frequency of shifting gears - Frequency of horn honking.
The driver uses the horn frequently (horn honking a lot)	46		

Research cycle 3: Investigation of time pressure as a proxy of being in haste

In order to study the phenomenon of driving in haste we needed to recreate this situation. As has been said already, reproducing haste in a laboratory setting appeared to be the most feasible alternative approach. Due to the fact that haste resulting from different stressors (e.g. physiological urges, time constraint, etc.) could in turn result in different observable manifestations, the phenomenon of driving in haste was further reduced to the phenomenon of driving in haste due to a temporal constraint, also referred to as time pressure. Time pressure was selected because it has been suggested in literature as a key factor influencing driver safety [14] or even the only one to significantly differentiate between accident-involved and accident-free drivers [15]. Additionally, relative to the other stressors that can result in haste, imposing a time constraint on a participant was more feasible from an ethical point of view than, for instance, inducing a physiological urge that could affect the well-being of the participant. Finally, time pressure had been previously manipulated successfully in laboratory settings studying office related tasks [16].

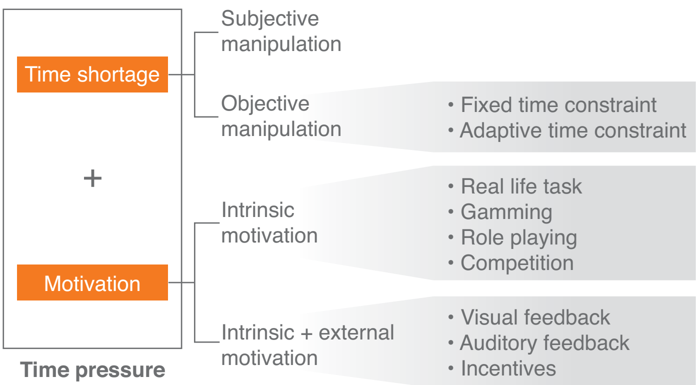

Figure 7.4. Manipulation of time pressure

A systematic literature review of reports and journals related to induction of haste by applying a time constraint (also referred to as time pressure) revealed that, in order to induce time pressure, the time constraint imposed on the completion of a task had to work as a stressor. The Variable State Activation Theory (VSAT) states that, to work as a stressor that leads to acceleration of actions, two criteria had to be fulfilled [17]: (i) the amount of time available to complete the task had to be less than the amount of time the subject needed to complete it (i.e. there was a time shortage), and (ii) the person who was to perform the task had to be motivated to complete it in the available time (i.e. the task had to be sufficiently important for the person). Accordingly, if one of these components were missing subjects would not experience pressure and, therefore, would not manifest accelerated actions. Moreover, the manipulations for both components that had been used by other researchers were also derived from the literature review and were taken as the basis for this research (Figure 7.4).

Consequently, the objective of this research cycle was to determine a reliable motivation and level of time manipulation to induce the feeling of being in haste in driving simulator studies. The aim was to provide the guidelines (in terms of motivation and time manipulation) for the development of a posterior study to further explore the identified set of detectable behavioral indicators for the recognition of driving in haste. For such purpose, various forms of motivations in combination with a time shortage strategy were tested in an experimental study with a small subject sample. Adaptive time constraint was used as the manipulation strategy for time shortage. From the different motivations identified on literature, the following were selected for testing: gaming, role playing or contextualization in an imaginary situation, competition, gaming plus money reward and competition plus money reward. In all these motivations visual feedback in the form of a timer was used to reinforce the time pressure. This option was chosen because it was often reported in literature. A timer clock was included since it is typically present in real driving conditions. Auditory feedback in the form of a beeping sound was not considered in the time-pressured task because it could become a source of stress in itself.

It was found that any of the motivation strategies used, be it imagining a fictitious scenario, competing or rewarding, would equally result in a detectable form and level of feeling haste in all the participants. Indeed, the driving simulator, which was new to most participants, seemed to be by itself an effective stimulus to perform well and, hence, designing an experiment that retained subjects' attention and curiosity (i.e. intrinsic motivation) together with a time constraint for completing a task appeared to be enough to ensure a detectable level of hurriedness on the driver.

This small study, despite not having statistically significant differences among the several motivations tested, provided evidence about the successful induction of haste lacked by the few previous empirical studies in this research area.

Research cycle 4: Finding indicators of driving in haste based on temporal constraint

Based on the findings reported above, the fourth research cycle allowed for the final establishment and assessment of the set of detectable behavioral indicators for the state of driving in haste resulting from a time constraint imposed on the driving task.

In order to clarify important concepts and definitions for the current study, a framework that describes the processes and mechanisms associated with human performance under haste due to a

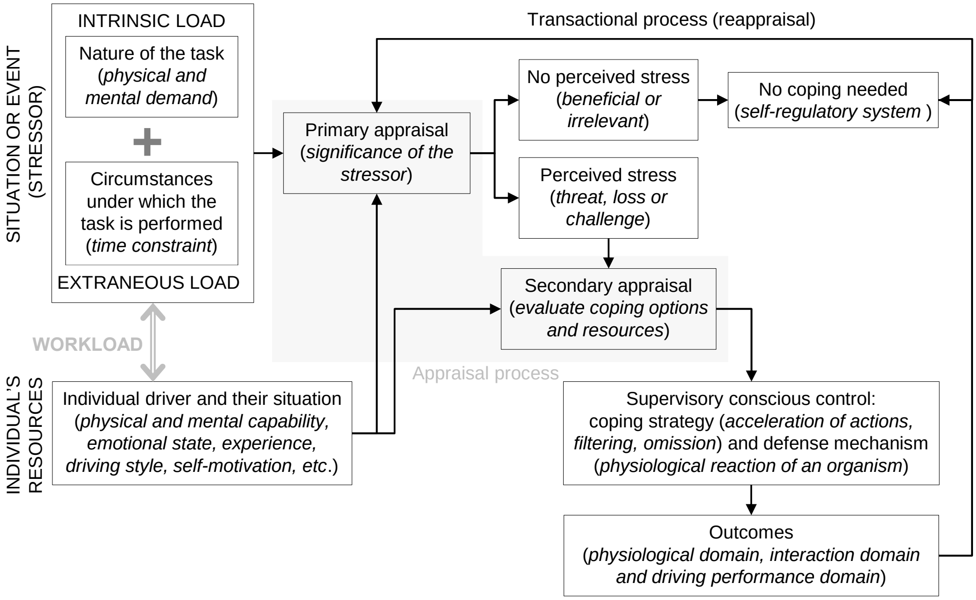

Figure 7.5. Time pressure coping model based on the Transaction Model of Stress [10]

time constraint was constructed based on previously proposed transactional models of stress (Figure 7.5). In this model, stress is viewed as the interaction between the environment (demands of the task) and the individual (resources for coping), emphasizing the role of the individual's appraisal of situations in determining their responses. The demands of the task are a sum of both an intrinsic and an extraneous load consisting of (i) the nature of the task with its associated physical and mental demand and (ii) the circumstances under which the task is performed (in this case the time constraint), respectively. Moreover, workload is defined as the construct that reflects the degree to which the demands of the task fall within the mental and physical capabilities of the individual (the driver). The combination of intrinsic and extraneous loads defines the situation or stressor.

The assessment of time pressure is a two-level process, relating the stressor to the individual's resources, and involving a primary appraisal and a secondary appraisal. During these appraisal processes, the current state of cognitive/physical activity is continuously compared to a target state [18]. Whenever stress is perceived following the primary appraisal, defense mechanisms are activated and coping strategies are selected as a result of the secondary appraisal process in order to manage the demands of the stressor. Four regulatory modes are available to cope with the increased cognitive/physical activity: (i) increase the control effort, by accelerating control actions, (ii) modifying the target state, by filtering the input, (iii) changing or eliminating demands (omission or change in strategy), and (iv) take no action (associated with anxiety and panic). The implementation of such coping strategies leads to outcomes reflected as physiological, interaction and performance responses. These responses can be measured with specific lower level indicators accordingly.

Following the described model, for instance in a context of driving (intrinsic load) under time pressure (extrinsic load), the driver's primary appraisal compares the estimated time needed to arrive at a given destination (constantly considering road events, as well as personal resources, etc.) with respect to the externally imposed time constraint and the consequences of not arriving on time. In a secondary appraisal, the driver assesses his coping resources to manage the demands of the situation (e.g., acceleration of driving control actions, choice of alternative route, modification of time constraint, etc.). The implementation of coping strategies leads to outcomes reflected as physiological, interaction and performance responses. If coping strategies cannot be implemented or estimations are unfavorable, then negative emotions may appear. Contrarily, if the task is perceived as a challenge for which resources to cope are available and guarantee success or optimal performance, positive emotions may arise.

Then, based on literature specific to time pressure and its effects on human behavior, physiology and body dynamics, the observable manifestations found as a result of the previous research cycles (mainly in the physiological and interaction domains) were reduced only to those that could originate from a time constraint. Indicators associated to the driving performance domain, derived from focus groups studies and the previous literature review on haste, were included on the list of possible indicators due to the fact that existing solutions for driver state recognition often give priority to these indicators. Then, for this reduced set of indicators, a set of hypotheses in terms of expected tendencies resulting from driving under time pressure was also derived based on literature, questionnaires and focus group studies.

Specifically, it was expected that, from the physiological activity, the cardiovascular activity, respiration and visual behavior were affected during the time pressure condition relative to the normal condition of driving. Similarly, from the human body dynamics, the kinematics of the body and forces exerted on the controls of the car were also expected to change. Table 7.2 includes the indicators and expected tendencies related to physiological activity, human body dynamics and driving performance.

After fully defining the list of indicators and their expected tendencies, equipment for measuring those indicators was analyzed. In terms of cardiovascular activity, since both heart rate and heart rate variability (HRV) needed to be measured, the only suitable equipment from the ones reviewed was the electrocardiograph. Specifically, an ambulatory monitor was chosen because it was less expensive, non-invasive, portable and more reliable than a telemetric device. An inductance belt was selected to measure respiratory activity due to its lower sensitivity to movement artifacts and band tension-related errors relative to resistive belts. For the measurement of eye behavior, a table-mounted image-based method (eye tracking system) was chosen because it was accurate, provided good estimates of pupil diameter and blink rate, and did not cause any discomfort to the driver.

Table 7.2. Outcomes, indicators and expected tendencies when driving under time pressure

OUTCOMES	LOWER LEVEL INDICATORS OF THE OUTCOME	EXPECTED TENDENCY RELATIVE TO NORMAL CONDITION
Driver physiology		
Cardiovascular activity	Heart rate (mean)	Increase
	Heart rate variability (SD RR, LF,HF, LF/HF)	Decrease
Respiratory activity	Respiratory frequency (mean)	Increase
	Respiratory amplitude (mean)	Decrease
	Mean inhalation time (mean)	Decrease
	Duration of each respiratory cycle (mean)	Decrease
	Mean duty cycle (mean)	Increase
Eye activity	Blink frequency (mean)	Decrease
	Pupil diameter (mean)	Increase
Driver-vehicle interaction		
Kinematic activity	Number of operations of vehicle controls - Pedals and	Increase
	RMS acceleration and jerk of the upper and lower extremities - arms, legs	Increase
	Pedal displacements - Throttle, Brake (Max,variance)	Increase
	Speed pressing pedals - Throttle, brake, clutch (mean)	Increase
	Steering speed (mean)	Increase
Kinetic activity	Force exerted on the steering wheel (mean)	Increase
Driving performance		
Visual behavior	Percentage of time looking at road Centre	Increase
	Horizontal Gaze Variance	Decrease
	Percentage Dials (%)	Decrease
	Percentage Clock (%)	Increase
Lateral control	Lateral position (mean,standard deviation)	Increase
Longitudinal vehicle	Engine speed (mean)	Increase
	Vehicle speed (mean)	Increase
	Vehicle acceleration (mean)	Increase
	Car following time (min)	Decrease

Finally, to measure forces exerted by the driver, both force sensing resistors and strain gage load cells were selected. The latter was selected due to its high precision, while the former were chosen due to their flat profile, low cost and ease for implementation.

The discriminative power of the now reduced set of indicators was analyzed and evaluated through the execution of an experiment using a driving simulator and a custom sensing system specifically devised, based on the equipment mentioned in the previous paragraph, for the assessment of the required data. Prior to the execution of the full-scale experiment, nonetheless, an iterative pilot study was used to refine the experimental design. The procedure of the modified research design can be seen in Table 7.3.

The full-scale experiment was executed according to this final setup. The length of the experiment was about 90 minutes per participant. In terms of sample, 56 healthy subjects, 46 males and 8 females between ages 23 and 37, were recruited. Participants were recruited from the Delft University of Technology student and employee community.

Concise overview of the empirical data

In order to analyze the data of the full-scale experiment, a first confirmatory analysis (hypothesis-driven analysis) was performed in order to test the hypothesized indicators of someone driving in haste. Then an exploratory analysis of the data, was carried out by interpreting visualizations with the aim to discover new patterns that could characterize people driving in haste. Detectable effects of time pressure were recognized on physiological activity, driver interaction with the controls of the vehicle and driving performance.

Most physiological measures were found to respond differently to an increase in time pressure. Specifically, heart rate, respiratory frequency, respiratory duty cycle, blink frequency and pupil diameter, have a discriminatory power that could eventually be used to identify drivers under high time pressure (HTP) from drivers under no time pressure (NTP). These measures have been

Table 7.3. Procedure for conducting the experiment

Step number	Procedure
1	Fill out the questionnaires (enhanced version of questionnaires)
2	Watch video: General instructions and Training session
3	Attach sensors to participants (Pedal sensors are not used)
4	Check the proper functioning of all sensors
5	Seat inside the driving simulator (Do not wear the seat belt)
6	Calibration of the eye tracker
7	Relax for 5 minutes inside the driving simulator cabin
8	Baseline recording of the heart and respiration activity for 1 minute
9	Run training session (lengthened driving segment and lowered sound)
10	Fill out the NASA-TLX questionnaire inside the driving simulator cabin
11	Relax for 5 minutes inside the driving simulator cabin
12	Recording of the heart and respiration activity for 1 minute
13	Watch video: instructions for Session 1
14	Run session 1 (increased traffic density to guarantee the following and stop and go behavior)
15	Fill out the NASA-TLX questionnaire inside the driving simulator cabin
16	Relax for 5 minutes inside the driving simulator cabin
17	Recording of the heart and respiration activity for 1 minute
18	Watch video: instructions for Session 2
19	Run session 2 (increased traffic density to guarantee the following and stop and go behavior)
20	Fill out the NASA-TLX questionnaire inside the driving simulator cabin

related to the higher mental effort investment resulting from the driver's perceived lack of time to complete the task [19-21]. In addition to mental demand, pupil diameter and blink frequency have also been related to the visual demand which is inherent to the driving task and increases as a result of some of the effects of time pressure (e.g., speed) [22] .

However, further research is needed before any of these measures can actually be used for detection purposes. On the one hand, these measures seem to be affected by specific driving situations (e.g. overtaking, car following, etc.), which means that no single value can be used as a threshold between NTP and HTP conditions. Figure 7.6 presents an example of how heart rate and heart rate variability change depending on the driving situation. On the other hand, physiological measures highly depend on individuals and, therefore, vary considerably from person to person and even within the same person. Additionally, the response of most of these measurements with respect to time pressure may be masked by external factors. Physical load, for example, affects heart rate and respiratory activity. Environmental light conditions can result in a potential confounding effect with regards to pupil dilation. Finally, concerning blink frequency, special care must be taken because its response, contrarily to what happens to pupil diameter, may vary in opposing directions depending on the activation state (visual or mental demand). In a driving task, visual and mental demands are always present to a higher or lower degree depending on the situation and level of time pressure. Indeed it could be possible that no effect was observable on HRV for the current study due to moderate level of time pressure that was induced. As a result, considering that the effects observed in the physiological measures highly depend on the level of visual and mental demand, the use of these measures is subject to further research in order to fully understand their behavior relative to all possible driving situations.

Some interaction-related measurements in terms of the subject's kinematic and kinetic activity also showed distinguishable differences between HTP and NTP conditions. However, the visual inspection of the plotted data revealed that these differences were mainly noticeable when analyzed per individual participant and were rarely observable for the combined data set of all participants. Note however that the fact that in the combined data set a difference between the HTP and NTP condition is observable does not mean that the difference is large enough to be used for detecting the state of driving haste. The majority of the assessed measurements related to body-motion significantly increased during the HTP condition, including: speed in the operation of the controls of the vehicle and acceleration of the limbs associated to these operations.

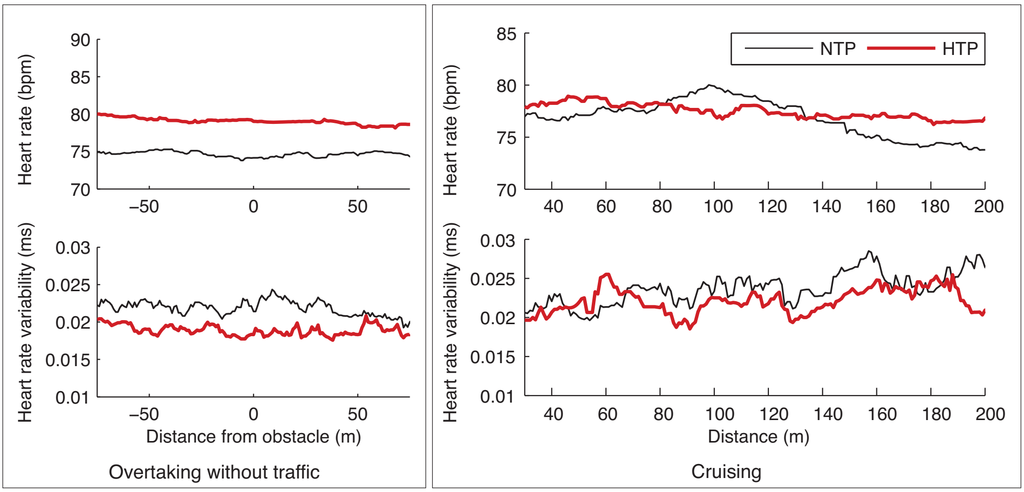

Figure 7.6. Heart rate and heart rate variability for the participants in overtaking and cruising situations

Moreover, the pedal displacement was clearly distinguishable between HTP and NTP drivers. Drivers under HTP condition press the throttle pedal farther than those under NTP condition. This observed result was even clearer when the analysis was done on an individual basis. The above outcome supports the idea that indicators should be studied within individual drivers rather than for combined groups of people. The impossibility of finding distinguishable results for some of the measurements such as force exerted on the steering wheel lies in the fact that the opposite behavior observable among all drivers leads to masking of effects when all results are studied together. For example, Figure 7.7 shows how the force exerted on the steering wheel has opposite behavior for some drivers in intersections situations.

Similarly, even when the same tendency is present between participants, the range of values for particular indicators varies considerably from driver to driver. Hence, their combination often averages results, eliminating the separation between distributions, as it was the case for the operation of the vehicle controls. Furthermore, not only the within and between driver variability affects the interpretation of results, but driving situations (e.g. car following, overtaking with and without traffic on the opposing lane, intersections with and without traffic and cruising) also reveal different effects in terms of tendencies and separation between distributions.

Then, since different drivers have different driving styles that cause variation in driving patterns and since different influencing factors might interact with each other, further research is needed to better understand driver variability and its implications on the identification of drivers under a time pressure condition. Moreover, the tendencies found in the number of operations for the controls of the vehicle were different from what was expected: instead of increasing, they often decreased. This result seems logical considering that the frequency of operations increases as time pressure increases but only for those tasks in which productivity is enhanced by such action. In this order of ideas, drivers could be omitting or limiting the use of those vehicle controls that are not essential for the completion of the task. Still, however, similar influences may result from other physically demanding activities within the vehicle (e.g. picking up the cell phone or having a discussion with a passenger) and, thus, further research on most of these measures is needed before they can be used for detecting a time pressure condition in car driving.

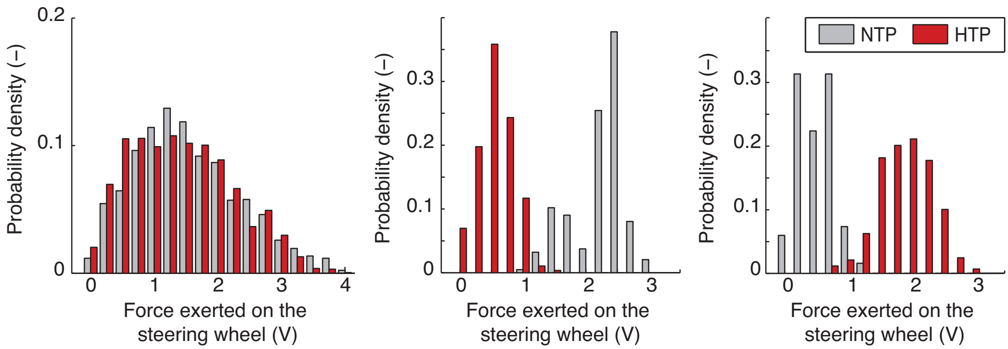

Figure 7.7. Probability distribution of the combined data set of all participants (left) and two individual participants with opposing tendencies (middle and right) for force exerted on steering wheel in car following situations

In terms of performance-related metrics, the effects of time pressure were generally as expected. The response of mean engine RPM, as well as the observed mean and maximum speed and acceleration of the vehicle, most possibly correspond to the acceleration of actions expected as the first coping mechanism used by most individuals under a time pressure condition. The results observed in terms of the minimum car following time and lateral positions of the vehicle also correspond to the fact that externally imposed time pressure overrules other goals in driving and induces an increased level of risk in the driving strategy. In turn, this risk-taking compensatory behavior leads to speed-accuracy trade-offs, and is observable in the standard deviation of lane lateral position. Again, though a difference between the two conditions exists, the combined results for all participants often do not reveal separable distributions between the HTP and the NTP conditions. The results studied per participant and per driving situation, as was already mentioned in the previous paragraph, provide differentiable results between the two driving conditions. Specifically, the findings of this study suggest that indicators such as engine speed, time headway, vehicle speed/acceleration and vehicle acceleration per throttle pedal operation filtered by velocity bands, show, at least for some participants, a clear separation between the two conditions. This means that performance metrics related to both longitudinal and lateral vehicle control are candidate measures for identifying driving under time pressure. Still, however, further research is needed because their response could easily be found for several other situations with increased visual demand or a different source of stress. Furthermore, a high value of acceleration cannot be defined without linking it to the speed at that particular moment. Thus, the use of vehicle acceleration/deceleration per throttle/brake pedal filtered by vehicle velocity bands are promising for identifying the state of driving under time pressure. More research is needed to establish the real potential of this finding.

In general, contrary to our initial hypothesis, there is no single indicator that is fully independent from the driving context and fully insensitive to differences among drivers. Besides, we could not find sufficient evidence suggesting that indicators closer to the source (i.e. the driver) were enough and the best for identifying driving in haste. Most probably the combination of indicators from different domains would result in a better recognition of this risky state and hence should be further explored.

Conclusions and propositions

Promising distinguishable differences between HTP and NTP conditions were recognized on physiological activity, driver interaction with the controls of the vehicle and driving performance. Though, these differences were mainly evident when analyzed per individual participant and were seldom observable for the combined data set of all participants. This refutes the initial belief that there existed at least one indicator that was completely insensitive to differences between drivers and, on the contrary, supports the idea that indicators should be studied within individual drivers rather than for combined groups of people. Further research is needed to better understand driver variability (driving style) and its implications on the identification of drivers under a time pressure condition. Furthermore, not only the within and between driver variability affects the interpretation of results, but driving situations (e.g. car following, overtaking with and without traffic on the opposing lane, intersections with and without traffic and cruising) also reveal different effects in terms of separation between distributions. These results similarly disproof the initial belief that there existed at least one indicator that was completely independent of the driving context. Despite the promising results, interaction-related indicators should be studied carefully since similar influences may result from other physically demanding activities within the vehicle and, thus, further research is needed before most of these measures can be used for detecting a time pressure condition in car driving.

Below, we present the technical propositions derived in this research:

Proposition 1:	As evidenced in the case of revealing observable manifestations of driving in haste, a review of the literature should be combined with other research methods, such as focus group sessions, if the researcher wants to generate reliable preliminary hypotheses.
Proposition 2:	The use of a driving simulator is in itself a source of intrinsic motivation for subjects taking part in the study of driving in haste, hence there is no need to use other external motivations in combination with a time constraint at completing a task.
Proposition 3:	It is necessary to consider the environment of driving because the studied indicators are different in specific driving situations and vary according to the associated mental/visual/physical demands (e.g., overtaking, car following, etc.) and external factors (e.g. environmental lighting conditions, etc.).
Proposition 4:	Contrarily to the belief that speed is sufficient to identify driving in haste, its potential to discriminate between NTP and HTP driving conditions in specific driving situations, such as driving in a traffic jam, is limited.
Proposition 5	The maximum vehicle acceleration/deceleration per throttle/brake pedal operation is not a sufficient indicator of driving under time pressure, because it cannot be assessed without considering the actual speed of the vehicle.
Proposition 6:	The threshold value of each indicator of driving in haste should be set on an individual basis because the studied indicators vary considerably from person to person and even relative to the same person.

Recommendations for future research

The main recommendation derived from this research is that indicators should be studied within individual drivers rather than for combined groups of people, as well as they should be studied per driving situations or individual maneuvers (e.g. overtaking, car following). Due to the fact that a driving simulator was used to gather the information regarding indicators of driving in haste, some validity issues exist. The extent to which the results can be compromised is not clear. Therefore it is recommended to perform a validation study using data collected in real driving situations through the use of an instrumented vehicle.

This research involved a limited number of driving situations (overtaking, car following, cruising and stop and go behavior in intersections) and a limited context (urban road with moderate traffic). It is therefore recommended to expand this research to include other driving situations such as stop and go behavior in traffic lights, roundabout negotiation, and lane shifting maneuvers, among others. Other driving contexts such as highways and rural roads should also be taken into account. Since mainly longitudinal behavior was considered, it is recommended to perform research on identifying indicators of driving in haste in lateral driving behavior. This research should be performed for more driving situations as well as for more driving contexts such as highways and rural roads.

The influence of physical activity on physiological data was not investigated in the current study. It is therefore recommended to perform future research on the influence on the physiological behavior of the driver caused by other activities executed in the car, such as talking on the phone. Influences of age, ethnicity, driving experience and gender are potential biases for the physiological, interaction and driving performance responses. Therefore, we recommend the study of whether these characteristics modulate the indicator responses when driving in haste.

Long-term exposure to driving under time pressure was not studied. Hence, studies with longer periods of driving should be designed in order to understand the effects of fatigue on the indicators of driving in haste. Studies with variations in the motivation or in the time constraint should be performed to further understand the phenomenon of driving in haste and the particular influences of different levels of time pressure.

Finally, the levels of mental and visual demands were not controlled during the current study. Since this could have significant impact on the behavioral responses, it is imperative to understand the effects of both mental and visual demand over the indicator in order to be able to define the expected outcome. For instance, assuming that blink rate is expected to increase as a result of high mental demand and to decrease as a result of high visual demand, then what determines the effects is the combination of both of these demands. If the mental demand is higher the expected outcome is an increase in blink rate, whereas if visual demand is higher the expected outcome is a decrease.

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Samenvatting

Achtergrond van het onderzoek

Met het toenemend dagelijks gebruik van auto's en het regelmatig voorkomen van complexe situaties bij het rijden is het aantal ongelukken dat gepaard gaat met gewonden of doden aanzienlijk toegenomen. Een onderzoek van de Wereldgezondheidsorganisatie WHO heeft aangetoond dat het gaat om jaarlijks maar liefst 50 miljoen gewonden en 1,24 miljoen doden [1]. Deze cijfers suggereren dat verkeersgerelateerde ongelukken kunnen worden beschouwd als een belangrijk sociaal en technologisch probleem van globale omvang. Daarom is verkeersveiligheid niet alleen van hoge prioriteit geworden voor de overheid, maar ook voor de meeste autofabrikanten en andere betrokkenen. Om de veiligheid van mobiliteit te verbeteren zijn een aantal projecten voorgesteld, uiteenlopend van verbetering van de infrastructuur tot veiligheidssystemen in voertuigen [2].

Conventionele benaderingen om verkeersveiligheid te verbeteren concentreren zich vooral op passieve veiligheid (bijvoorbeeld airbags, veiligheidsriemen, gordelspanners, gelamineerde ruiten en samendrukbare stuurkolommen) met het doel de ernst van verwondingen te verminderen in plaats van verwondingen te voorkomen. In hedendaagse voertuigen zijn de genoemde passieve veiligheidssystemen aangevuld met actieve veiligheidssystemen die tevens beogen ongevallen te voorkomen. Daarbij valt te denken aan elektronische stabiliteitsregeling, tractiecontrole, en toegewijde bestuurdersondersteuning zoals adaptieve cruise control, waarschuwingssystemen voor het verlaten van de rijstrook, botsingswaarschuwings- en preventiesystemen, en parkeerassistentie. Omdat het gedrag van bestuurders als belangrijkste factor bijdraagt aan verkeersongelukken en omdat het beter is ongelukken te voorkomen dan alleen de ernst van verwondingen te verminderen, is er de laatste jaren veel aandacht geweest voor actieve veiligheidssystemen, en verscheidene *advanced driver assistance systems* (ADAS) hebben aan populariteit gewonnen [3].

De huidige ADASen ondersteunen de bestuurder vooral in een of meer hoofdtaken bij het sturen, d.w.z. perceptie, analyse en besluitvorming, en handeling [4]: ze helpen de bestuurder de omgeving te herkennen, de situatie te beoordelen, of in handelingen die moeten worden uitgevoerd. De meeste systemen die tot nu to ontwikkeld zij werken als een proces parallel aan dat van de bestuurder, daarbij alleen input van de omgeving en het voertuig in beschouwing nemend. Met andere woorden: ze nemen de rijomstandigheden waar en ondernemen dan actie zoals de bestuurder dat had moeten doen. De meeste ADASen houden geen rekening met de bestuurder in de terugkoppelkring en zijn zich dientengevolge niet bewust van de eigenschappen, de gesteldheid en het gedrag van de bestuurder. Onlangs zijn, in een poging het aantal valse alarmen dat deze systemen afgeven te verminderen, zijn meer geavanceerde z.g. *mensge-*

richte ADASen voorgesteld die niet alleen de omgeving en de toestand van de auto in de gaten houden, maar ook de bestuurder om zo rekening te houden met diens bedoelingen (draaien, stoppen, van rijstrook wisselen), omstandigheden (vermoeid, onder invloed, alert, geïrriteerd etc.).

Momenteel kunnen nog niet al te veel systemen zich aanpassen aan kenmerken van de bestuurder, maar nu geavanceerde informatietechnologie, geminiaturiseerde componenten en waarnemings- en regelsystemen in toenemende mate in alledaagse producten worden toegepast, wordt aangenomen dat de systemen die zich aanpassen aan de kenmerken, emotionele gesteldheid en andere condities van de bestuurder niet alleen verfijnder zullen zijn maar ook vaker worden toegepast in de toekomst [5]. In een maatschappij waarin alomtegenwoordige netwerken in opkomst zijn zullen bestuurder-monitoringfuncties van doorslaggevend belang worden in systemen ter ondersteuning van het autorijden, en veiligheidssystemen zullen waarschijnlijk in staat zijn de bestuurder volledig te begrijpen en tegemoetkomen aan diens individuele behoeften. Om dit mogelijk te maken zullen ondersteuningsinstrumenten voor autorijden de kenmerken, de actuele gemoedstoestand en verschillende andere condities van de gebruiker moeten kunnen herkennen. Vrijwel zeker zal de eerste stap naar intelligente monitoring van gebruikers bestaan uit het automatisch detecteren en interpreteren van de gesteldheid van de bestuurder.

Voor de meest-bestudeerde gevaarlijke condities zijn al enkele detectie- en monitoringsystemen ontwikkeld, namelijk voor het vermoeid, afgeleid en onder invloed van drugs zijn. Hoewel deze condities bovenaan staan in de ongevallenstatistieken van de gehele wereld, kan wangedrag van bestuurders vele andere vormen aannemen. Veel daarvan treden op als bestuurders haast hebben. De gesteldheid 'haast' is een mentale gesteldheid waarin iemand zich tot spoed gemaand voelt. Het wordt algemeen erkend dat zich haasten meer nog dan (te) hard rijden een belangrijke oorzaak is van auto-ongelukken, ook omdat de meeste botsingen plaatsvinden beneden de maximumsnelheid. Kinderen zijn bijvoorbeeld op tragische wijze overreden door auto's die achteruit een huisoprit verlieten. Onderzoeken in Europa en Japan hebben aangetoond dat haast op de weg vele levens gekost heeft [6,7]. Gehaast rijden verhoogt de kans op ongelukken door te hard rijden, sneller optrekken, heftiger remmen, gevaarlijk inhalen en bumperkleven [8].

Haast is een complex verschijnsel dat ontstaat vanuit verscheidene factoren, waarvan de belangrijkste zijn (i) fysiologische condities (bijv. een volle blaas), (ii) sociale druk (bijv. culturele normen die voorschrijven dat hard rijden stoer is), (iii) motivatie-gerelateerde gesteldheden (bijv. irritatie, woede), en (iv) tijdgerelateerde condities (bijv. ergens te laat dreigen te komen). Al deze verschillende factoren, die kunnen worden gedefinieerd als stressoren, zetten iemand onder druk en veroorzaken gevoelens van gespannenheid [9]. Op basis van Lazarus en Folkmans Transactionele Model voor stress en de omgang daarmee, kan worden gesteld dat deze stressoren, of potentieel stressvolle gebeurtenissen, een inschattingsproces activeren waarin de mens de mate van bedreiging beoordeelt die de stressor vormt voor zijn welzijn, en vaststelt hoe hij/zij zijn/haar capaciteiten kan inzetten bij het omgaan met deze bedreiging [10]. In dit proefschrift wordt met 'haast' die vorm van stress bedoeld die, getriggerd door bovenvermelde factoren, wordt ondervonden als een aandrang tot spoed, waarbij het als eerste ingezette mechanisme om dit te bedwingen is, handelingen snel uit te voeren (Figuur 7.1, p. 195): Transactioneel model voor stress en het omgaan daarmee).

Hoewel haast gewoonlijk geassocieerd wordt met het fysieke verschijnsel dat handelingen snel worden uitgevoerd, kan het fenomeen zich, als versneld handelen verhinderd wordt, ook manifesteren in andere gedragsveranderingen. Om deze andere veranderingen te begrijpen moest de literatuur over haast tijdens het rijden verder bestudeerd worden.

Reeds bekend onderzoek op het gebied van haast tijdens het rijden

Vanuit verscheidene onderzoeken wordt gerapporteerd dat gehaast autorijden gewoonlijk riskante gedragingen veroorzaakt. De meeste publicaties gaan echter niet in op de specifieke manifestaties van gehaast rijden, en concentreren zich slechts op het meest voor de hand liggende riskante rijgedrag, zoals (te) hard rijden, bumperkleven en snel optrekken. Bovendien zijn de meeste onderzoeken gebaseerd op enquêtes waarbij de respondenten video's of foto's moesten beoordelen in hoeverre de getoonde bestuurders haast hadden en hoe ze daarop zouden reageren. De antwoorden die deze respondenten gegeven hebben mogen dan over het algemeen wel waar zijn, maar wellicht hebben ze niet allemaal eerlijk geantwoord en daarmee de onderzoeksresultaten vertekend. De neiging om antwoorden te veinzen is goed gedocumenteerd in [11]. Resultaten van op enquêtes gebaseerd onderzoek moeten zorgvuldig beschouwd en geverifieerd worden door objectievere benaderingen toe te passen, zoals studies in een rijsimulator of naturalistische observatie. Het gebruik van enquêtes voor het afleiden van hypothesen en vervolgens rijsimulatoren om deze te toetsen, lijkt een effectieve aanpak om voorspellende indicatoren van gehaast rijden bevestigd te krijgen.

Weliswaar zijn in enkele technisch georiënteerde onderzoeken rijsimulatoren gebruikt om bepaalde uitingen van haast te identificeren, maar in deze onderzoeken is alleen voertuiggerelateerde informatie gebruikt (snelheid, acceleratie etc.) om haast te karakteriseren. Gezien het feit dat in het gehele proces van autorijden het gedrag van de bestuurder wordt overgedragen via de bestuurdersinteractie, en dat het gedrag van de auto en zijn interactie met de omgeving daar weer een reactie op is, lijkt voertuiginformatie (d.w.z. indirecte rijparameters) alleen niet voldoende voor het detecteren van gevaarlijke condities bij de bestuurder. Daarentegen is het redelijk om te veronderstellen dat het combineren van indirecte rijparameters met directe, bestuurdergerelateerde gegevens (d.w.z. indicatoren die te maken hebben met de kennisdomeinen 'fysiologie van de bestuurder' en 'interactie van de bestuurder met de auto') het onderscheidend vermogen kunnen verhogen, en daarmee leiden tot nauwkeurigere detectie van haast. Eigenlijk kan het al voldoende zijn om uitsluitend te kijken naar indicatoren dichter bij de bron (directe bestuurdergerelateerde meetwaarden), en daaruit voorvloeiende indirecte waarden niet mee te nemen. Weliswaar bieden sommige onderzoeken naar gehaast autorijden bruikbare uitgangspunten voor het begrijpen van de effecten van gehaast rijden, maar de resultaten zijn nog exploratief en gekleurd door meningen van bestuurders. Er is weinig bekend over de afzonderlijke kenmerken die de effecten van gehaast rijden bepalen. Om de impact van deze kenmerken op de gevolgverschijnselen van haast te kunnen begrijpen moet meer empirisch onderzoek gedaan worden naar de relatie tussen rijstijl en gehaast rijden.

Onderzoeksproblemen

Uit de bestudeerde literatuur ontstond een eerste indruk en aanname dat er in de toekomst meer mensgerichte ADASen nodig zouden zijn. In zulke systemen zal de bestuurdersmonitoringfuncte doorslaggevend worden bij het detecteren van de bedoeling en de gesteldheid van de bestuurder, alsmede voor het beoordelen van een bepaalde gevaarlijke situatie. Daarom zal het nodig zijn om alle mogelijke gesteldheden en activiteiten van de bestuurder te bestuderen die verkeersongelukken kunnen veroorzaken. Omdat als gevaarlijke gesteldheid die bijdraagt aan verkeersongelukken, gehaast autorijden vaak bovenaan verschijnt in resultaten van onderzoeken waarin zowel mentale als fysieke gesteldheden direct voor het ongeluk worden meegenomen, wordt er in dit onderzoek van uitgegaan dat de ontwikkeling van een systeem voor het detecteren van haast aanzienlijk zal bijdragen aan het reduceren van het aantal verkeersongelukken. Begrip van het fenomeen, in tremen van hoe het wordt ontwikkeld en de manifestaties ervan, ia nodig voor de ontwikkeling van een technisch ondersteuningssysteem. Om uitgebreid begrip te krijgen van het fenomeen en om optimale detectiemogelijkheden te verkennen moet de kennis van psychologen en ingenieurs m.b.t. gehaast rijden worden gecombineerd, ook al zijn er in de literatuur geen aanwijzingen dat er inspanningen in die richting verricht zijn.

Als haast nu kan worden beschouwd als een vorm van stress teweeggebracht door een bepaalde stressor, kan worden verwacht dat de bestuurder reageert op deze stressor op een manier gelijkend op de manier waarop hij/zij reageert op andersoortige stressoren zoals hitte of lawaai: door uitzonderlijke mentale of fysieke inspanning of door veranderingen in prestatie te vertonen. Deze stressor zal, zoals elke andere dat zou doen, mogelijk beïnvloeden hoe de bestuurder presteert (in termen van gedrag), hoe hij zich voelt (emotioneel) en hoe lichaamsfuncties reageren (fysiologisch). Bijgevolg kan worden verwacht dat gehaast rijden enige herkenbare symptomen te zien zal geven in de fysiologie van de bestuurder en in zijn/haar interactie met het voertuig. Onze hoofdaanname is daarom dat het gedrag van de haastige automobilist verschilt van diens gedrag in normale situaties en dat de veranderingen die zich voordoen in het gedrag, vanuit de bestuurder zullen doorwerken via de auto naar de omgeving. Tot nu toe hebben onderzoekers zich echter geconcentreerd op het detecteren van gehaast autorijden door slechts enkele vormen van gedrag van het voertuig te beschouwen, en wel de meest voor de hand liggende. Daarom kan worden gesteld dat de methodes gebaseerd op deze vormen van gedrag pogen de gesteldheid van de bestuurder op een indirecte manier vast te stellen.

Dit onderzoek concentreert zich daarentegen op het probleem, gehaast rijden niet alleen op basis van voertuiginformatie maar ook op basis van informatie over de fysiologie van de gebruiker en van zijn interactie met de auto. Meer specifiek gaat het daarbij om het identificeren van de gevolgen die gehaast rijden heeft op de fysiologie van de bestuurder, diens interactie met de auto en de rijprestaties. Om gehaast rijden te onderzoeken, moet het verschijnsel worden opgewekt, ofwel in het echt, ofwel in een virtueel scenario. Het is echter moeilijk om gehaast rijden in het echt te onderzoeken, omdat er dan allerlei invloeden meespelen die niet onder controle kunnen worden gehouden. Bovendien kan het met opzet opwekken van haast bij bestuur in het normale wegverkeer leiden tot onveilige situaties, waardoor dit onethisch is. Haast reproduceren in een laboratoriumomgeving blijkt de meest haalbare benadering te zijn. Ervan uitgaand dat haast kan worden opgewekt in een kunstmatige omgeving, was dan het volgende vraagstuk in dit onderzoek hoe dit kan worden gedaan in een rijsimulator.

Hoofddoel van het onderzoek

Omdat haast wereldwijd een aanzienlijk aantal verkeersongelukken veroorzaakt en omdat onderzoek op dit gebied tot dusver tekort geschoten is qua kwaliteit (aantal onderzoeken) en kwaliteit (vooral enquêtes en kleine steekproeven), het hoofddoel van dit promotieonderzoek was om indicatoren van gehaast autorijden te identificeren die voldoende discriminerend vermogen hebben, en die uiteindelijk kunnen worden gebruikt voor het ontwikkelen van detectie-algoritmes onder echte rijomstandigheden.

Meer specifiek is beoogd het verschijnsel haast beter te begrijpen om (i) deze toestand te kunnen opwekken in een rijsimulator, (ii) op basis van literatuur en kennis aangeleverd door deskundigen, mogelijke verschijnselen en indicatoren van haast te identificeren die waarneembaar zijn, en (iii) het discriminerend potentieel van de gevonden indicatoren empirisch te beoordelen d.m.v. het opzetten en uitvoeren van een experiment in een rijsimulator.

Hypothesen en aannames

Zoals reeds vermeld was de belangrijkste aanname voor het promotieonderzoek dat het gedrag van een bestuurder die haast heeft verschilt van diens normale rijgedrag en dat de optredende gedragsveranderingen via de auto naar de omgeving doorwerken. De gedragstoestand van de bestuurder zou dus niet allen zijn weerslag moeten hebben op het menselijk lichaam, maar ook in waarneembare vorm op de interactie met de auto, de auto zelf en de interactie tussen auto en omgeving.

Bovendien was de hoofdhypothese voor het onderzoek dat er ten minste een indicator zou zijn die volkomen onafhankelijk is van de context van het rijden en volkomen ongevoelig voor verschillen tussen bestuurders. M.a.w., voordat het onderzoek was uitgevoerd was ervan uitgegaan dat er in elk geval één indicator kon worden gevonden die daaraan voldeed.

Een ondergeschikte hypothese was afgeleid van het feit dat, in het algehele proces van autorijden, het gedrag van de auto (snelheid, acceleratie etc.) voortkomt uit het bestuurdersgedrag en dat rijparameters dus indirect volgen uit bestuurdershandelingen. Omdat zowel indirecte als indirecte meetwaarden vergelijkbare informatie leveren, werd verder verwacht dat indicatoren dichter bij de bron (de bestuurder) het meest geschikt zouden zijn om haast te detecteren. Feitelijk werd aanvankelijk verwacht dat zulke indicatoren alleen al genoeg zouden zijn voor dat doel.

Een andere hypothese was gerelateerd aan het opwekken van haast in bestuurders in een laboratoriumopstelling met een rijsimulator. De premisse was dat, omdat er een tijdgerelateerde stressor werd gebruikt, gehaast rijden kon worden geïnduceerd door toepassing van het construct 'tijdsdruk' gedefinieerd als een tijdbeperking plus een motivatie om een rit binnen de opgegeven tijd te voltooien. M.a.w., zolang de proefpersoon daartoe voldoende gemotiveerd was, werd verwacht dat haast veroorzaakt door een tijdgerelateerde stressor opzettelijk kon worden opgewekt door de beschikbare tijd voor de rit te beperken.

Algehele onderzoeksaanpak

Om gehaast autorijden te herkennen is het nodig om kennisbestanden op te bouwen vanuit de gedragswetenschappen en de technische wetenschappen. Het verzamelen en samenbrengen van kennis uit meerdere vakgebieden maakt het onderzoek gecompliceerder. Om daarmee om te gaan, is op het onderzoeksontwerp een multi-methodologische opzet toegepast. Het gehele promotietraject is onderverdeeld in vier onderling gerelateerde cycli, zoals te zien is in Figuur 7.2, p. 198: Organisatie van de onderzoekscycli). Elke cyclus had bepaalde doelstellingen en was opgezet volgens een vastgestelde methodologie. Daarvoor is de *methodological framing theory* van Horváth [12] gebruikt. De eerste drie onderzoekscycli waren gericht op het verzamelen van kennis over indicatoren die bij situaties van gehaast rijden worden aangetroffen en over het opwekken van haast in een rijsimulator. Deze cycli waren methodologisch opgezet als onderzoek in een ontwerpcontext (OOC). De vierde cyclus, waarin indicatoren worden gekozen, gecombineerd, en geassocieerd met meettechnologie, was opgezet Ontwerpomvattend onderzoek (OOO).

Deze methodologische opzet was nodig omdat de eerste drie onderzoekscycli gericht waren op het samenbrengen van inzicht in, en begrip van, het verschijnsel 'haast' in een bepaalde context, namelijk autorijden, terwijl in de vierde cyclus een experimentele opzet was gebruikt om de indicatoren te detecteren en te toetsen, die ook diende als een onderzoeksinstrument in ontwikkeling. Het specifieke doel van de eerste twee cycli was om in de onderhavige context een groep waarneembare gedragsindicatoren te bepalen. We hebben onderzocht welke verschijnselen sterk gerelateerd waren aan gehaast rijden, en hoe verschillende manifestaties daarvan konden worden beschreven door een verband te leggen met indicatoren. Omdat gehaast rijden moeilijk in het echt kan worden bestudeerd, is in de derde cyclus onderzocht hoe een emotionele gemoedstoestand zodanig in proefpersonen kan worden opgewekt dat we zeker konden zijn dat ze ook echt haast ondervonden. In de vierde cyclus zijn de indicatoren verder onderzocht en verfijnd teneinde die indicatoren te vinden die voldoende discriminerend vermogen boden.

Onderzoekscyclus 1: Verkenning van waarneembare gevolgverschijnselen van gehaast autorijden

Onze voorafgaande literatuurstudie gaf aan dat er veel gerapporteerd is over waargenomen of veronderstelde gevolgverschijnselen van haast of haastig handelen. Daarom hebben we als specifiek doel van deze onderzoekscyclus gesteld, algemeen waarneembare gevolgverschijnselen van haast te verkennen en samen te brengen die samenhangen met (i) de fysiologische toestand van de bestuurder, (ii) de interactie van de bestuurder met de auto, (iii) het gedrag van de auto, en (iv) de algehele rijprestaties. We waren van plan de resultaten van dit secundaire onderzoek niet alleen te gebruiken om bestaande informatie en kennis te verzamelen, maar ook om vanuit dit bestaande bestand te extrapoleren en nieuwe inzichten en verbanden vast te stellen. De bedoeling was, deze informatie over waarneembare gevolgverschijnselen van haast te hergebruiken in een volgende onderzoekscyclus gewijd aan het identificeren van detecteerbare gedragsindicatoren ter herkenning van gehaast rijden.

Zoals hierboven aangegeven waren de belangrijkste, elkaar aanvullende, onderzoeksmethoden in deze onderzoekscyclus de kwalitatieve en de kwantitatieve literatuurstudie. Praktisch gezien, op basis van meerdere steekwoorden op internet gezocht naar zowel wetenschappelijke publicaties als websites. Informatie en gegevens over gevolgverschijnselen van gehaast rijden werden samengebracht door verscheidene gestructureerde lijsten met zoekterm en geciteerde referenties. In de kwalitatieve fase van het onderzoek werden de gegevens weergegeven in de geschreven tekst geïnterpreteerd en gecodeerd, en op inductieve wijze werden aannames gedaan. In de kwantitatieve fase van de studie werden de verschijningsfrequenties van de bevindingen vastgelegd en bestudeerd.

Qua bestuurdersfysiologie berichtten de bestudeerde artikelen over verscheidene gevolgverschijnselen van haast, zoals (i) veranderingen in cardiovasculaire activiteit (hartslag, bloeddruk), (ii) variaties in ademhalingsactiviteit (frequentie), (iii) variaties in andere lichamelijke reacties (spierspanning, huidtemperatuur), (iv) variaties in elektrische geleidbaarheid (veroorzaakt door transpiratie), alsmede (v) het vertonen van openlijke reacties zoals grove gebaren, vloeken en schelden, en (vi) het vertonen van ongebruikelijke gezichtsuitdrukkingen (fronsen).

Bovendien werd bericht over verscheidene waarneembare gevolgverschijnselen van haast in termen van interactie tussen bestuurder en auto, gerelateerd aan (i) intensiteit van bediening van bedieningsorganen (bijv. kracht uitgeoefend op versnellingspook, gaspedaal en/of koppeling), (ii) bewegen van het stuur, (iii) kracht uitgeoefend op het stuur, en (iv) snelheid van pedalen wisselen. Daarnaast werd nog (v) overmatig gebruik van waarschuwingssignalen zoals toeteren en knipperen met de koplampen genoemd.

Qua gedrag van de auto werden genoemd (i) snelheidsprofiel over de tijd en (ii) acceleratie- en deceleratieprofiel.

Tot slot omhelsden de rijprestatie-gerelateerde verschijnselen verscheidene riskante gedragingen zoals (i) door rood of geel rijden, (ii) negeren van verkeersborden en waarschuwingssignalen, (iii) onvoldoende afstand houden tot voorganger, (iv) gevaarlijk inhalen, en (v) anderen op hun rijstrook afsnijden. Verder werden nog genoemd (vi) voetgangers niet laten oversteken en (vii) vaak van rijstrook wisselen.

Onderzoekscyclus 2: Interrogatief onderzoek naar waarneembare gevolgverschijnselen van haast

Om de verzameling van de in de eerste cyclus gevonden gevolgverschijnselen van haast uit te breiden hebben wij een interrogatief onderzoek beraamd. Deze werd met verscheidene personen uitgevoerd in de vorm van focusgroepssessies (FGSs). De deelnemers aan de FGSs waren doorsnee automobilisten, deskundigen op het gebied van gedragspsychologie en medische wetenschap en verkeerstechnici. Hun opdracht was verslag te doen van hun ervaringen met, en hun mening te geven over, de manifestatie en identificatie van haastig autorijden. We waren vooral geïnteresseerd in identificatie van instrumenteel detecteerbare verschijnselen. Dezelfde vier aspecten als in de vorige onderzoekscyclus kwamen aan de orde. Doel van dit deelonderzoek was ook, een datatriangulatie te kunnen uitvoeren, d.w.z. de bevindingen uit de eerste cyclus te vergelijken met die uit de tweede, en overlappingen en aanvullingen vast te stellen.

Wat betreft de uitvoering van de eerste twee cycli moet het volgende worden opgemerkt. Zoals gezegd werden de explorative componenten hiervan respectievelijk volbracht in de vorm van een literatuur- en een focusgroep-studie. De concluderende fasen van beide cycli zijn uitgevoerd en samengebracht als reeds beschreven, met de noodzaak en het nut van datatriangulatie in gedachten. Dit onderzoeksontwerp maakte het mogelijk, beide cycli zowel epistemologisch als methodologisch volledig te maken [13]. We hebben vastgesteld dat er een redelijk grote overlap bestaat tussen de waarneembare verschijnselen uit de literatuurstudie en die uit de focusgroepssessies, en dat een aanvullende verzameling verschijnselen kon worden samengesteld op basis van de toegevoegde en niet-ontkende bevindingen.

De focusgroepssessies zijn gebruikt als een kwalitatieve methodologische benadering van gegevensverzameling m.b.t. gehaast rijden. In elk van de vijf sessies, die waren uitgevoerd als discussieforums met een open einde en een niet-dwingend voorgeschreven opzet, werd de deelnemers gevraagd hun mening te geven over de houding, gedragingen, handelingen etc. van gehaaste automobilisten. Om het bewustzijn van de deelnemers te verhogen, een gerichte discussie te bevorderen en elk commentaar van de deelnemers vast te leggen, hebben we (i) een visuele begrippenlijst, (ii) een video met verkeerssituaties en (iii) een enquête gebaseerd op afbeeldingen ontwikkeld.

Na elke focusgroepssessie werden de opnames uitgeschreven. De informatie van de deelnemers en de aantekeningen van de discussieleider werden uitgetikt. De gegevens uit de verschillende sessies werden samengebracht in een bestand. Deze ruwe data werden ontdaan van overbodige gegevens en semantisch geanalyseerd. Veel inspanning is verricht om overbodige data te verwijderen, zodat de grote hoeveelheid opnamen en notulen beheersbaar te houden, en een beschrijvende theorie te ontwikkelen omtrent de relevante indicatoren van haastig autorijden.

De procedure om de data uit de focusgroepstudie te analyseren omvatte met name de volgende activiteiten (Figuur 7.3, p. 201: Procedure van data-analyse voortkomend uit de focusgroepstudie): (i) datatransscriptie, (ii) groeperen van de ruwe data (verbale expressies) op basis van hun betekenis (in semantische groepen), (iii) karakterisering van elke groep d.m.v. een beschrijving in tekst, (iv) sorteren van de beschrijvingen (mogelijke waarnemingen betreffende gehaast rijden) volgens de indeling *bestuurder / bestuurdersinteractie met de auto / auto / interactie tussen auto en omgeving,* (v) vaststelling van de achterliggende gevolgverschijnselen van haast op basis van de beschrijvingen, (vi) afleiden van nieuwe indicatoren voor elk verschijnsel en (vii) indicatoren volgens bovengenoemde indeling sorteren en beoordelen. Tabel 7.1 (p. 202) bevat een selectie uit de lijst van gesorteerde indicatoren gerelateerd aan de bestuurdersinteractie met de auto.

Uit congruentieanalyse bleek dat sommige beweringen uit de focusgroepen weliswaar beweringen uit de literatuur bevestigden, maar dat anderen slechts bevestigd werden door enkele deskundigen. Daaro werd een correspondentieanalyse doorgevoerd om zichtbaar te maken hoeveel kennis en welke stukjes kennis daadwerkelijk het verkregen corpus aan kennis bevestigden. M.a.w. de frequentie waarin bepaalde verschijnselen genoemd waren, werd gebruikt om de relevantie ervan uit te drukken, d.w.z. in hoeverre een gevolgverschijnsel daadwerkelijk gehaast rijden beschreef. Een eerste hypothese voor dit deelonderzoek was dat indicatoren dichter bij de bestuurder zelf konden worden beschouwd als toereikend om gehaast rijden vast te stellen. Overeenkomstig werden verschijnselen met hoge relevantie geselecteerd voor verder onderzoek. Het ging daarbij om (i) hartslag, (ii) bloeddruk (cardiovasculaire activiteit), (iii) variatie in blikrichting (visueel gedrag), (iv) huidtemperatuur en -geleidbaarheid, (vi) ademhalingsfrequentie, (vii) intensiteit van lichaamsbewegingen en (viii) intensiteit van interactie met bedieningsorganen. De congruentie- en correspondentieanalyse lieten echter ook zien dat enkele gevolgverschijnselen waarneembar in gedrag van de auto en de interactie tussen auto en omgeving potentiele kandidaten zouden zijn voor het detecteren van haast.

Onderzoekscyclus 3: Onderzoek naar tijdsdruk als een substituut voor haast

Om het fenomeen haastig autorijden te onderzoeken moest deze conditie in bestuurders worden opgewekt. Zoals eerder gesteld leek dit het beste te realiseren in een laboratoriumomgeving. Omdat verschillende stressoren (bijv. fysiologische aandrang, tijdbeperking etc.) op zich weer tot verschillende gevolgverschijnselen konden leiden werd ‘gehaast rijden’ verder gereduceerd tot ‘gehaast rijden als gevolg van een tijdbeperking’, ook wel bekend als ‘tijdsdruk’. Tijdsdruk werd gekozen omdat de literatuur het heeft genoemd als een sleutelfactor die van invloed is op bestuurdersveiligheid [14], of zelfs de enige factor die significant differentieert tussen ongelukkenmakers en niet-ongelukkenmakers [15]. Bovendien is het opleggen van een tijdbeperking in vergelijking met andere stressoren, zoals bijvoorbeeld het opleggen van een fysieke aandrang die het welzijn negatief kan beïnvloeden, vanuit ethisch oogpunt wenselijker en ook beter realiseerbaar. Ook was tijdsdruk al eerder succesvol in een laboratoriumopzet gemanipuleerd, bij onderzoek naar kantoorwerk [16].

Systematische bestudering van de literatuur over het opwekken van haast d.m.v. een tijdbeperking, of tijdsdruk, liet zien dat tijdsdruk als stressor kon worden opgelegd door deze te koppelen aan een te volbrengen opdracht. De *variable state activation theory* (VSAT) stelt dat er, om te effectief te kunnen zijn als stressor die leidt tot versneld uitvoeren van handelingen, aan twee voorwaarden moet worden voldaan [17]: (i) de hoeveelheid tijd beschikbaar om de opdracht te volbrengen moet minder zijn dan de tijd die de proefpersoon daarvoor nodig heeft en (ii) de proefpersoon moet gemotiveerd worden om de opdracht in de beperkte beschikbare tijd te voltooien (m.a.w. de opdracht moet belangrijk genoeg zijn voor de persoon). Proefpersonen zouden dus geen tijdsdruk ervaren als aan een van deze voorwaarden niet voldaan wordt. Bovendien waren de manipulaties voor beide componenten die andere onderzoekers al hadden gebruikt ook afgeleid uit de literatuurstudie en als uitgangspunt genomen voor dit onderzoek (Figuur 7.4, p. 203: Manipulatie van tijdsdruk).

Het doel van deze onderzoekscyclus was dus om een betrouwbare motivatie en mate van manipulatie te bepalen, zodanig dat in het rijsimulator-onderzoek een gevoel van spoed werd ervaren. Doel was, in termen van motivatie en tijdmanipulatie, richtlijnen te uit te vaardigen voor het opzetten van een volgend deelonderzoek om de vastgestelde verzameling gedragsindicatoren om gehaast autorijden te detecteren verder te onderzoeken. Met het oog daarop werden verscheidene motivaties in combinatie met een tijdbeperkingsstrategie getoetst in een experimenteel onderzoek met een klein aantal proefpersonen. Een adaptieve tijdbeperking werd gebruikt als manipulatiestrategie voor tijdbeperking. Uit de verschillende motivaties genoemd in de literatuur werden de volgende gekozen om te toetsen: gaming, een rollenspel oftewel verplaatsing in een denkbeeldige situatie, competitie, gaming met een financiële beloning en competitie met financiële beloning. In al deze motivaties werd visuele feedback gegeven d.m.v. een timer die de tijdsdruk moest benadrukken. Een dergelijke timer is volgens de literatuur al vaak toegepast, en bovendien is in echte auto's meestal ook een klok aanwezig. Een audiosignaal is niet overwogen omdat dat een extra bron van stress kan vormen.

De uitkomst was dat elk van de motivatiestrategieën, of er nu wel of niet een denkbeeldige situatie, een competitie-element of een beloning werd gebruikt, evenzeer bleken te leiden tot een detecteerbare vorm van, en mate van haast bij alle proefpersonen. Het was zelfs zo dat de rijsimulator, die de meeste proefpersonen een nieuwe ervaring bood, op zichzelf al een effectieve stimulus vormde om goed te presteren Deze biedt dus een goed uitgangspunt om een experiment op te zetten dat de bij de proefpersonen aandacht opeist en nieuwsgierigheid wekt (m.a.w. intrinsieke motivatie), en samen met een tijdsbeperking om een opdracht te vervullen voldoende blijkt te garanderen dat proefpersonen in detecteerbare mate haast ervaren.

Hoewel dit beperkte onderzoek geen statistisch significante verschillen tussen de getoetste motivaties kon aantonen, leverde het in tegenstelling tot het beperkte aantal reeds verrichte empirische onderzoeken op dit gebied, voldoende onderbouwing voor het succesvol opwekken van haast

Onderzoekscyclus 4: Het vinden van indicatoren voor gehaast rijden onder invloed van tijdsbeperking

Op basis van het voorafgaande kon in de vierde onderzoekscyclus de uiteindelijke groep detecteerbare gedragsindicatoren voor gehaast autorijden als gevolg van inperking van de tijd waarin een rit moest worden volbracht, worden vastgesteld en beoordeeld. Om belangrijke begrippen en definities binnen dit onderzoek te verduidelijken, is een opzet vastgesteld voor de processen en mechanismen die te maken hebben met menselijke prestatie bij haast als gevolg van een tijdbeperking. Dit is gedaan op basis van eerder voorgestelde transactionele modellen van stress (Figuur 7.5, p. 205: Model van het omgaan met tijdsdruk gebaseerd op het Transactioneel Model voor Stress). In dit model wordt stress beschouwd als een interactie tussen de omgeving (eisen die een opdracht stelt) en het individu (capaciteiten om stress te bedwingen), waarbij de rol van het inschatten van situaties door het individu bij het bepalen van zijn responsen benadrukt wordt. De eisen die een opdracht stelt zijn een som van zowel een intrinsieke als een uitwendige belasting, respectievelijk bestaand uit (i) de aard van de opdracht met zijn fysieke en mentale uitdagingen en (ii) de omstandigheden waaronder de opdracht wordt uitgevoerd (in ons geval de tijdbeperking). Daarbij wordt werkbelasting gedefinieerd als het construct dat weerspiegelt in hoeverre de eisen die de opdracht stelt binnen het bereik van de mentale en fysieke mogelijkheden van het individu (de bestuurder) vallen. De combinatie van intrinsieke en uitwendige belasting definieert de situatie of de stressor.

Beoordeling van tijdsdruk is een proces dat zich op twee niveaus afspeelt: het relateren van de stressor aan de capaciteiten van het individu, en het uitvoeren van een primaire en een secundaire inschatting. Tijdens deze inschattingsprocessen wordt continu de actuele toestand van cognitieve/fysieke activiteit vergeleken met een beoogde eindtoestand [18]. Elke keer als er stress wordt ondervonden na de eerste inschatting, worden verdedigingsmechanismen in stelling gebracht en als gevolg van de tweede inschatting worden strategieën geselecteerd om de stress te bedwingen. Vier regelende modi zijn beschikbaar om toegenomen cognitieve/fysieke belasting te bedwingen: (i) intensivering van de beheersingsinspanning door aansturende handelingen te versnellen, (ii) veranderen van de beoogde eindtoestand door de input te filteren, (iii) eisen veranderen of elimineren (weglating of verandering van strategie), en (iv) niets doen (geassocieerd met angst en paniek). Het tot uitvoering brengen van zulke strategieën om stress te bedwingen uit zich in fysiologische reacties, in de interactie en in de rijprestaties. Deze responsen kunnen overeenkomstig gemeten worden met specifieke indicatoren op laag niveau.

Als we het beschreven model volgen, bijvoorbeeld in de context van autorijden (intrinsieke belasting) onder tijdsdruk (uitwendige belasting), vergelijkt het eerste inschattingsproces van de bestuurder de geschatte tijd nodig om op de gegeven bestemming aan te komen (met constante beschouwing van gebeurtenissen onderweg, evenals persoonlijke capaciteiten etc.), met betrekking tot de extern opgelegde tijdbeperking en de consequenties van te laat aankomen. In een tweede inschatting beoordeelt de bestuurder de beschikbare middelen om stress te bedwingen, om zo de eisen gesteld vanuit de situatie te beheersen (bijv. versnellen van interactie met bedieningsorganen, alternatieve route kiezen, aanpassing van de tijdbeperking etc.). Als de strategieën met dat doel niet ten uitvoer kunnen worden gebracht of als schattingen ongunstig uitkomen kan dat leiden tot negatieve emoties. Daarentegen, als de opdracht wordt ervaren als een uitdaging waarvoor de middelen om stress te bedwingen beschikbaar zijn en succes of optimale prestaties garanderen, kan dat leiden tot positieve emoties.

Op basis van de literatuur over tijdsdruk en de effecten ervan op menselijk gedrag, menselijke fysiologie en de dynamica van het lichaam, zijn vervolgens de waarneembare gevolgverschijnselen uit de vorige cycli (vooral op het gebied van fysiologie en interactie) gereduceerd tot slechts die, die konden zijn ontstaan als gevolg van een tijdbeperking. Indicatoren gerelateerd aan het domein rijprestaties, afgeleid van focusgroepstudies en de voorafgaande literatuurstudie, werden meegenomen in de lijst van mogelijke indicatoren omdat bestaande oplossingen voor het herkennen van de toestand van de bestuurder vaak een voorkeur tonen voor zulke indicatoren. Voor deze gereduceerd groep indicatoren is vervolgens op basis van literatuur, enquêtes en focusgroepstudies een reeks hypotheses afgeleid over in welke richting ze naar verwachting veranderen (trends) bij rijden onder tijdsdruk.

Specifiek werd verwacht dat van de fysiologische activiteit de cardiovasculaire activiteit, de ademhaling en het visueel gedrag zullen verschillen als we rijden onder normale omstandigheden vergelijken met rijden onder tijdsdruk. Wat betreft de dynamica van het menselijk lichaam werden veranderingen verwacht in de kinematica en de grootte van krachten uitgeoefend op bedieningsorganen. Tabel 7.2 (p. 206) toont per indicator de verwachte trends.

Als volgende stap is de apparatuur geïnventariseerd die in aanmerking komt om de indicatoren te meten. Voor cardiovasculaire activiteit bleek van de geïnventariseerde apparaten alleen de elektrocardiograaf geschikt omdat zowel hartslag als de hartslagvariabiliteit moesten worden gemeten. Uiteindelijk is voor een ambulante monitor gekozen omdat die goedkoper is, niet-invasief, draagbaar en betrouwbaarder dan een telemetrisch apparaat. Vanwege de relatieve ongevoeligheid voor bewegingsartefacten en gordelspanningsfouten werd voor een inductieve gordel gekozen om ademhalingsactiviteit te meten. Om ooggedrag te meten is voor een tafelmodel oogvolgsysteem, omdat het nauwkeurig is, de pupildiameter en de knipperfrequentie goed afschat en bij de bestuurder geen discomfort veroorzaakt.

Om kinematische activiteit, d.w.z. veranderingen in positie en oriëntatie van lichaamsdelen, te meten werd een systeem gebaseerd op accelerometers en gyroscopen gebruikt. Het voordeel van dit systeem is dat het volledig zelfstandig functioneert, niet gekalibreerd hoeft te worden t.o.v. de gewrichten, en ongevoelig was voor elektromagnetische interferentie. Ook was het ongevoelig voor reflecties van licht en geluid. Tenslotte werden voor het meten van door de bestuurder uitgeoefende krachten zowel krachtgevoelige weerstanden als drukdozen gekozen: de eerstgenoemde omdat ze zeer dun zijn, goedkoop en gemakkelijk in te bouwen, en drukdozen vanwege hun grote nauwkeurigheid.

Het discriminerend vermogen van de overgebleven kleinere groep indicatoren is geanalyseerd en geëvalueerd d.m.v. een experiment in een rijsimulator die speciaal voor dit experiment en de benodigde gegevens was uitgerust met de hierboven genoemde instrumentatie. Niettemin is eerst een iteratieve pilot uitgevoerd om de opzet van het experiment te verfijnen. De procedure voor de herziene onderzoeksopzet is beschreven in Tabel 7.3 (p.207). Het uiteindelijke volledige onderzoek werd volgens die opzet uitgevoerd. Het duurde ongeveer 90 minuten per deelnemer. Qua steekproef ging het om 56 gezonde proefpersonen, 46 mannen en 8 vrouwen tussen 23 en 37 jaar oud. Zij zijn geworven binnen de studenten- en medewerkersgemeenschap van de TU Delft.

Beknopt overzicht van de empirische gegevens

Om de gegevens uit het volledige onderzoek te kunnen bestuderen werd een eerste bevestigende (hypothese-gedreven) analyse uitgevoerd waarin de gehypothetiseerde indicatoren van gehaast rijden zijn getoetst. Vervolgens werd de data exploratief geanalyseerd door visualisaties te beoordelen en zo nieuwe patronen te ontdekken die gehaast rijden zouden kunnen karakteriseren. Zo wedren detecteerbare gevolgen van tijdsdruk waargenomen in fysiologische activiteit, in de interactie tussen bestuurder en bedieningsorganen en in de rijprestaties.

Vastgesteld werd dat de meeste fysiologische waarden in verschillende een toename van de tijdsdruk weerspiegelen. Met name hartslag, ademfrequentie, de ademhalingscyclus, de knipperfrequentie van de ogen en de pupildiameter vertonen een discriminerend vermogen dat uiteindelijk gebruikt kan worden om bestuurders onder hoge tijdsdruk (HTD) te onderscheiden van bestuurders die niet onder tijdsdruk (NTD) rijden. Een verband tussen deze meetwaarden en een verhoogde mentale inspanning doordat bestuurders een gebrek aan tijd ervaren om een rit te voltooien was al gelegd in [19-21]. Niet alleen voor mentale inspanning maar ook voor visuele inspanning, die inherent is aan autorijden en die toeneemt door sommige gevolgen van tijdsdruk (bijv. snelheid) was een soortgelijk verband gevonden op basis van knipperfrequentie en pupildiameter [22].

Vervolgonderzoek is echter nodig voordat deze meetwaarden daadwerkelijk gebruikt kunnen worden voor detectiedoeleinden. Enerzijds lijken deze waarden te worden beïnvloed door de specifieke verkeerssituatie (bijv. inhalen, achter een andere auto rijden), waardoor er geen universele drempelwaarde kan worden vastgesteld die onderscheidt tussen de NTD- en de HTD-condities. Figuur 7.6 (p. 208) toont een voorbeeld van hoe hartslag en -variabiliteit veranderen afhankelijk van de verkeerssituatie. Anderzijds hangen fysiologische waarden ook nog sterk af van individuele verschillen en variëren ze zelfs bij een en dezelfde persoon. Bovendien kan de respons van deze meetwaarden als gevolg van tijdsdruk gemaskeerd worden door externe factoren. Fysieke belasting beïnvloedt bijvoorbeeld hartslag en ademhaling. Omgevingslicht kan een invloed hebben op de pupildiameter. Ook kan de knipperfrequentie van de ogen qua respons bij hogere belasting tegengesteld reageren, ervan afhankelijk of die hogere belasting visueel of mentaal is. Tijdens het rijden zijn, afhankelijk van de situatie en de eventuele tijdsdruk, visuele en mentale belastingen altijd in meer of mindere mate aanwezig. Door de matige tijdsdruk was het tijdens ons onderzoek inderdaad mogelijk dat in de HTD-conditie geen effecten waarneembaar waren. Dientengevolge, rekening houdend met het feit dat de gevolgen waargenomen in de fysiologische waarden sterk afhankelijk van de visuele en mentale belasting, wordt het gebruik van deze waarden onderworpen aan verder onderzoek opdat hun gedrag in relatie tot alle mogelijke rij-situaties volledig begrepen kan worden.

Ook enkele interactiegerelateerde meetwaarden, uitgedrukt in kinematische en kinetische activiteit van de proefpersoon, vertoonden onderscheidbare verschillen tussen de HTD- en de NTD-conditie. Visuele inspectie van de geplotte gegevens maakte echter duidelijk dat deze verschillen vooral merkbaar waren als ze per individu geanalyseerd werden, en zelden voor de gecombineerde dataset van alle proefpersonen. Merk echter op dat het feit dat er in de gecombineerde dataset een verschil merkbaar is tussen de twee condities niet betekent dat dit groot genoeg is om gehaast rijden te detecteren. De meeste beoordeelde meetwaarden gerelateerd aan beweging van het lichaam, met inbegrip van snelheid van het manipuleren van bedieningsorganen en de daarmee gepaard gaande versnelling van ledematen, namen significant toe bij de HTD-conditie. Bovendien toonde de verplaatsing van het gaspedaal duidelijke verschillen tussen de HTD- en NTD-condities. Dit verschil was nog groter als er op individueel niveau naar gekeken werd. Deze uitkomsten bevestigen het inzicht dat indicatoren moeten worden onderzocht met individuele bestuurders en niet met gecombineerde groepen van mensen. Het feit dat het onmogelijk bleek om onderscheidbare resultaten te vinden voor sommige meetwaarden, zoals kracht op het stuur, ontstaat door het feit dat proefpersonen waarneembaar tegengesteld reageerden waardoor het netto effect niet meer waarneembaar is. Figuur 7.7 (p. 209) toont bijvoorbeeld zulke tegenstellingen voor enkele proefpersonen bij het oversteken van kruisingen (Waarschijnlijkheidsverdeling van de gecombineerde dataset van alle deelnemers, resp. twee individuele deelnemers met tegengestelde reacties - midden en rechts - voor kracht op het stuurwiel).

Ook bij meetwaarden waarvoor geldt dat alle deelnemers volgens dezelfde trend reageerden, varieerde het bereik van meetwaarden aanzienlijk van individu tot individu. Daarom geldt dat het middelen van resultaten vaak heeft geleid tot het wegvallen van een eventuele scheiding tussen waarschijnlijkheidsverdelingen, zoals het geval was voor het omgaan met de bedieningsorganen. Verder beïnvloeden niet alleen de variabiliteit binnen de waarden van een bestuurden en die van de waarden tussen bestuurders de interpretatie van de uitkomsten, maar ook verkeerssituaties (bijv. achter een andere auto rijden, inhalen met en zonder tegenliggers, kruisingen met en zonder verkeer, en *cruisen*) brengen verschillende effecten aan het licht als het gaat om de trends van verdelingen en de scheidbaarheid daarvan.

Omdat verschillende bestuurders verschillende rijstijlen hebben die variaties in rijpatronen veroorzaken, en omdat verschillende invloedsfactoren op elkaar kunnen inwerken, is dan ook vervolgonderzoek nodig om variabiliteit onder bestuurders beter te begrijpen, alsmede de implicaties daarvan voor bestuurders onder tijdsdruk. Bovendien waren de trends die we vonden in de aantallen handelingen met bedienorganen anders dan we hadden verwacht: in plaats van toe te nemen namen deze vaak af onder tijdsdruk. Dat resultaat lijkt logisch als we in acht nemen dat de frequentie van handelingen toeneemt bij toenemende tijdsdruk, maar alleen voor die taken die daarvan een productiviteitsverhoging ondervinden. Deze denktrant volgend, kan het zijn dat bestuurders die bedienorganen ontzien die niet essentieel zijn voor het tijdig op de bestemming aankomen. Toch kunnen soortgelijke invloeden echter het gevolg zijn van andere veeleisende activiteiten in de auto (bijv. de telefoon opnemen, of een gesprek met een passagier voeren), dus is verder onderzoek naar de meeste van deze meetwaarden nodig voordat ze kunnen worden gebruikt om de aanwezigheid van tijdsdruk tijdens het rijden te detecteren.

Wat betreft de prestatiegerelateerde onderzoeksgegevens waren de uitkomsten over het algemeen zoals verwacht. Zowel de respons van het gemiddelde motortoerental als de gemeten maximumsnelheid en -versnelling van de auto lijken de verwachte versnelling van handelingen die door de meeste mensen als eerste mechanisme worden ingezet om tijdsdruk te bedwingen, te bevestigen. De gevonden resultaten m.b.t. de minimumvolgtijd t.a.v. de voorligger en de dwarspositie van het voertuig komen ook overeen met het feit dat van buitenaf opgelegde tijdsdruk andere doelen tijdens het rijden overheerst en een riskantere rijstijl tot gevolg heeft. Op zijn beurt leidt dit riskante compensatiegedrag tot compromissen tussen snelheid en nauwkeurigheid, en is het waarneembaar in de standaardafwijking van de dwarspositie op de rijbaan. Opnieuw, laten de gecombineerde resultaten voor alle deelnemers vaak geen scheidbare waarschijnlijkheidsdistributies zien tussen HTD- en NTD-gedrag, hoewel er wel verschillen zijn tussen de twee condities. Zoals al vermeld in de vorige alinea geven de resultaten beschouwd per persoon en per verkeerssituatie onderscheidbaar verschillende resultaten voor de condities. In het bijzonder suggereren de resultaten dat indicatoren zoals motortoerental, volgtijd, voertuigsnelheid en -versnelling, en versnelling per gaspedaalbeweging gefilterd naar snelheidsband tenminste voor enige deelnemers blijk geven van een duidelijk onderscheid tussen de twee condities. Dit betekent dat prestatiemaatstaven m.b.t. zowel longitudinale als laterale voertuigbeheersing kandidaat-meetwaarden zijn om rijden onder tijdsdruk te herkennen. Toch is echter meer onderzoek nodig omdat dezelfde respons gemakkelijk kon worden gevonden voor verscheidene andere situaties onder verhoogde visuele belasting of een andere vorm van stress. Verder is de definitie van het begrip 'grote versnelling' afhankelijk van de actuele snelheid. Daarom is het gebruik van versnelling/vertraging per gas-/rempedaalbeweging gefilterd naar snelheidsband veelbelovende meetwaarden voor het herkennen van rijden onder tijdsdruk. Meer onderzoek is nodig om het werkelijke potentieel van deze bevinding vast te stellen.

Over het algemeen is er, in strijd met onze hypothese, niet een enkele indicator die volledig onafhankelijk is van de rijcontext en geheel ongevoelig voor verschillen tussen bestuurders. Daarnaast konden we niet voldoende bewijs vinden voor het vermoeden dat indicatoren dichter bij de bron (d.w.z. de bestuurder) al voldoende zouden zijn, en het meest geschikt om gehaast rijden te herkennen. Hoogstwaarschijnlijk zou een combinatie van indicatoren uit de verschillende domeinen leiden tot betere herkenning van deze riskante bestuurderstoestand, en daarom verdient die richting verder onderzoek.

Conclusies en stellingen

Veelbelovende onderscheidbare verschillen tussen de HTD- en de NTD-toestand werden gevonden in fysiologische activiteit, bestuurdersinteractie met de bedieningsorganen en rijprestaties. Hoewel deze verschillen vooral evident waren als ze werden geanalyseerd per individuele deelnemer waren ze zelden waarneembaar in de gecombineerde data van alle deelnemers. Dit weerspreekt onze oorspronkelijke overtuiging dat er ten minste een indicator zou bestaan die geheel ongevoelig zou zijn voor verschillen tussen bestuurders, maar daarentegen wordt het inzicht gevoed dat indicatoren per individuele bestuurder moeten worden bestudeerd in plaats van op basis van gecombineerde gegevens uit een groep. Vervolgonderzoek is nodig om variaties tussen bestuurders qua rijstijl te doorgronden en de gevolgen daarvan voor het identificeren van haastige bestuurders. Verder beïnvloeden niet alleen de variabiliteit binnen het gedrag van een bestuurder en tussen bestuurders onderling de interpretatie van uitkomsten, maar ook leiden verschillende verkeerssituaties tot verschillende effecten waar het gaat om onderscheidbaarheid van distributies. Op soortgelijke wijze ontkrachten deze resultaten onze oorspronkelijke overtuiging dat ten minste een indicator geheel onafhankelijk zou zijn van de rijcontext. Ondanks veelbelovende resultaten moeten interactiegerelateerde indicatoren nog zorgvuldig worden bestudeerd, omdat gelijksoortige invloeden kunnen voortkomen uit verschillende fysiek veeleisende activiteiten in de auto, en dus is voor de meeste van deze indicatoren vervolgonderzoek nodig voordat zij kunnen worden ingezet om tijdsdruk bij het autorijden te detecteren.

Hieronder vermelden we de uit dit onderzoek afgeleide technische stellingen:

Stelling 1: Als de onderzoeker betrouwbare voorlopige hypotheses wil opstellen moet, zoals aangetoond voor het vinden van waarneembare verschijnselen van gehaast autorijden, een literatuurstudie worden gecombineerd met andere onderzoeksmethoden zoals focusgroepsessies.

Stelling 2: Het gebruik van een rijsimulator is op zichzelf een bron van intrinsieke motivatie voor proefpersonen deelnemend aan het onderzoek naar gehaast autorijden, daarom is het niet nodig andere externe motivaties toe te passen in combinatie met een tijdslimiet op het voltooien van een opdracht.

Stelling 3: Omdat de onderzochte indicatoren verschillen per specifieke rijsituatie, en variëren naargelang de overeenkomstige mentale/visuele/fysieke eisen (bijvoorbeeld inhalen, achter een voorligger rijden etc.) en externe factoren (bijvoorbeeld omgevingslicht etc.), is het nodig om ook de omgeving van het rijden in beschouwing te nemen.

Stelling 4: In tegenstelling tot wat algemeen wordt aangenomen volstaat snelheid alléén niet als gegeven om gehaast autorijden te detecteren, omdat snelheid onder specifieke rijsituaties, zoals filerijden, onvoldoende discriminerend vermogen biedt om de NTD- en HTD-rijcondities van elkaar te onderscheiden.

Stelling 5: De maximale acceleratie en deceleratie per gas-, c.q. rempedaalbeweging voldoen niet als indicatoren voor rijden onder tijdsdruk, omdat deze waarden niet beoordeeld kunnen worden zonder de actuele snelheid van de auto in beschouwing te nemen.

Stelling 6: De drempelwaarde van elke indicator voor gehaast autorijden moet worden vastgesteld op individuele basis, omdat de onderzochte indicatoren van persoon tot persoon aanzienlijk verschillen, en zelfs verschillen voor een en dezelfde persoon.

Aanbevelingen voor toekomstig onderzoek

De voornaamste aanbeveling voortvloeiend uit dit onderzoek is dat indicatoren moeten worden onderzocht binnen het gedrag van individuen in plaats van voor samengenomen groepen mensen, alsmede dat zij moeten worden onderzocht per verkeerssituatie of individuele manoeuvre (bijv. inhalen of achter een voorligger rijden). Omdat voor het verzamelen van de informatie over indicatoren van gehaast rijden een rijsimulator gebruikt werd, is validiteit een punt van aandacht. Het is niet duidelijk in hoeverre het resultaat in twijfel getrokken kan worden. Daarom wordt aanbevolen om een validerend onderzoek te doen met data verzameld in echte rijsituaties met een geïnstrumenteerde auto.

In dit onderzoek is een beperkt aantal rijsituaties meegenomen (inhalen, achter een voorganger rijden, *cruisen* en *stop-and-go*-gedrag op kruisingen) in een beperkte context (betrekkelijk rustig stadsverkeer). Daarom wordt aanbevolen om het onderzoek uit te breiden naar andere rijsituaties zoals verkeerslichten, rotondes en meerdere rijstroken. Andere rijcontexten zoals snelwegen en landwegen moeten ook worden meegenomen. Omdat allen longitudinaal rijgedrag beschouwd is, wordt aanbevolen om ook onderzoek te doen naar het herkennen van indicatoren van gehaast rijden bij lateraal rijgedrag. Dat onderzoek moet worden uitgevoerd voor meer rijsituaties alsook in meer rijcontexten zoals snelwegen en landwegen.

De invloed van fysiek gedrag op fysiologische gegevens is in dit onderzoek niet bestudeerd. Daarom wordt aanbevolen om in de toekomst onderzoek te doen naar invloeden van andere activiteiten bij het rijden, zoals telefoneren, op het fysiologische gedrag van de bestuurder. Leeftijd, etniciteit, rijervaring en geslacht kunnen bias veroorzaken in de respons qua fysiologie, interactie en rijprestaties. Daarom bevelen we onderzoek aan naar de mate waarin deze eigenschappen de respons qua indicatoren beïnvloeden.

Langdurige blootstelling aan tijdsdruk bij het rijden is niet bestudeerd. Derhalve moeten studies met langere rijperiodes worden opgezet om zo de gevolgen van vermoeidheid op de indicatoren van gehaast rijden in kaart te brengen. Onderzoeken met variaties qua motivatie of qua tijdsbeperking moeten worden verricht om het fenomeen gehaast autorijden en de specifieke invloeden van verschillende niveaus van tijdsdruk beter te doorgronden

Tenslotte werd het niveau van mentale en visuele belasting niet gecontroleerd in dit onderzoek. Omdat dit een aanzienlijke impact kan hebben op responsen qua gedrag, is het dringend noodzakelijk om begrip te krijgen van de gevolgen van zowel mentale als visuele belasting op de indicatoren, en zo de verwachte uitkomsten te kunnen vaststellen. Bijvoorbeeld, uitgaand van de verwachting dat de knipperfrequentie van de ogen zal toenemen als gevolg van een hoge mentale belasting en af te nemen als gevolg van een hoge visuele belasting, wat bepaalt dan de gevolgen van beide belastingen gecombineerd? Als de mentale belasting hoger is, dan wordt een hogere knipperfrequentie verwacht, terwijl een lagere frequentie wordt verwacht bij hogere visuele belasting.

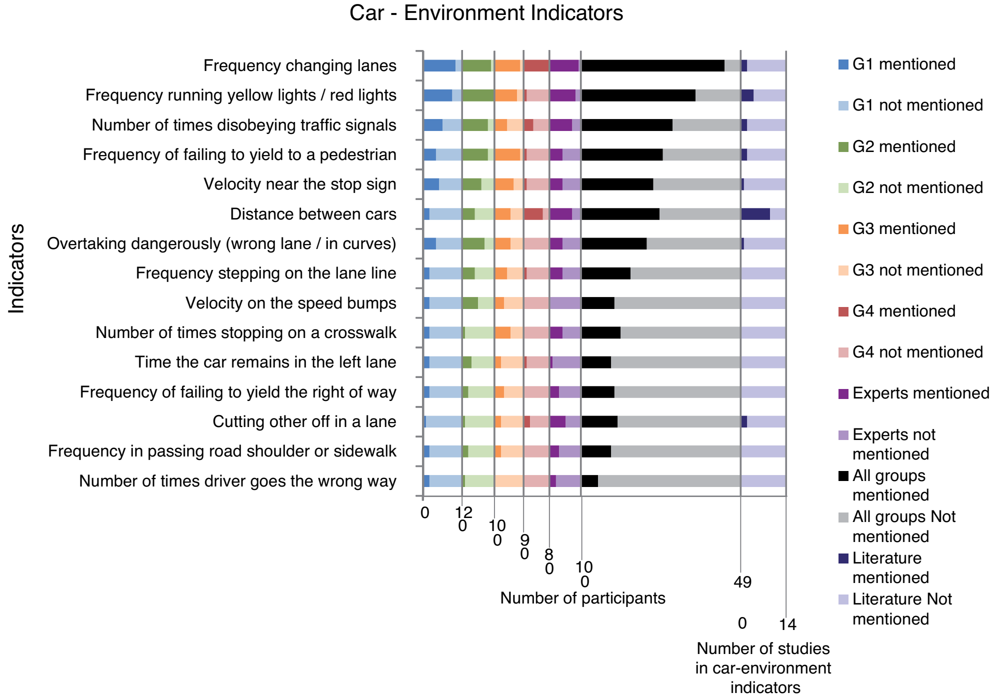
Referenties

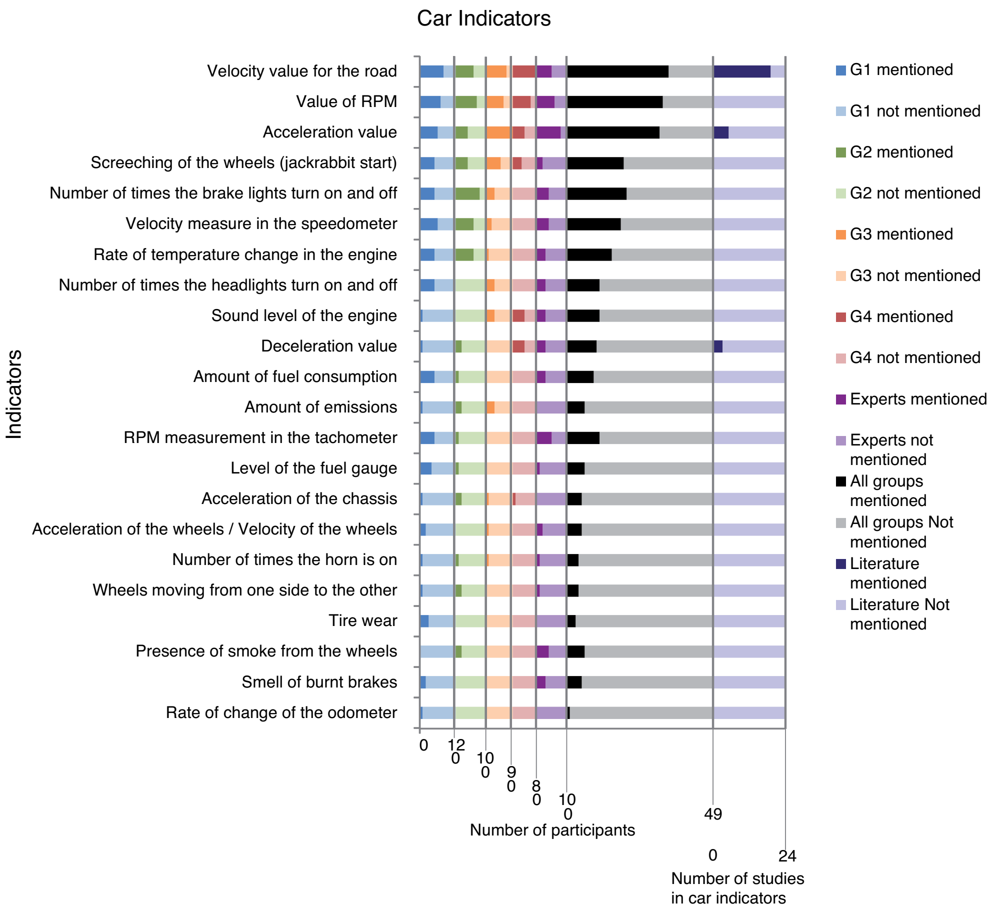
Referenties op pagina 212.

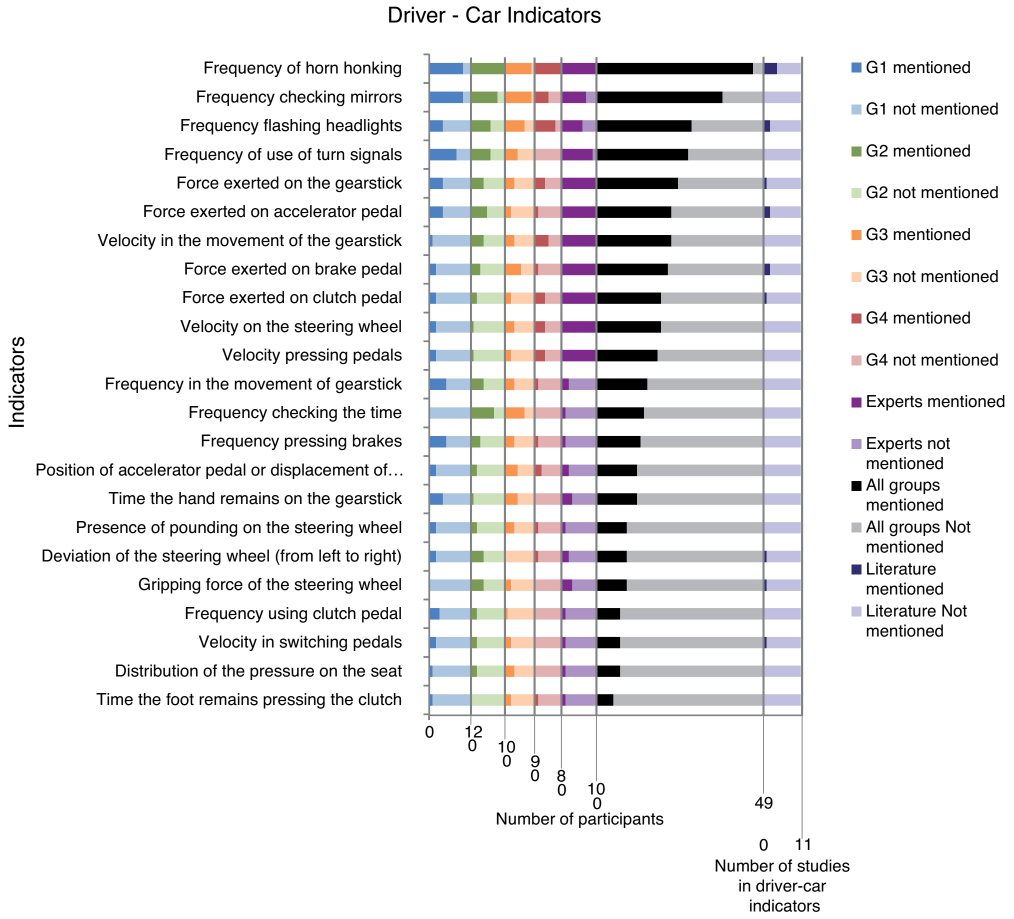
Appendix A

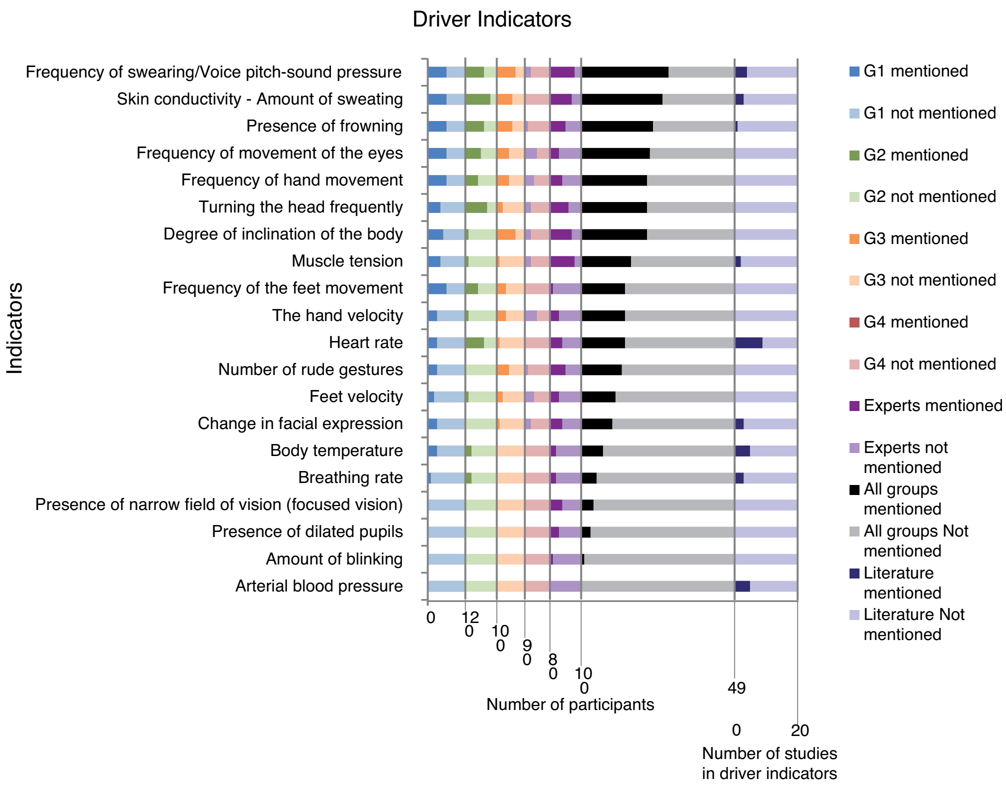
Frequency of manifestations

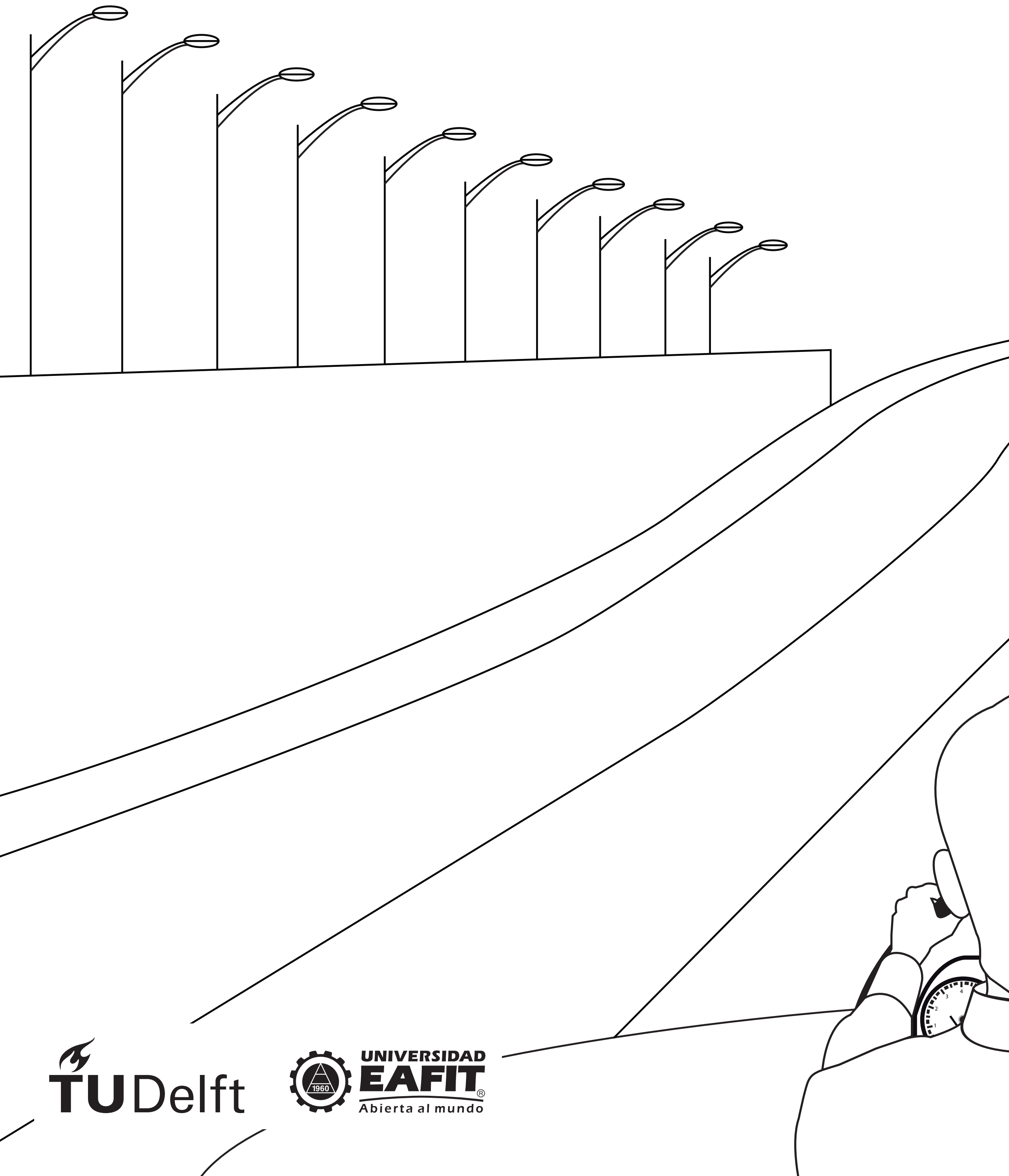
This appendix contains all the frequency of mentioning observable manifestations of driving in haste relative to each of the four domains. The frequencies, determined for the reviewed literature and for each of the focus group sessions, were used for conducting the congruency and correspondence analyses presented in Section 3.4.




Car Indicators
Indicators
Velocity value for the road
Value of RPM
Acceleration value
Screeching of the wheels (jackrabbit start)
Number of times the brake lights turn on and off
Velocity measure in the speedometer
Rate of temperature change in the engine
Number of times the headlights turn on and off
Sound level of the engine
Deceleration value
Amount of fuel consumption
Amount of emissions
RPM measurement in the tachometer
Level of the fuel gauge
Acceleration of the chassis
Acceleration of the wheels / Velocity of the wheels
Number of times the horn is on
Wheels moving from one side to the other
Tire wear
Presence of smoke from the wheels
Smell of burnt brakes
Rate of change of the odometer
0
12
0
10
0
9
0
8
0
10
0
49
Number of participants
0
24
Number of studies in car indicators
G1 mentioned
G1 not mentioned
G2 mentioned
G2 not mentioned
G3 mentioned
G3 not mentioned
G4 mentioned
G4 not mentioned
Experts mentioned
Experts not mentioned
All groups mentioned
All groups Not mentioned
Literature mentioned
Literature Not mentioned


Driver - Car Indicators
Indicators
Frequency of horn honking
Frequency checking mirrors
Frequency flashing headlights
Frequency of use of turn signals
Force exerted on the gearstick
Force exerted on accelerator pedal
Velocity in the movement of the gearstick
Force exerted on brake pedal
Force exerted on clutch pedal
Velocity on the steering wheel
Velocity pressing pedals
Frequency in the movement of gearstick
Frequency checking the time
Frequency pressing brakes
Position of accelerator pedal or displacement of…
Time the hand remains on the gearstick
Presence of pounding on the steering wheel
Deviation of the steering wheel (from left to right)
Gripping force of the steering wheel
Frequency using clutch pedal
Velocity in switching pedals
Distribution of the pressure on the seat
Time the foot remains pressing the clutch
0
12 0
10 0
9 0
8 0
10 0
49
Number of participants
0 11
Number of studies in driver-car indicators
G1 mentioned
G1 not mentioned
G2 mentioned
G2 not mentioned
G3 mentioned
G3 not mentioned
G4 mentioned
G4 not mentioned
Experts mentioned
Experts not mentioned
All groups mentioned
All groups Not mentioned
Literature mentioned
Literature Not mentioned


Driver Indicators
Indicators
Frequency of swearing/Voice pitch-sound pressure
Skin conductivity - Amount of sweating
Presence of frowning
Frequency of movement of the eyes
Frequency of hand movement
Turning the head frequently
Degree of inclination of the body
Muscle tension
Frequency of the feet movement
The hand velocity
Heart rate
Number of rude gestures
Feet velocity
Change in facial expression
Body temperature
Breathing rate
Presence of narrow field of vision (focused vision)
Presence of dilated pupils
Amount of blinking
Arterial blood pressure
0
12
0
10
0
9
0
8
0
10
0
49
Number of participants
0
20
Number of studies in driver indicators
G1 mentioned
G1 not mentioned
G2 mentioned
G2 not mentioned
G3 mentioned
G3 not mentioned
G4 mentioned
G4 not mentioned
Experts mentioned
Experts not mentioned
All groups mentioned
All groups Not mentioned
Literature mentioned
Literature Not mentioned



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